NATURAL RESOURCES SYSTEMS PROGRAMME

PROGRAMME DEVELOPMENT REPORT

PD Number

PD045

Title

An Overview of Soil Fertility Reviews

Author

Barry Pound

Organisation

Natural Resources Institute

Date

July 1997

NRSP Production System

Forest Agriculture Interface

The citation for this report is:

Pound, B. 1997. *An Overview of Soil Fertility Reviews.* DFID NRSP Programme Development Report PD045: *Soil fertility review desk study.* Hemel Hempstead, UK: NRSP.

This is a report submitted to the UK Department for International Development's (DFID) Natural Resources Systems Programme (NRSP) to fulfil requirements under the research contract PD045. The views expressed are not necessarily those of DFID or NRSP.

DFID Natural Resources Systems Programme

NRSP, HTSPE, Thamesfield House
Boundary Way, Hemel Hempstead, HP2 7SR
United Kingdom

t: +44 (0) 1442 202447
f: +44 (0) 1442 219886
e: nrsp@htspe.com
w: www.nrsp.org.uk

AN OVERVIEW OF SOIL FERTILITY REVIEWS

INTRODUCTION

This review forms part of preparation for a soil fertility workshop to be held in September 1997, organised and sponsored by the Natural Resources Systems Programme of the Department For International Development (DFID) Renewable Natural Resources Research Strategy (RNRRS).

The purposes of the workshop are to formulate a medium-term strategy for soil fertility research, and to identify criteria for the selection of a limited number of research projects. It had been noted that a large number of reviews of various aspects of soil fertility had been commissioned within the several Programmes and Production Systems[2] of the RNRRS in recent years, including the NRSP. To ensure that information is used optimally, and duplication minimised, this review was commissioned to summarise and synthesise the results of existing reviews.

The 13 reports reviewed were selected by the NRSP for this study, and are as follows:

Paper number	*Author, date and title of paper*
1	**Coulter JK 1971 Soils of Central Africa: A Review of Investigations of their Fertility and Management Land Resources Division, Tolworth, UK**
2	**Floyd CN 1991 The Use of Crop Residues to Improve Soil Fertility in Sub-Saharan Africa. Chatham: NRI (for Agronomy and Cropping Systems Programme)**
3	**Yates RA and Kiss A 1992 Using and Sustaining Africa's Soils. Agriculture and Rural Development Series No. 6. Washington: The World Bank**
4	**Anderson LS and Bell SA 1995 Definition of the Researchable Constraints to Improved Productive Potential and Sustainability of Land Use Systems at the Forest-Agriculture Interface. Bangor: UCNW (for the Plant Sciences Programme)**
5	**ICRAF 1994 The African Highlands Initiative: A Conceptual Framework. Nairobi: ICRAF**
6	**Kiff E, Turton C, Tuladhar JK and Baker R 1995 A Review of Literature Relating to Soil Fertility in the Hills of Nepal. Silsoe, Beds.: SRI (for NRSP Hillsides System)**
7	**Turton C 1995 An Analysis of Soil Fertility Systems in the Hills of Nepal. Silsoe, Beds.: SRI (for NRSP Hillsides System)**
8	**Gregory PJ 1995 1995 A Strategy for Soil Fertility Research at Lumle. In: Proceedings of a Workshop held in Lumle Agricultural Research Centre, Pokhara, Nepal, 17-18 August 1995. Silsoe, Beds.: SRI (for NRSP Hillsides System)**
9	**McBride (Ed.) 1995 The Foundation for a Refocussed Soil Management Collaborative Research Support Programme. USAID**
10	**Yates RA and Gibberd G ~ 1995 Literature Review of Fertility Maintenance in Africa. London: ODA (ASC- funded for IBRD study).**
11	**Gregory P, Nortcliff S and Livesley S 1996 Review of Soil Fertility with Regard to the Forest/Agriculture Interface System. Chatham: NRInternational (for NRSP F/A I System)**
12	**Morse K 1996 A Review of Soil and Water Management Research in Semi-Arid Areas of Southern and Eastern Africa. Chatham, UK: NRI Chatham: NRInternational (for NRSP Semi Arid Production System)**
13	**ODA/World Bank 1996 Soil Fertility Management in Sub-Saharan Africa London: ODA (Regional study funded by ODA and managed by the World Bank)**

N.B. Summaries of each report will be given as an Annex to the full version of this paper to be distributed at the Workshop in September.

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[2] There are 12 RNRRS Programmes: Natural Resources Systems; Crop Production Research, Crop Post-Harvest; Plant Sciences; Forestry Research; Animal Health Research; Livestock Production Research; Aquaculture Research; Fisheries Management Research; Fish Genetics Research; Fish Post-Harvest Research; Environment and the Flexibility Fund. These Programmes are further sub-divided into a number of Production Systems. The full list of Production Systems is: Semi-arid; High potential; Hillside; Forest-agriculture interface; Land-water interface; Peri-urban interface; Socio-economic methodologies; Moist tropical forest.

General Conclusions

All reviewers agree that soil fertility is a priority concern, requiring immediate action. The problems most commonly mentioned by reviewers are:

1. The inherent low nutrient status of weathered tropical soils
2. The rapid loss of soil organic matter due to continuous cropping, burning and overgrazing
3. The losses of nutrients through erosion and leaching

Many of these are a result of increasing populations, poor policy frameworks, and unsustainable and intensifying agricultural practices.

More specific areas of concern identified in the reviews are:

1. In sub-Saharan Africa, nutrient mining over decades is a serious constraint to land productivity.
2. At the forest margins unsustainable slash and burn practices are depleting nutrient reserves at a rapid rate.

Key areas for research arising from the reviews include:

1. The interaction between nutrients and water supply to crops (especially in semi-arid areas)
2. The interactions between fertility and genetics
3. The interactions between components of farming systems (e.g. crops, livestock and forestry)
4. Phosphorus is a key element in many situations. Several papers suggest further study and exploitation of local rock-phosphate deposits
5. Increased use of mineral fertilisers, often in combination with organic materials, taking care to avoid acidification and nutrient imbalance
6. Responses to micronutrients.
7. Policy issues (e.g. land tenure and distribution, investment in infrastructure, liberalisation of input supplies, forest legislation), which can profoundly affect soil fertility decisions

Several papers recommend changes to the way in which research is conducted:

1. Participation by farming families in soil fertility research and development decisions is seen by several reviewers as vital to successful technology development and adoption. Several reviewers recognise the high level of local knowledge (and classification) of soils, and point out that some indigenous soil fertility maintenance, and soil and water conservation practices, are being lost.
2. Integrated Nutrient Management is suggested as an appropriate approach to whole farm fertility maintenance and improvement[3].
3. Soil and water management recommendations that are general, and not site specific, are not seen as helpful. Research must develop options that are sufficiently flexible to cater for local circumstances, and extension must be re-cast to assist farmers to make the best decisions for their situations.
4. Several papers highlight the constraint of information availability to researchers, and the low level of use of historical data when developing research programmes.
5. Inter-donor co-ordination of soil fertility research is poor, and inter-institutional networking of soil fertility experience should increase.

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[3] Integrated Nutrient Management combines organic and mineral methods of soil fertility with physical and biological measures of soil and water conservation, and integrates technologies that are adapted to site specific agronomic and socio-economic circumstances to redress nutrient imbalances and soil organic matter deterioration.

SYNTHESIS OF THE REVIEWS BY GEOGRAPHICAL AREA AND PRODUCTION SYSTEM.

GEOGRAPHIC AND PRODUCTION SYSTEMS' SPREAD OF THE REPORTS UNDER REVIEW

The thirteen reports reviewed here were distributed between geographical area and RNRRS Production System as follows:

Table One: Distribution of papers reviewed by geographical area

Number of reviews	Area	Review number
7*	Africa	1, 2, 3, 5, 10, 12, 13
3**	Asia	6, 7, 8,
2	Latin America	4, 11
3	Pan-Tropical	4, 9, 11

* 4 reports had their origins in the seminar held in Washington D.C. in January 1992, sponsored by the World Bank and entitled "Managing the Fertility of Africa's Soils: Meeting Economic and Environmental Needs"

** All 3 reports contributed to one project "A systems analysis of soil fertility in Nepal".

Table Two: Distribution of papers reviewed by RNRRS Production System

Production System	Number of reviews	Review number
Semi-Arid	7	1, 2, 3, 9, 10, 12, 13
High Potential	2	1, 5
Forest/Agriculture Interface	3	3, 4, 11
Land/Water Interface	None specifically address this system	-
Hillsides	4	5, 6, 7, 8
Peri-Urban	None specifically address this system	-
Moist Tropical Forests	None specifically address this system	-
Socio-economic methodologies	None specifically address this area	-

CONCLUSIONS BY GEOGRAPHICAL AREA

Sub-Saharan Africa

Seven of the thirteen papers reviewed refer specifically to sub-Saharan Africa. Tables 3 and 4 below synthesise the main development issues, institutional issues and researchable constraints identified by the papers. More detail is given in the summary of each paper in Part (B) of this review.

Table Three: Development and Institutional issues for sub-Saharan Africa

A. Development issues
Population growth leading to pressure on land resources and serious mining of nutrient resources
Urgent need to build African soil fertility and maintain increased levels of productivity.
Intensification of production methods and the conversion of marginal lands to arable production, the displacement of pastoralists and increased migration
Low level of farmer financial resources and poor distribution systems limit fertiliser use to a very low level
Insufficient organic residues available as soil amendments to maintain levels of nutrients at an optimum level.

B. Institutional issues
Weak research, extension, input supply and marketing institutions, contributing to the problem of poor technology identification, dissemination and use.
Much of soil fertility research carried out on-station. Greater participation of farmers needed to develop sustainable land-use systems.
Poor flow and use of information. Some information inaccessible due to language or lack of suitable systems to access international information (CD ROMs). Practice of comprehensive literature reviews should be revived. Some information, in country (particularly older grey literature), is being lost, and is generally undervalued. Other information, in the hands of ex-colonial countries (e.g. soil maps), should be made more available by those countries.
Improved co-ordination between donor-driven research efforts is necessary, as is networking between institutions (national, international and NGOs)
Research could be made more effective by improving methods (e.g. site selection, site characterisation) and allowing longer time horizons, especially for research into the effects of organic matter on soil systems..

Researchable constraints identified by the eight papers dealing with Africa are synthesised in Table Four below. The numbers in parenthesis in the last column refer to the number of the paper in which the constraint was identified.

Table Four: Researchable constraints for sub-Saharan Africa Semi-Arid Production Systems

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
Low productivity	Low soil nutrient status	Increase inorganic fertiliser use	(a) Identify way to overcome obstacles to increased fertiliser use (technical, economic, institutional). (1) (b) Identify mixtures of cash and food crops that optimise fertiliser use. (1), (5) (c) Studies on local fertiliser production (e.g. rock phosphate) (3) (d) Use of non-industrial techniques for increasing the solubilities of native rock phosphate (10) (e) Investigate combinations of inorganic and organic sources of nutrients (2), (13) (f) Synthesise past research and identify gaps (5) (g) Investigate ways of synchronising nutrient availability to needs (5) (h) Find more productive ways of using of available nutrients (high value crops, rotations, crop-tree-livestock interactions) (5) (i) Re-evaluate FAO country fertiliser programmes (10) (j) Identify ways of increasing fertiliser-use efficiency (13) (k) Identify extent of micro-nutrient deficiencies (13) (l) Develop a GIS capability to model the flow of nutrients, the effectiveness of fertiliser recommendations and the growth of the major food crops (13) (m) Implement a technical and economic programme to evaluate the long-term residual benefits from the use of local mineral reserves (e.g. rock phosphate) (13)
	Low soil organic matter	Increase SOM	Determine the extent to which OM composition influences soil fertility (2), (10) Investigate crop residue effects on soil biomass activity (2) Identify the range of SOMs that can be achieved under a range of conditions using modelling (2)
	Soil acidity, low ECEC	Increase SOM	Determine the potential of SOM to counteract soil acidity, low ECEC, Al toxicity (2)
	Poor soil mgt.	Improve farmer knowledge	Development of location-specific nutrient management recommendations (2) Investigate effects of cultural techniques on dynamics of SOM (e.g. burning, minimum tillage, mulching, bush fallowing) (10)
	Moisture status of soils	Adapt plant genetics Improved tillage Harvest water	For semi-arid areas develop varieties that establish quickly, thereby covering soil and developing a robust root system (12) Develop moisture conserving tillage techniques (12) Develop rainwater harvesting techniques (12)
	Pests and diseases	Increase plant health through improved soil fertility	Develop management strategies based on integrated crop and soil management (5)

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
Land pressure	Population growth	Intensify systems	Identify ways of intensifying systems without degrading natural resources. (1),
Low productivity of poor soils	Lack of research	Increase research	Identify reasons for low productivity of poor soils (e.g. sandveldt) (1)
Degradation of soils	Soil erosion	Reduce erosion	Identify methods for soil erosion control, thereby contributing to the maintenance of soil fertility. (1), (5), particularly non-mechanical methods, including leys, cover crops, relay crops, intercropping and rotations (10), and hedgerows and trashlines (12)
Lack of recognition of local knowledge	Research approaches	Change approaches	Explore and harness diversity of native agriculture (e.g. termite mounds) (1) and dambos, sodic lands (12)
Lack of knowledge of farmer practice	On-station research emphasis	Work with farmers	Obtain better understanding of farmers practices: e.g. crop residue use (2)

Asia

Three papers deal specifically with Asia. All three were components of one project that formed part of the NRSP Hillsides Production System portfolio. The project was "A systems analysis of soil fertility in the hills of Nepal", and its purpose was to develop a medium-term soil fertility research strategy for the hills of Nepal. The conclusions from these papers are reported below under the "Hillsides" Production System.

Latin America

None of the papers reviewed were specifically based on Latin American soil fertility situations. Those that are most relevant to Latin America are those on the Forest/Agriculture Interface, for which a synthesis is presented below.

CONCLUSIONS BY PRODUCTION SYSTEM

Semi-Arid Production System

The conclusions summarised above under sub-Saharan Africa (Tables Three and Four) can also be applied to the Semi-arid Production System, as almost all of the papers for Africa were focused on the difficult problems facing the seasonally arid areas which make up the greatest proportion of that part of the continent. No papers dealing with semi-arid parts of other continents were reviewed.

Hillsides Production System

Of the four papers relevant to the Hillsides system, three formed components of one project ("A systems analysis of soil fertility in the hills of Nepal"), while the other was the framework paper for a regional initiative to reduce land degradation and raise productivity in the highlands of eastern and central Africa.

Development issues; Nepal

- Hill land-use (in Nepal) also affects downstream users (in India, Bangladesh)
- Changes in policy (infrastructure development, commercialisation, forestry policy, land tenure and fertiliser supply) have profound effects on hill agriculture
- Land holdings are small, leading to increasingly intensive use of arable land
- Farmers, in general, see soil fertility as declining
- Land tenure status important in decision-making on soil fertility maintenance practices
- Interdependence between crops, livestock and forestry
- Indigenous soil fertility maintenance techniques in place, but some being lost
- Concern over the institutional separation of research and extension

Development issues; Africa

- Declining land productivity
- Encroachment of agriculture on fragile land-forms (valley bottoms, steep slopes, wetlands, forests)
- Diminishing capacity to support growing population
- Failure of T&V extension system

Researchable constraints

Table Five below summarises the researchable constraints for Hillsides systems in Africa and Nepal.

Table Five: Researchable constraints for the Hillsides Production System

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
A. Eastern and Central Highlands (see paper 5)			
Declining soil productivity	Existing resource management system; inappropriate national agricultural policies; internal strife; high cost of inputs	Maintenance and improvement of soil fertility	a) Synthesis of past research b) Reduction of nutrient losses c) Improved recycling of nutrients d) Ways for making greater productive use of available nutrients
		Management strategies to protect crops from pests and diseases resulting from declining soil fertility.	Studies on banana nematodes, bean stem maggots, bean root rot, potato bacterial wilt and striga.
		Study indigenous NR management	Diagnostic and socio-economic studies of indigenous NR management
		Improved capacity of NARS	Identify weaknesses and support needs

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
B. Nepal (See papers 6,7 & 8)			
Poor understanding of farmers perceptions	Research approaches	Modify research approaches	a) Devise practical soils classification to include farmers criteria b) Survey reasons for farmers observations of declining fertility c) Understand factors affecting farmers soil fertility decisions d) Understand role of women in soil fertility management
Soil organic matter decline	Multiple	Increase availability and efficiency of use of organic matter	a) Organic fertiliser quality and rates of release, and role in reducing nutrient losses and improving physical condition of soil b) Management systems for compost-producing areas (forest) Investigate ways of producing more compost from cultivated areas c) Determine effective means of conserving nutrients in manures and composts
Low nutrient status of soils	Low inputs; losses to erosion and leaching	Increase nutrient inputs; decrease losses	a) Development of appropriate fertiliser recommendations b) Investigate ways of harnessing nutrients from outside closed farm/village system (e.g. irrigation water, N-fixing plants, common property resources) c) Determine importance of erosion and leaching under different land-use categories d) Devise management practices to reduce erosion and leaching losses using a participatory approach e) Surveys to develop quantitative baseline to understand relative rates of soil fertility decline across agroecological zones and land types
Soil acidity	Chemical fertilisers	Change fertilisers and/or their use	Devise appropriate measures to reduce soil acidity caused by chemical fertilisers
Poor understanding of nutrient cycles	Fragmented research	Coordinated research strategy	a) Collate existing information on the nutrient cycles of the farming systems in mid, high and low hills; identify key sub-systems and initiate research to fill the gaps so that cycles are complete within 3 years b) Development of Integrated Nutrient Management systems

Forest Agriculture Interface System

Three very different papers are relevant to this production system (papers 3, 4 and 11). There is consensus that soils that are stable when undisturbed are often precariously fragile following conversion to agriculture, and there is often a rapid loss of soil nutrients and organic matter, followed by a more gradual decline. The majority of forest soils are highly weathered and of inherently low fertility. Shifting cultivation, both in Africa and Latin America, is ceasing to be an option for maintaining soil fertility.

Development issues

- Estimates of forest clearance vary between 3-24.5 M ha/yr. 50% may be due to agriculture, including shifting agriculture, continuous cropping, plantation agriculture and ranching (other losses are due to logging and industrial uses of forest products)
- The likely link between soil degradation and aridity, and the loss of natural vegetative cover
- Unsustainable practices such as destructive slash and burn agriculture, low-input ranching and destructive logging methods are using forest resources wastefully and causing irreversible damage to the environment.
- Need for greater participation of communities in identification and implementation of priorities
- More effective coordination between donors, and between institutions
- Need for a change in emphasis in agroforestry research towards understanding the processes involved in interactions between components of agroforestry systems. Many of the agroforestry hypotheses (that have previously been taken as advantages of agroforestry) remain to be proven[4].

Researchable constraints

Table Six shows the researchable constraints for the Forest/Agriculture Interface Production System.

[4] See Table One in the review of Paper 11 (Gregory et al, 1996) for a summary of agroforestry hypotheses.

Table Six: Researchable constraints for the Forest/Agriculture Interface Production System

PROBLEM	CAUSE	POSSIBLE SOLUTION	RESEARCHABLE CONSTRAINT
From paper 3			
Low soil productivity	Low soil nutrient and organic matter status	Use of inputs	Investigate interactions between mineral fertilisers and organic/biological sources of nutrients Study feasibility of local fertiliser production
From paper 4			
Low productivity of agroforestry systems	Poor understanding of plant interactions and nutrient dynamics	Mechanistic agroforestry research	a) Studies to understand rooting patterns in the context of competition and facilitation b) Phosphorus as a limiting nutrient, and its links to mycorrhizas and "environmental grain" c) Dynamics of nutrient release from plant litter, and their synchronisation with acquisition and use by crops.
From paper 11			
Degradation of natural resources at the forest margin	Unsustainability of present forest margin agricultural practices	Development of appropriate sustainable practices based on an understanding of soil and crop interactions	**Soil nutrients:** a) dynamics of P in the inorganic/organic soil system b) consider the application of a wide range of rock based P sources. c) investigate the process of "deep nitrate capture" and to identify the nature of rooting systems required to optimise the efficiency of these systems. d) nutrient budgets at the forest/agriculture interface. e) changes in soil nutrient pools in the post-clearance phase (especially for Oxisols). f) optimum management of organically-based and fertiliser-based nutrient inputs. **Roots:** a) the morphology and nature of tree root systems necessary to optimise the roots' role in "closing the nutrient cycle". b) the distribution, decomposition and nutrient release patterns of perennial tree and annual crop root systems. c) the interaction between tree and arable crop root systems, both under normal and stressed conditions. The different root architectures and nutrient and water capture strategies must be identified. Soil organic matter: a) mechanistic research of the release and immobilisation of nutrients in organic residues added to the soil as soil surface and below-ground additions. b) the nature and composition of plant residues with respect to their "liming" effect, and to investigate response in both field and laboratory environments. c) characterise the nature of tree plant residues, their rate of breakdown, and the release of nutrients during this breakdown, and to synchronise these releases with the needs of the crop plants and soil system. d) demonstrate beneficial effects of fallow tree species and identify the extent to which particular trees may be used for ameliorating soil with respect to particular nutrients. Develop a mgt. strategy on this basis. e) monitor the nature and dynamics of soil organic matter and plant litter decomposition over seasons and longer time periods.

ANNEX

SUMMARY OF THE MAIN CONCLUSIONS AND PRINCIPAL RESEARCHABLE CONSTRAINTS IDENTIFIED IN EACH DOCUMENT

For each paper, a brief introduction of the origin of the paper is made, followed by a review of the main conclusions, a list of the researchable constraints identified by the author, and some comments - where appropriate - on wider development issues.

1. Coulter JK 1971 Soils of Central Africa: A Review of Investigations of their Fertility and Management

Geographical Area:	Africa (Central)
RNRRS Production System:	Relevant to semi-arid and high potential systems

Introduction
This early paper (1971) has been included to contrast thinking at that time with views held today, and to determine if different constraints and opportunities have arisen as a result of changes in technology, methodology or approach.

The paper was written as Farming Systems Research was starting to gain credibility, and before participation of farmers in research on their farms became more common. The emphasis at the time was on a reductionist approach that sought to control nature and emphasised production, as opposed to minimising risk and maximising outputs of use across livelihood needs.

Summary of report's main conclusions
Soil surveys of Zambia, Malawi and Southern Rhodesia (Zimbabwe) indicate that Central Africa has extensive areas of highly leached, sandy soils with low cation exchange capacity. Population density is still relatively low on poor soils, but has reached a high concentration on the better soils. In the areas of greatest population pressure there is reported to be almost continuous monoculture with maize. Food cropping is encroaching on grazing areas so that land for stock decreases and the *dambos*, which should be reserved for dry season grazing, are grazed all the year round. *Chitemene* (slash and burn) systems in Zambia are breaking down due to shortening fallow periods.

Intensive systems of native agriculture in some parts are also tending to break down because young men are migrating to work elsewhere.

The agriculture shows great diversity, and use of natural resources (e.g. anthill soils).

Correct time of planting has been shown to be very important in determining production, together with weeding, control of parasitic weeds and correct plant spacing. The long dry season and variability of rainfall render soil moisture studies important. There is little use of fertiliser, even in areas of high population density. Nitrogen is the most widespread limiting nutrient; responses to phosphorus and potassium are less frequent. Sulphur deficiency is widespread and maize and tea have given spectacular responses. Calcium deficiency in groundnuts leads to blind shells. Boron is the most widespread trace element and Manganese toxicity is regarded as a potentially serious problem.

Cash crops are sometimes fertilised, so that resultant fertility also helps food crops (e.g. maize). However, little experimentation has been done for poorer soils, or for non-cash crops, although it is thought that in order to achieve high levels of productivity on the poorer soils their fertility would need to be built up (with fertilisers and/or manures) over a period of several years. Experiments with continuous cropping of maize in Zambia and Rhodesia indicate that continuous cropping is possible, even on poor sandveld soils, providing soil erosion can be controlled and that secondary nutrients and pH are kept at optimum levels.

Studies showed that there was twice as much organic matter and five times as much clay in eroded material from sandveld soils as in the original soil, so erosion can bring about a serious decline in fertility. One measure to reduce this is to use leys to provide large amounts of bulky organic matter to reduce erosion.

Principal researchable constraints

The paper gives no specific research recommendations; however possible lines of research that could be inferred from the paper are:

- intensification of systems as a response to increasing pressure on soil resources
- overcoming obstacles to increased fertiliser use
- ways of exploring and harnessing the diversity of native agriculture
- mixtures of cash and food crops to optimise fertiliser use
- increased experimentation for poorer soils
- maximising soil erosion control to maintain soil fertility

Development issues

The most important issues emerging at the time are :

- increasing pressures on land, especially better land, leading to continuous cropping, encroachment onto grazing land and migration.
- "poor" husbandry (late planting, poor weeding and crop spacing) and the low level of fertiliser use are identified as limiting productivity, but no suggestions are made as to why "better" practices are not adopted.
- the lack of experimentation on poorer (non-European, non-cash crop) land is recognised. Although not stated it is thought that most of the experimentation referred to in the paper was done on experimental stations, not farmer's fields.
- the recognition of the diversity of agriculture presages the importance that will later be given to indigenous/local knowledge.

2. Floyd CN 1991 The Use of Crop Residues to Improve Soil Fertility in Sub-Saharan Africa

Geographical Area: Sub-Saharan Africa
RNRRS Production System: Semi-arid

Introduction
This desk study was commissioned by the Agronomy and Cropping Systems sub-Programme of the previous RNRRS. It sought to clarify the potential of crop residues used directly (rather than indirectly via manures or composts) to improve soil fertility for small-scale farmers in semi-arid, sub-Saharan Africa. Semi-arid (SA) was here divided into dry SA (60-150 days growing season; 400-900mm annual rainfall) and wet SA (150-210 days growing season; 900-1400mm annual rainfall). Soil fertility was defined as the capacity of the soil to support plant growth on a sustained basis.

Summary of main conclusions
Most main soil groups in semi-arid, sub-Saharan Africa (SASSA), apart from luvisols, are suggested as being at risk of, or experiencing, soil fertility decline, the main features of which are low soil organic matter (OM) levels, low nutrient content, low cation exchange capacity and poor soil structure and stability.

In SASSA crop production is the primary source of subsistence, and yields are low. There is considerable demand for crop residues as fodder, grazing, construction material and fuel, with the result that only a small proportion may be returned to the soil in which the crop grew. There seems to be good evidence that even if the supply of crop residues increased, farmers may still prefer to utilise them for purposes other than return to the soil.

Research suggests that at least 60% of crop residues are consumed in typical post-harvest grazing situations, and that little of the manure generated is returned to the field of origin. With increasing aridity, the dependence on crop residues (CR) for grazing increases, and that CR are increasingly used for fuel and construction purposes. By the end of the season few CR may remain following consumption by foraging termites.

Root biomass (ca. 40% of above ground biomass) accounts for the majority of OM return to cultivated SASSA soils, and - unlike above ground residues - its rate of return can be expected to increase proportionately as crop yields increase.

Crop residue management can be a major determinant of soil OM levels on many SASSA soils since other sources of OM are likely to be uneconomic or unavailable. Typically SASSA soil OM levels of cultivated soils decline to a fraction (1/2 - 1/3) of those under natural vegetation. In many places crop residues are the major source of organic return to the soil. Where yields are low, the quantities involved will be insufficient to prevent a decline in levels of soil OM and soil nutrient content.

The effects of crop residue management on soil fertility are likely to depend largely on the contribution that crop residues make to the maintenance of soil OM levels. Early stages of CR decomposition are associated primarily with the chemical and biological effects of soil OM on soil fertility, while the later stages of decomposition are associated also with the physical effects of soil OM on soil structure and stability.

The supply of nutrient from CR decomposition tends to be asynchronous with the nutrient demands of crops.

Tillage increases the rate of soil OM decomposition while termites collect and concentrate organic matter, and enhance soil mixing, aggregation and permeability. Mulching consistently reduced soil temperatures and improved soil water availability. However mulching was often tested at rates that required import of residues. A degree of N immobilisation can be expected from CR return, especially when CR are incorporated immediately before planting.

Consistent beneficial effects of CR return on soil OM levels were found, most often reducing the rate of an established decline, or, less frequently, resulting in a net gain. The limited evidence assembled in this study suggests that in the semi-arid and sub-humid tropics complete residue return from an average farmer yield would maintain soil OM levels. The majority of results show only a modest CR return effect on crop yields (<10%). The largest effects were on degraded sandy soils (entisols and alfisols). Results show that a number of years (typically 4-5) is needed to establish the pattern of response to CR return.

Researchable constraints
Research is presented here at three levels: agronomic, soil and systems. These should be linkages between them, preferably through some association or working group arrangement. Past research should be taken into account, and soils used carefully characterised.

Agronomic research priorities are to:

- Obtain a better understanding of farmers' practices of crop residue use, particularly with respect to the maintenance of soil fertility, as a basis for developing research proposals and interpreting results
- Obtain a reliable estimate of the effects on soil properties and crop yields that can be achieved by CR return options on an adequate range of SASSA soils and climatic conditions.

A more limited **soil research** programme should concentrate on:

- The potential of soil OM to counteract soil acidity and enhance ECEC
- The importance of soil OM composition in maintaining soil fertility
- Determine the relative contribution of stover and root residues make to the maintenance of soil OM levels and soil fertility.
- Research on effects of CR return on pH and Al toxicity for SASSA oxisols and alfisols is a particular deficiency.
- Research dealing explicitly with CRR effects on soil biomass activity or microbiological processes (Rhizobia or mycorrhizae).

Sustainable solutions to low soil fertility will also require **research at a systems level.** Initially research should:

- Identify the range of soil OM levels that can be achieved in SASSA under a range of potential farming systems using existing soil and climatic data, agronomic information and SOM modelling techniques.
- Consider the potential for combining organic and inorganic sources of nutrients and mixed farming.

General research areas identified were:

- There is a lack of recent, reliable and relevant information about the use and supply of crop residues as a soil amendment. Research reported is fragmentary, with poor coverage of the soils occurring in SASSA. Insufficient attention has been given in experimental design to identifying mechanisms involved in treatment effects.
- Translation and more detailed reporting of the research from francophone West Africa, particularly multilocational trials by IRAT, would be beneficial.

Note: The research examining the effects of CR return on soil properties and crop yields was predominantly station based, technology oriented and researcher designed, with little interpretation of results in relation to farming practice. A particular risk of this research approach is that many of the experimental soils and their management may have been unrepresentative of those used in normal (smallholder) farming.

Development issues
This study is part of the wider concern about the poor sustainability of farming systems in sub-Saharan Africa. While there seems little doubt that low levels of soil organic matter contribute to the apparent soil fertility problem, it is less certain whether the solution lies with changing the farming system (improved methods of crop residue management, agroforestry or mixed farming) or with changes in the social, economic and political framework of the countries concerned. South Australia and the Southern Plains of the USA experienced soil fertility problems. Government policy, R&D and socio-economic conditions were key features in the recovery of soil productivity and sustainability.

While a potential for crop residues to contribute to improving soil fertility has been demonstrated, it is not possible to quantify the extent to which it can be realised in practical farming.

The prospects of improving soil fertility in SASSA by increased return of CR appear poor, partly due to alternative uses for the CR and partly due to the asynchronous release of nutrients. The improvement of CR return through improved crop and soil management appear limited. The use of inorganic fertilisers have the potential to improve soil fertility, but may require radical change in the systems of farming and economic situation of the region.

Farmers are aware of the need for soil fertility maintenance, including CR return, but are often unable to apply these principles for operational and economic reasons.

3. Yates RA and Kiss A 1992 Using and Sustaining Africa's Soils. Agriculture and Rural Development Series No. 6. The World Bank

Geographical Area:	Sub-Saharan Africa
RNRRS Production System:	Particularly relevant to semi-arid and forest agriculture interface

Introduction
The publication reviewed was the summary of the conclusions of a seminar held in Washington D.C. in January 1992, sponsored by the World Bank and entitled "Managing the Fertility of Africa's Soils: Meeting Economic and Environmental Needs".

Its purpose was to review the existing status of knowledge about African soils and their management, to identify gaps in that knowledge, and to identify action (that could be undertaken by the World Bank) to fill those gaps. The seminar focused on: the physical and chemical nature and constraints of African soils; an evaluation of chemical fertilisers as one means of addressing the problem of low soil fertility; an evaluation of other technologies such as organic amendments, microbial agents and farming systems both alone and in combination with chemical fertilisers; the role of economic and human factors in limiting or promoting different technical solutions; and recommendations for research to broaden options and for actions to implement them.

Summary of main conclusions
A rate of growth of 4% pa in African agricultural production is needed to stimulate general economic development. In the past growth has been through increase in area cultivated; now farmers are forced to cultivate less suitable soils, and it is estimated that 72% of arable and 31% of pasture land in Africa is physically degraded.

Of the immense amount of accumulated data on the soils of Africa, much is more accessible in developed country archives than in Africa, and some of that in Africa has been, or is in danger of being, lost. Funds are constraining the transfer of data to CD-ROM by institutions such as CABI.

The seminar limited its discussion to four major zones: a) the Sudano-Sahelian savannas and similar regions of East, Central and Southern Africa b) the Guinea savannas c) a transition zone which straddles the forest/savanna boundary d) the humid forest zone. Some soils (up to 4% of the total) of wetlands and those formed from basic and ultra-basic rocks are of higher fertility status and their use must be maximised, to minimise the need for intensification of less suitable soils.

All four soils mentioned above are mostly permeable and deep, with good agricultural potential where rainfall is adequate. However, the aggregates forming the structural units are easily disrupted and they are highly erodable. The roles of mulching and minimum tillage are of particular interest in this context. Once soil cover is removed, erosion proceeds rapidly.

Most African soils are impoverished (even in undisturbed state). The major means by which nutrients are lost are through erosion, crop removal and leaching. As it is unusual for African farmers to replace these losses by imported materials, most African soils have suffered nutrient mining for centuries. A recent survey (Stoorvogel, JJ and Smaling EMA. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa, 1938-2000. Wageningen, Netherlands: Winard Staring Centre) has given the mean net nutrient removals from arable soils in 38 countries of sub-Saharan countries in 1983 as 22 kg nitrogen, 6 kg phosphorus and 23 kg potassium per hectare per annum with this negative balance becoming more adverse. It is urgent to build African soil fertility and maintain those increased levels of productivity.

The soils in all four main groups are dominated by "low activity" clays with low cation exchange capacity. The low nutrient holding potential of the clay minerals also makes the soils susceptible to nutrient imbalance and acidification, which in turn leads to the problem of aluminium toxicity. This is exacerbated by most nitrogen fertilisers apart from calcium ammonium nitrate. Deficiencies of sulphur are widespread, yet research on this subject is negligible.

The cycling of nutrients is largely dependent on the soil microflora, which both depends on, and is part of, soil organic matter (SOM). SOM is also of fundamental importance for the maintenance of soil structure, and is therefore very important for water infiltration and resistance to erosion. The SOM contents of the two drier zones are mostly low or very low, partly due to widespread burning (which has short term benefits, but in the long term destroy OM and the diversity of soil fauna). The quantities of organic soil amendments produced on-farm are insufficient to maintain SOM levels, and there are comparatively few instances of the import of nutrients to arable lands (e.g. livestock grazing stubbles, use of mulches for coffee, use of composted urban refuse). According to Young (1989)[5] the plant biomass that would have to be returned to the soil in order to maintain SOM at normal equilibrium levels is 14, 7 and 3.5 tons/ha in the humid, sub-humid and semi-arid regions respectively: this approximates to the return to the soil of the total of all residues from current cropping activities, whereas most farmers have competing uses for these residues (feed, fencing, fuel etc.).

The level of chemical fertility in all four main soil groups is low, even in virgin soils. Many speakers made the point that "organic farming" will not drive the growth required in African agriculture. Low-external-input agriculture can only support low-productivity subsistence type agriculture, condemning most Africans to continuing poverty levels of productivity. However nor are inorganic fertilisers alone sufficient to maintain good yields under continuous arable cultivation - applications of organic matter are also required.

At present the use of inorganic fertilisers by African peasant farmers is very low, much of which can be attributed to the poor levels of profitability under smallholder farming conditions (which do not justify the investment risk).

Phosphorus is almost universally deficient in cultivated soils in Africa even though Africa has about 70% of the world's estimated phosphate reserves. Further research is needed on the utilisation of this resource.

Shifting cultivation is ceasing to be an option for maintaining fertility because of increasing population pressure. Legume cover crops are unlikely to be grown unless they have a food or feed value (e.g. cowpea). The integration of crops and livestock is complex, and deserves more research attention. Mulching provides major benefits through the protection of the soil surface from erosion, and through the recycling of nutrients. As mulching often involves the import of organic material, it also imports nutrients. Minimum tillage originated as an extension of mulching, which does not require the import of materials. While technically efficient minimum tillage has not been widely adopted in the tropics, the reason most often given being the high cost of herbicides.

Some form of agroforestry (notably agroforestry) is traditional practice in many tropical countries. In recent years, much attention has been given to modifying these to improve their effectiveness. While it is commonly agreed that certain forms of agroforestry have a wide range of benefits, some of these have not been proved. It is now held that, in most cases, to maintain soil OM levels, 30-40% of the area needs to be under trees. Tree strips can be effective for erosion control, but the original alley cropping "package" has been poorly adopted. A recent development is improved tree fallows using fast growing leguminous species. Additional research is required (e.g. to overcome the problem of poor crop germination following *Sesbania* fallow). A variant is the transfer of tree-biomass from specially planted of tree blocks (e.g. for mulching of coffee). This removes the crop/tree competition of alley cropping, but there are dangers of nutrient imbalances arising. Multi-storey gardens would seem to be a potential area for further research.

The importance of Rhizobia and other N-fixing micro-organisms (*Azospirillum, Azotobacter* and blue-green algae) was acknowledged. Among other micro-organisms, the mycorrhizae have received much attention, but there are major difficulties in making practical use of their potential: First, VA mycorrhizal fungi are present in most soils and introduced ones would need to be robust to compete; second, large quantities (150tons/ha) are required to be applied to the field; also mycorrhizae tend to assist crops to mine fertility, although growth in the short term can be greatly enhanced.

[5] Young, A. 1989. *Agroforestry for soil conservation.* Wallingford, U.K. and Nairobi, Kenya: CAB International and ICRAF.

Principal researchable constraints

The meeting did not generate specific research topic suggestions, but did come up with a number of general items requiring special attention. These were:

a) **Research - general**

- Greater participation of local communities in identification and implementation of priorities
- More effective co-ordination between donor-driven research efforts, and better networking between research institutions, especially in sustainable agriculture.

b) **Research targeting**

- Need for more adaptive research and extension (e.g. site specific fertiliser recommendations); but concurrently increasing the emphasis on strategic research on selected subjects (e.g. ICRAF)
- Increased attention to interactions between mineral fertilisers, and between these and organic/biological sources.

c) **Research techniques**

- Improved site selection
- Improved site characterisation
- Longer time horizons for soil fertility research

d) **Research implementation**

- The participation of local communities is essential at all stages
- Any form of top-down approach soon becomes ineffective. This will frequently require a change in extension techniques.

e) **Extension**

- Increased awareness of senior extension staff of the dangers and complexities of the problem, and the potential range of solutions as a starting point in creating awareness across all extension staff.

f) **Data recovery**

- Encouragement of researchers to carry out exhaustive data reviews, including all that (unpublished data) available on their own research stations.
- Access for researchers to published information through CD-ROM (from CABI and CIRAD) and from FAO information on soil and land suitability maps.

g) **Planning, monitoring of Research and Development**

- The Consortium for Soil Resource Management is suggested as a starting point (together with regionally active CGIAR centres) for the co-ordination of soil research programmes.

h) **Fertiliser production**

- Stimulation of local fertiliser production (e.g. local rock phosphate extraction and grinding) in a manner appropriate to local circumstances is within the World Bank's mandate.

Development issues

The seminar recognised the serious and growing problem of soil degradation which threatens to undermine Africa's agricultural base, and that mismanagement and misuse of the land are at least partially responsible. There is also growing concern over the regions apparent increasing aridity, and the likely link with destruction of the natural vegetative cover.

4. Anderson LS and Bell SA 1995 Definition of the Researchable Constraints to Improved Productive Potential and Sustainability of Land Use Systems at the Forest-Agriculture Interface

Geographical Area:	India, Brazil, Ghana, Indonesia (countries covered by the Forest Agriculture Interface of the Plant Sciences Programme)
RNRRS Production System:	Forest Agriculture Interface of the Plant Sciences Programme

Introduction

This paper was commissioned by the RNRRS Plant Sciences Programme to determine the current state of knowledge concerning the physiology of nutrient accumulation, utilisation and recycling within tree-crop based production systems through a process of review and consultation, and also to identify the major researchable constraints to improved productive potential and sustainability of such systems.

The reviewers took the forest agriculture interface to mean an amalgamation, in space or time, of two types of land use, agriculture and forestry, into the collection of land-use practices known as agroforestry.

Summary of main conclusions

Present understanding of plant mineral nutrition has come mainly from study of crops that evolved from nutrient rich sites and have been bred for greater productivity at high nutrient levels. The expansion of agriculture into marginal areas may require a combination of (a) soil improvement, (b) lowered expectation of crop yield, and (c) crop breeding for characteristics that more effectively exploit infertile soils.

The emphasis on research in the field of plant mineral nutrition is shifting from studies of ion transport physiology and uptake kinetics at high external concentrations (laboratory studies carried out with unrealistic below-ground environmental conditions e.g. liquid culture/pots) to studies in which the whole soil-plant system is considered, leading to an understanding of allocation patterns, morphology and growth physiology under conditions of low nutrient availability, and ultimately the breeding of crops for low-input agriculture.

In agroforestry two principles are at work: competition (between individuals or populations) and its converse - facilitation (in which one species assists the other). In agroforestry a greater relative yield can be achieved than in monocultural crop production by minimising competition and maximising positive interactions.

Principal researchable constraints

- The need for understanding of rooting pattern is a re-occurring theme in the context of both reduced competition and facilitation (degree of overlap of nutrient depletion zones; extent of nutrient pumping that facilitates growth of its companion; extent to which tree and crop rooting patterns reduce the flow of nutrients out of the system).
- A second major theme links 3 research issues: (i) phosphorus as a major, limiting nutrient in many tropical soils; (ii) mycorrhizas, which can support the plants efficient acquisition and utilisation of phosphorus, and (iii) environmental grain (looking to see the heterogeneity of distribution of nutrients).
- A third theme concerns the dynamics of nutrient release from plant litter, and the synchronisation of release with acquisition and utilisation by the growing crop.

The paper gave no further detail of specific research topics within these three main areas.

Developmental issues

Agroforestry has moved from an initial period of advocacy and promotion, description and classification. The emphasis should now be on mechanistic approaches, understanding the interactions that are taking place between tree and crop components and the specific processes involved.

5. ICRAF 1994 The African Highlands Initiative: A Conceptual Framework

Geographical Area: Africa (East and Central)
RNRRS Production System: Hillside, high potential

Introduction
The African Highlands Initiative is a response to the major concern of National Agricultural Research Systems (NARS) and (IARCs) that decades of agricultural research in the relatively high-potential, but densely populated, highlands have not achieved commensurate results in terms of improved and sustainable land productivity. The Directors of NARS of Burundi, Ethiopia, Rwanda, Kenya, Tanzania, Uganda and Zaire and those of the CGIAR centres based in those countries met in June 1992 to explore the potential for a collaborative regional research initiative focusing on the management of the natural resource base for agricultural production.

Summary of main conclusions
Land productivity in the highlands is declining markedly. The major factors contributing to the diminishing capacity of the NR base to meet the needs of the rapidly growing population are the existing resource management systems and their response to inappropriate national agricultural policies, internal strife and escalating cost of agricultural inputs.

The goal of the AHI is to sustainably improve or enhance land productivity within intensive land-use systems of the highlands of east and central Africa by working with farmers to evolve policy and technologies that increase agricultural production while maintaining the NR base. This will be achieved through a regional programme of research (see below), better understanding of the natural and socio-economic environment, strengthened capacity of NARS to deal with NR management problems, and co-operation between NARS and with IARCS and others. The beneficiaries will be small-scale farmers in the highlands, the urban poor and those responsible for agricultural and land-use policies.

The AHI will operate at 3 levels: The first level will comprise national teams operating at selected research sites (watersheds) in collaboration with farmer groups and development agencies (including NGOs). The second level will involve regional co-ordination through a Technical Advisory Panel. The third level will comprise the governing body or legal authority for the initiative.

The first phase of the long-term initiative will promote and demonstrate to participating institutions the potential benefits of the integrated approach to research. Implementation will require the commitment of resources at national (institutional) and regional levels. These will come mainly from existing resources, but will be supplemented by funds from donor sources to facilitate co-ordination and collaboration. Until a regional body is constituted, ICRAF will manage the funds and ensure delivery of Phase 1 outputs.

Principal researchable constraints
The two main research themes of the AHI will be:

- Maintenance and improvement of soil productivity. Initial activities will be to synthesise past research and identify gaps. Teams will then take an integrated approach that involves both improving nutrient availability, for example by reducing nutrient losses, improved recycling and synchronising nutrient availability to needs, and making greater productive use of available nutrients, for example by introducing higher value crops, more efficient rotations or new crop-livestock-tree combinations.

- Management strategies to protect crops from pests and diseases resulting directly from the decline in soil fertility due to intensification of land use through the design of appropriate control strategies based on integrated soil and crop management. Priority will be given to studies on banana nematodes, bean stem maggots, bean root rot, potato bacterial wilt and striga (on maize).

During the initial stages these will be limited to three land forms: steep and moderately steep slope, plateaux and highland valleys. The theme of management of genetic resources will be introduced later in the AHI programme.

Supporting activities will be:

- Diagnostic and socio-economic studies to understand traditional techniques of NR management

- Strengthening professional capacity of NARS through training, and information access on natural resource management to farmers, policy makers and scientists.

Development issues

The highland ecosystems are threatened by degradation and depletion of natural resources, and a diminishing capacity to support the growing population. To date the majority of research efforts have concentrated on breeding and the introduction of higher yielding and better adapted varieties and livestock breeds. The assumption of this research and programmes such as Global 2000, and the T&V system is that farmers will be motivated to apply fertilisers and other inputs to maintain a productive ecosystem. This has not happened due to reasons that include: a) insufficient input in technology design by land users; b) inability of farmers to absorb initial investment costs; c) unreliable inputs; d) emphasis on limited and broadly adapted technologies that optimise yield without offering choice; e) ineffective extension; f) separation of conservation from production.

The conflict between conservation and production is manifested in the encroachment of production on steep slopes, forests, valley bottoms and wetlands, loss of genetic diversity, shortages of wood fuel and drying up of springs and streams.

6. Kiff E, Turton C, Tuladhar JK and Baker R 1995 A Review of Literature Relating to Soil Fertility in the Hills of Nepal

Geographical Area: Nepal
RNRRS Production System: Hillsides

Introduction
This review of Nepalese hill farming and related soil fertility issues is one of three papers reviewed here that were all components of an RNRRS initiative to determine a long-term strategy for research into soil fertility for the hills of Nepal.

Summary of main conclusions
Average arable land holdings in the hills (200-3000m) is 1.12 ha, but over 60% of households have <1 ha, so that soils are intensively used. In addition to arable land households have access to common property, including forested land that has come under community management over the last 10-15 years. There is great interdependence for nutrients between forest, livestock and arable components, with little import of external inputs from outside this system. These systems have evolved over centuries, and land tenure and farming practices reflect a complex culture and power relations.

Soil fertility is seen by farmers as a major problem, together with scarcity of water, land, labour and capital. Intensification has led to some positive effects on efficiency of resource use, such as through stall feeding of cattle and the increased planting of trees on farm and on communal property.

Land ownership and landlord-tenant relations influence the investment made in farmed land (e.g. soil and water conservation measures, tree planting and the greater use of organic composts, green manures and mulch by owner cultivators). The large share of production (50%) appropriated by landlords encourages the use of measures that will give short-term returns such as inorganic fertilisers.

Nepal's hill soils are young and the strata steeply tilted leading to variations over short distances. The majority of soils are light to medium texture, easily worked and have good water holding capacity. However they are likely to be inherently infertile due to low clay content and low CEC. In the absence of organic matter to increase the CEC, there is a potential rapid loss of nutrients through leaching.

Farmers have their own detailed soil classification systems, with colour and texture being the main differentiating criteria, and physical conditions and management implications as further refinements. Terminology varies markedly between regions, limiting this otherwise practical soil "language".

Nepalese farmers maintain that with sufficient amounts of water, compost and labour and a suitable climate and management any soil can be made fertile and productive. From the farmer's perspective water, fertility and labour management are interdependent, interactive and inseparable components of soil management.

The review suggests that increased cropping intensities, declining livestock numbers, losses of fertile top soil and a reduction in the rate of FYM/compost application have singly or in combination contributed to a decline in soil productivity. While there may be an overall increase in production, this is usually brought about by an increase in cropping intensity - which is often accompanied by decreasing crop yields on both irrigated and rainfed land. Fallow has now ceased to be the prime method of fertility management, and FYM/compost is now by far the most important additive used by farmers to manage soil fertility.

The hill soils are particularly vulnerable to losses of organic matter and nutrients through a combination of natural factors: heavy seasonal rainfall, erosion-prone nature of the soils, steep topography and removal of ground cover.

Chemical fertilisers have shown large increases in yields, but farmers are aware of negative effects such as soil hardness, acidity, reduced moisture holding capacity and nutrient leaching (especially where the mineral fertilisers replace organic sources). Productivity is not the only consideration for subsistence-based hill farmers; risk reduction is also a primary concern.

Nepalese hill farmers use a wide variety of practices to maintain soil fertility, the most common of which are: FYM/compost application, chemical fertilisers, water-borne nutrients, grain legumes in rotation, mulching with weeds, forest litter or crop residues, short fallows, slicing and burning of terrace risers, in-situ manuring (grazing of stubbles), green manuring and burning of trash and collected leaf litter.

While there has been some description of farmer's practices there has been very little investigation of farmers perceptions of the processes of plant nutrition and soil productivity. It is suggested that factors affecting farmer's decision making on soil fertility measures include: land ownership, access to markets, access to off-farm employment, labour resources, water resources, compost/manure resources and financial resources.

Intensification is leading to changes in soil fertility management, with a greater share of nutrients being applied to irrigated land. There are reports of a decline in knowledge about plants for green manuring and of sophisticated organic fertiliser techniques.

While there is no doubt that a large amount of soil particulate loss occurs through erosion in many areas, and that where associated with agricultural land this is a serious cause of nutrient loss, the extent to which this process contributes to a decline in overall productivity will depend on the balance with ameliorating management practices that conserve and add nutrients to the soil. Surprisingly farmers do not cite soil erosion as a major cause of soil productivity decline.

The review details responses of major crops to inorganic and organic fertilisers, as well as to some combinations. Studies on composting methods and the timing of compost incorporation have given mixed results. Farmers recognise at least three different compost quality grades, which are used for different purposes.

The use of a number of green manures (*Sesbania acuelata, Vigna umbellata, Lens culinaris, Eupatorium adenophorum and Adhatoda vasica)* are used for maintenance of soil fertility - particularly in rice seedbeds or paddies.

Principal researchable constraints

- Devise a practical soils classification system that can be used in the field to give advice on appropriate nutrient management. Farmer's own classifications should be included.
- Organic fertiliser quality and rates of nutrient release, and their role in reducing nutrient losses and improving physical conditions.
- Monitoring and management of the soil fertility and productivity of areas associated with the production of compost (e.g. over-exploited forest areas)
- investigate ways of producing more materials for composting from cultivated areas; e.g. growing multi-purpose trees, grasses and compost crops from under-utilised areas.
- Development of recommendations for sustainable chemical fertiliser use for different crops (including in combination with organic fertilisers).
- Appropriate measures for the alleviation of soil acidity caused by the use of chemical fertilisers.
- Investigate new ways of harnessing nutrients from outside the closed farm/village system; e.g. nutrient flows to irrigated land; N-fixing bacteria and plants; management of common property resources that act as a source of bedding and fodder.
- Survey reasons for farmers observations of declining fertility associated with increasing productivity
- Understand factors affecting farmer's soil fertility decisions and practices
- Management of forests in relation to soil fertility: a) how community resource is managed, and to whose advantage; b) how to maintain the flow of nutrients to agricultural land without mining the forest resource.
- Importance of the contribution of erosion and leaching to nutrient loss under different land-use categories. Ways of harvesting presently "lost" nutrients. Management practices to reduce losses.

Development issues

The hills of Nepal form the upper catchment of the Ganges, Indus and Brahmaputra rivers in whose basins >10% of the world's population live. The catastrophic floods of the late 1970s and early 1980s were blamed on farming practices and the loss of forest cover in Nepal. Forest degradation has been slowed, and in some places reversed, through the change of ownership from National forest to community-management. Also in contrast to Malthusian predictions greater intensification of land-use in the hills has not led to massive land degradation.

7. Turton C 1995 An Analysis of Soil Fertility Systems in the Hills of Nepal

Geographical Area: Nepal
RNRRS Production System: Hillsides

Introduction
This analysis, based on detailed field surveys of soil fertility using questionnaires and PRA techniques conducted in collaboration with Lumle Agricultural Research Centre in 1994/5, was commissioned by the ODA RNRRS (NRSP Hillsides system) as part of a larger study to draft a comprehensive strategy to guide the development of a soil fertility research programme. It is particularly valuable in being one of the few studies that takes full account of farmers perceptions and decision making processes in respect of soil fertility issues.

Soil fertility was taken by this review to mean all those soil characteristics which influence crop growth and impose limitations on yield, the main components of these being structure and porosity, nutrient availability and biomass activity.

Summary of main conclusions
Farming systems in the hills of Nepal are characterised by strong linkages between crops, livestock and forest. The links between the components are critical to the cycling of nutrients necessary for crop production and hence soil fertility, and point to the need for a systems approach to soil fertility research.

A review of past literature (see *Kiff et al* above) emphasised the widespread concern over soil fertility in the hills, with erosion, declining crop yields and soil degradation the main issues highlighted. Analysis of soil sample data revealed wide variation in fertility status across the hills, according to differences in land type, altitude and soil type.

From detailed surveys of representative sites, the majority of farmers reported that soil fertility was declining, both on (irrigated) *khet* land and on (rainfed) *bari* land. A decrease in soil fertility was also identified as a major contributing factor to crop yield decline. However there was considerable variation in the responses of different villages. A logistical regression model indicated that market availability, rainfall, household wealth category, and altitude affected the probability of fertility decline on both land types. Availability of forest resources and compost:land ratios were key factors influencing the likelihood of soil fertility decline.

Participatory Rural Appraisal (PRA) techniques were used to explore farmer's soil fertility management strategies. The results emphasised the integrated nature of the nutrient management system, with up to seven different practices being used by farmers.

The PRAs indicated that the main changes in soil fertility management over the last 10-15 years have been an increase in relative importance of FYM/compost, a decline in in-situ manuring (stubble grazing), the introduction of chemical fertilisers and a decline in traditional practices such as trash burning, use of green manures and mulches. However the degree and direction of change differs across villages. Accessibility to roads and markets and/or altitude seem to be the main factors influencing change.
Socio-economic factors of importance to soil fertility include ethnic diversity, resource status of households, accessibility to roads, markets, and new technologies, land tenure arrangements, population pressure and differences in gender roles, responsibilities and perceptions.

The study found that:

- The overall soil fertility conditions in the survey area are poor with respect to total N and exchangeable K
- Altitude accounts for the largest proportion of the variation in other soil parameters
- Significant differences in NPK levels suggest that *khet* land has relatively lower fertility levels than *bari* land
- Farmer's knowledge of soil types and management is strongly related to the underlying chemical properties of the soil
- A large proportion of the variation in soil properties can be accounted for by variations in soil carbon. This emphasises the important role of FYM/compost as a balanced nutrient source

- The situation concerning soil fertility decline is unclear, but significant differences in current nutrient levels across altitudes suggest that the problem may be more critical at low altitude.

Despite the high variability of soils and the management environment, it is felt that it might be rational to divide the study area into three **recommendation domains:**

1) Low altitude, accessible areas close to markets. Here the traditional interdependence between crops, livestock and forest has weakened, and has been partly compensated by the increase in chemical fertiliser use. Soil fertility is mainly static or increasing, but there are negative effects from inorganic fertilisers.
2) More inaccessible areas, and/or those at mid and high altitudes. Here linkages between components of the farming system remain strong, and soil fertility maintenance is highly dependent on livestock. Farmers are not in a position to substitute declining FYM/compost with alternative sources, such as chemical fertilisers.
3) Sites above 2000m, where potato-based cropping systems dominate, and livestock management is unique. Soil fertility management is dominated by in-situ manuring, FYM/compost and manure from transhumance sheep flocks during the winter.

Principal researchable constraints

- The need for a quantitative baseline to understand the relative rates of decline in soil fertility across agro-ecological zones and land types.
- Understanding of the role of forests in maintaining soil fertility, and the identification of ways to positively enhance this role (technical, managerial, policy).
- Understanding the motivation and decision-making processes behind the strategies adopted by farmers as a starting point for determining research priorities.
- FYM/compost remains the most important source of nutrients for the majority of farmers. It is important to gain a better understanding of organic matter dynamics, and the most suitable combinations of organic and chemical fertilisers for sustainable improvements in soil fertility.
- The development of **integrated nutrient management systems** is stressed.
- Emphasis on the role women play in soil fertility management.
- Reduction of erosion, through a participatory approach to the development of soil and water conservation technologies.

Development issues

Changes in the policy, institutional and economic environments have had far reaching effects on hill agriculture. These include infrastructure development, the increasing commercialisation of hill agriculture, implementation of community forestry policies and changes in land tenure and fertiliser supply policies.

Since this review was published a major policy document for agricultural development in Nepal has been released. This is the "Nepal Agriculture Perspective Plan"[6], which lays out policy for agricultural change for the next twenty years. It emphasises the role of the hills in providing high value commodities (livestock products, citrus, apples, vegetables and vegetable seed and the products of apiculture and sericulture) for an increasing home and export markets. The strategy aims for a system of roads that will facilitate the commercialisation of agriculture, fertiliser supplies in the quantity and time required, improved technology, and improved water control.

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[6] APROSC and John Mellor Associates, Inc. 1995. Nepal Agriculture Perspective Plan. National Planning Commission/Asian Development Bank: Kathmandu, Nepal

8. Gregory PJ 1995 A Strategy for Soil Fertility Research at Lumle. In: Proceedings of a Workshop held in Lumle Agricultural Research Centre, Pokhara, Nepal, 17-18 August 1995.

Geographical Area: Nepal RNRRS Production System: Hillsides

Introduction

The RNRRS Hillsides project "A systems analysis of soil fertility in the hills of Nepal" supported the work by Kiff et al (1995) and Turton et al (1995) reported above. The project culminated in a workshop bringing together those interested in soil fertility research in Nepal. A proposed strategy for soil fertility, arising from the project, was outlined by Professor Gregory at the workshop, and is summarised below.

Summary of main conclusions

Previous soil fertility research at Lumle Agricultural Research Centre (LARC) has focused on green manuring, compost making and *in situ* manuring, with some additional work on identifying legumes for inclusion in the cropping cycle. While these studies provided some useful insights to problems facing farmers, they were to a large extent piece-meal, short-term and gave inconclusive results. Nutrients were not measured (because no analytical facilities were available) and the value of treatments was judged on crop yield response, usually in a single season.

The focus for future thinking about soil fertility should be based around the development of quantified nutrient cycles (principally N and P) for the low and mid-hills, and separately for *khet* (irrigated) and *bari* (rainfed) lands.

The strengths that should be built upon from previous research at LARC are: a multidisciplinary approach (technical and social sciences); a farming systems approach; the recognition of the crucial role of FYM/compost; recognition that farmers are in need of a basket of options (choices) - not a single solution; the increasing role of chemical fertilisers; and the realisation that the processes affecting fertility are operating at different time scales.

Principal researchable constraints

The major objectives identified for a medium-long term soil fertility research programme are as follows:

- To collate existing information on the nutrient cycles of the farming systems in the high, mid and low hills, identify the key sub-systems and initiate research to fill the gaps so that the cycles are complete in three years.

- To determine effective means of conserving nutrients in manures and composts in ways that are acceptable to farmers within five years.

- To analyse the decomposition/stabilisation of organic manures and the fate of in inorganic fertilisers in soils as a prelude to the development of integrated schemes for soil fertility management in different farming systems.

- To determine the role for nutrient inputs such as fertilisers and legumes in the farming systems of the mid and low-hills.

Development issues

The need to ensure research results reach farmers was highlighted, and there was concern about the separation of research from extension, thereby weakening both.

N.B. Since the publication of this paper the Hillsides Production System has produced a position paper (SRI, 1997)[7], which includes a project *"Soil fertility management for sustainable hillside farming systems in Nepal"* whose main outputs will be: a) A series of systems-based nutrient balances for major systems in the mid and high hills

b) A quantitative exposition of the effects of manure and fertiliser on the long term fertility of soils in the mid-hills

c) Development of recommendations for farmers on the utilisation of manures and fertilisers.

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[7] SRI. 1997. Hillsides Systems Nepal: Position Paper. ODA RNRRS NRSP Hillsides Production System: SRI

9. McBride (Ed.) 1995 The Foundation for a Refocussed Soil Management Collaborative Research Support Programme. USAID

Geographical Area: World-wide
RNRRS Production System: All

Introduction
This report outlines a framework for reconstructing and refocussing the USAID Soil Management Collaborative Research Support programme within USAID's mission of promoting sustainable development. It identifies the major soil-management constraints to sustainable food production and natural resource management.

Summary of main conclusions
The Programme's objective is to develop, evaluate and promote the transfer of soil-management and integrated-nutrient management technologies that increase agricultural productivity, enhance food security and serve the economic and environmental interests of developing countries and the United States.

The operational framework suggested is through interdisciplinary product-development teams to identify *constraints* and develop *products* through *tasks*. The main constraints are listed under researchable constraints below.

Each product-development team needs to integrate developmental research, strategic research and outreach activities. Developmental researchers should synthesise information to generate a problem-solving product. Strategic researchers should close knowledge gaps that limit product effectiveness and explore new research avenues with the greatest potential for reducing the target constraint. Outreach specialists should help identify, develop, disseminate, evaluate and refine the team's products. These three components will operate in the knowledge that the fundamentals of soil and water management are predictable and our understanding of the principles of soil management is good, but our ability to apply this knowledge to problems in complex, local settings is weak.

The teams will be most effective if they employ a systems approach that links agricultural, natural-science and social-science components at each phase of the research, product-development and outreach process.

CRSP products should be packaged for the following target groups: LDC farmers and land-users, policy makers and planners, NGOs, PVOs, extension agents and teachers, NARS, agribusinesses, regulatory agencies, banks and lending agencies and private consultancies.

The collaborative research would be led by US Land-grant universities who would work with National Agricultural research and Extension Systems (NARES), International Agricultural Research Centres (IARCs), NGOs and PVOs, private sector agribusiness and other CRSPs and projects.

Principal researchable constraints
The following constraints are perceived to have the greatest impact on global food production and long-term environmental security:

- Nitrogen deficiency constrains plant production on more than 50% of all cultivated soils. Technologies that improve N-use efficiency, both from organic and inorganic carriers and through the use of Biological Nitrogen Fixation, could dramatically increase crop productivity and protect the environment.

- Phosphorus deficiency constrains food production on an estimated 92% of all cultivated soils. Substantial export of P at harvest must be replace by inputs; agricultural productivity could be significantly improved by decision aids that promote enlightened fertilisation policies and by technologies that increase the efficiency of P amendments, including the role of biotic factors such as levels of mycorrhiza and the role of organic matter.

- Soil acidity. 50% of soils in the tropics are acidic. Acidity problems tend to be especially prevalent in areas most desirable for agricultural production (i.e. where rainfall exceeds evaporation). The principles of acidity and its effects on plant growth are well understood. Decision aids that help to apply current knowledge can significantly increase soil productivity.

- Water deficiency and nutrient use are highly interactive. Significant benefits could be derived from clarifying the interaction between nutrient management and water-use efficiency.

- Erosion and land degradation are major constraints to sustainable food production and responsible environmental management. Erosion degrades the chemical, physical and biological properties of land resources on site, and the resulting sedimentation and non-point source pollution destroy valuable downstream investments and resources. Degradation - whether by erosion, nutrient depletion, loss of biological properties or other factors - reduces soil quality. Sufficient information exists on erosion-control processes, but products that will lead to farmer-acceptable erosion-control practices are needed. Much is also known about soil degradation causes; methods to quantify the state of degradation and the resilience of a system are less well established.

10. Yates RA and Gibberd G 1995 Literature Review of Fertility Maintenance in Africa

Geographical Area: Africa (mostly sub-Saharan Africa)
RNRRS Production System: All

Introduction
The objective of this review is to assist in the long-term improvement of agriculture in Africa through sustainable soil and soil moisture conservation and amelioration, using techniques that are appropriate to, and within the capacities of, smallholder farmers.

This literature review scanned over 8000 titles in electronic records, and made a more selective review of earlier (and very recent) publications in hard copy. It is admitted that much of the data is from sites that are not typical of smallholder situations, and that the vast majority of reports fail to relate response data in any meaningful sense to soils, topography or climate.

Summary of main conclusions
There are three basic soil characteristics that need to be maintained or improved if agricultural productivity is to be sustained or increased: the availability of sufficient plant nutrients in the correct proportions, the availability of sufficient soil moisture and the maintenance of a soil environment that promotes healthy root growth.

In addressing these it is necessary to address the cropping system rather than one crop, the farming system rather than a field, and there are important crop-livestock interactions which have special influence on soil fertility.

Rainfall is the overriding constraint to agriculture in most of SSA. Non-mechanical methods for maximising water storage include increasing soil organic matter (SOM) and providing soil cover.

The authors of the review are concerned that farmers are not adopting known effective soil erosion control measures such as *Vetiveria zizanoides* and the maintenance of ground cover, and are still practising the burning of vegetation as part of "slash and burn" or to provide dry-season grazing. Other harmful practices that seem to be increasing are the cultivation of steep slopes and of waterlogged or seasonally flooded valley bottoms.

It is assumed that small-scale farmers will be constrained by the cost of imported soil amendments, so that local low-cost sources (on-farm and local - such as rock phosphates or agro-industrial bi-products) must be used efficiently.

SOM levels in the drier parts of Africa are very low (never >0.5% C), which might be related to burning and rapid decomposition rates at high temperature. In humid forest regions the level is much higher (1-3% C). After clearing of forest there is normally a rapid decline of SOM in the first few years, followed by a more gradual decline. Maintenance of high level of SOM would require 5.5-8.5 t DM/ha/yr as manure (equivalent to 11-42 cattle per cultivated hectare, grazing from 6-47 ha in addition to the arable area. An alternative is to increase plant residues (especially roots) through fertilisation.

Traditional bush fallowing is on the decline, unsurprisingly as this system requires up to 150-200ha of land per family. It is possible that agroforestry technologies might bring some of the benefits of bush fallows; however the disappointing performance of alley cropping, and the doubt cast on the claims of *Faydherbia albida* are emphasised in the review. It is suggested that the benefits of agroforestry be compared to those accruing from cover crops such as *Mucuna pruriens* (particularly weed control and organic matter accumulation).

Minimum tillage would appear to have several advantages for African soils in terms of moisture and nutrient retention and soil structure, despite disadvantages such as dependence on herbicides and the scarcity of, or competition for, mulching materials. The reviewers suggest that solutions to these disadvantages are available.

All reports agree (though to varying degrees) on the value of organic manures, and there is no doubt that such practices should be promoted, perhaps in conjunction with chemical fertilisers given that the quantities available are limited.

The general (but messy) positive effects of nitrogen on yields is reported. It is pointed out that although urea is widely used, there is potential for high losses of N through volatilisation. Careful placement and timing reduce these losses. Biological nitrogen fixation by legumes (including cover crops) is seen as the most promising avenue for low-cost fertility improvement in Africa. However the amount of research being conducted in Africa is disappointing.

Good responses to modest amounts of phosphorus are recorded, although most studies with rock phosphates were for too short a duration. Mixing fast action superphosphate with slow release rock forms is suggested. In many cases the response to phosphatic fertilisers (especially single-superphosphate) may be due to a response to sulphur, not phosphorus as there is widespread deficiency of this element.

Principal researchable constraints
Issues have been grouped into 4 categories, according to those most appropriately placed to tackle them:

International

- The use of non-mechanical techniques to control erosion
- The effects of cultural techniques on the dynamics of SOM, including burning, minimum-tillage and mulching. The potential of further research on the dying practice of bush-fallows needs to be re-evaluated.
- In association with the above, the evaluation of cultural techniques (as above but also including leys, cover crops, relay cropping, inter cropping and rotations) on all aspects of soil fertility improvement, including soil conservation.
- Comparative evaluation of green manures/cover crops with agro-forestry techniques.
- N-fixation and the use on non-industrial techniques for increasing the solubilities of native rock phosphate.

International-FAO

- Any possible acceleration and/or reinforcement of their exercise in re-evaluating their country fertiliser programmes.

Ex-colonial centres

- A complete listing for each country of the extent of coverage of soil surveys.
- A search of grey literature in archival files relevant to soil fertility

National Centres

- As for colonial centres, but emphasising more recent research.

11. Gregory P, Nortcliff S and Livesley S 1996 Review of Soil Fertility with Regard to the Forest/Agriculture Interface System

Geographical Area: Tropics
RNRRS Production System: Forest/Agriculture Interface

Introduction
This comprehensive review was commissioned by the Forest Agriculture production system of the Natural Resources Systems Programme of the ODA RNRRS.

Summary of main conclusions
Expansion of agriculture is taking place at the forest margins. An important consideration is that soils that are stable when undisturbed are often precariously fragile following conversion to agriculture. If these conversions are not to be wholly destructive it is essential that the conversion and subsequent management are based on sound principles.

Systems including trees and crops are composed of exceedingly complex and diverse sub-systems, which must be understood. Of particular importance is the need to consider above and below ground interactions, over short and log time periods.

Estimates of global forest clearance (for all purposes) vary between 3-24.5M ha per year, depending on definitions and assumptions. Agriculture (chiefly by shifting cultivators) is only one of several reason for clearing tropical forest, but probably accounts for ca. 50% (destroying 50,000 km^2 and degrading a further 10 million km^2).

Nutrient cycling under natural forest
Half of all tropical soils are highly weathered, and the majority of tropical forests are found on such soils. The means by which tropical forests can support high biomass stands is through efficient nutrient cycling, although forests growing on less fertile soils are less productive and recycle less nutrients.

The soil organic matter (SOM) under natural forest can be differentiated into 3 dynamic pools: an active fraction of cellular material dominated by the microbial mass (which responds rapidly to changes in management); a slow fraction (turnover 5 years) and a passive fraction of non-cellular, recalcitrant humified material (turnover 150 years). There are a number of mechanisms in tropical forests that capture and conserve nutrients: A large root biomass; mycorrhizal associations and surface/below ground community of micro and macro-organisms.

Nitrogen inputs to natural tropical forest occurs through biological nitrogen fixation (blue-green algae) and dry and wet deposition (insignificant except after burning). Nitrogen is rarely limiting in natural forests, but phosphorus (which is mostly derived from chemical breakdown or weathering of parent material) can be.

Two different nutrient cycling mechanisms are recognised: internal cycling, which involves cycling nutrients from decomposing litter to recapture by the root mat on the forest floor; external cycling, which involves cycling of minerals from the subsoil.

It is important (for the implications of clearing) to differentiate between the productivity of primary forest systems which are sustained by weathering of parent material in open cycles, and the productivity of closed cycles with nutrients accumulated over centuries where weathered products are inaccessible to forest roots.

Nutrient cycling and SOM dynamics in managed systems
a) Shifting cultivation: In shifting cultivation in its (varied) traditional form, the structure of the forest is destroyed, but the soil is not degraded to the point where native vegetation cannot re-establish. Between slashing and burning there may be considerable loss of nutrients (especially P and K). On burning some 95-98% of the nitrogen, 67-76% sulphur, 27-47% of the phosphorus is lost to the atmosphere. Such large losses cannot be replaced through atmospheric deposition during the subsequent land use, bringing into question the sustainability of slash and burn. The ash has high concentration of potassium. Effects of the burn on soil chemical properties include an increase in soil surface pH, an initial decline in CEC - which then recovers, and a decrease in Aluminium saturation. These positive changes are reversed in time. During cultivation P released from ash and

mineralised organic matter may be fixed by soil oxides. This coupled to the partial destruction of mycorrhizal associations may combine to make P the first limiting factor for crop production.

During burning up to 60% of above ground biomass might be burnt, the rest decomposing on or off site. The primary organic matter source is dead roots (ca. 50t/ha) which provide nutrients on decomposition. Fresh inputs during the cropping phase are restricted to crop roots and crop residues, which only represent 30-40% of the tropical forest system inputs, and many systems simply don't recycle all available residues. The result can be a loss of 20-60% of C from the top 30 cm when forest land is cultivated. This loss can be mitigated by the returning crop residues to the soil. Initially SOM loss is from the active pool, then from the slow pool, finally levelling off as residual C remains only in the passive SOM fraction. It is the active pool that is most relevant to soil fertility.

The beneficial effect of rapidly released mineral nutrients into the soil (from burning and decomposition) will be short-lived if the system is unable to store such additions of soluble nutrients against run-off, leaching, erosion or encourage uptake. Under cultivation the fine root biomass is as much as 20 times less than under forest, roots are not uniformly distributed in space and time and mycorrhizae are at least partially lost. The tight, closed nutrient cycle of natural forests is broken, leaving a high potential for leaching and gaseous losses. Leaching is often the dominant process (although nutrients may be stored in the subsoil). Erosion losses can be serious from uncovered soil on slopes.

Such losses from the stock of the original forest are recognised to be greatly reduced if the slash is allowed to decompose naturally - without burning.

Increased frequency of clearing and cultivation leads to a gradual destruction of the soil macropore system, increasing leaching and runoff. In addition burning and cultivation lead to a gradual destruction of the root mat, decomposition of the humified organic matter and a reduction in nutrient cycling from organic and microbial processes.

The main function of the fallow phase is to allow the transfer of minerals from the soil back into the forest biomass. Provided the cropping period is not too extended there will normally be sufficient viable seeds and stumps for the soil to redevelop a forest vegetation. However, due to losses in the cropping phase (volatilised, leached, eroded, harvested) recovery is less at each fallow. It is estimated that a period of 10-15 years of secondary vegetation establishment is necessary to restore SOM levels to 75% of primary forest levels. In many cases it appears that a fallow period of >10 years is necessary for sustainability. Current 4-5 year jhum cycles in NE India lead to frequent losses of nutrients and will eventually lead to severe degradation unless there is a change in management.

Traditional slash and burn land clearance causes least soil disturbance of all the forest clearance methods and problems of runoff and soil erosion are generally minimal. However mechanical methods are being increasingly used, with consequent detriment to compaction, porosity, moisture retention, infiltration, erosion and soil chemical alteration. Yields can be 1/3 of those from slash and burn plots.

Chemical clearance is thought to have potential, especially in savanna regions with low tree density.

b) Logging: Commercial logging is responsible for 1/4 of the annual loss of primary rainforest, and is often the primary reason for clearance before other land uses take over (over 90% of closed forest land logged each year is subsequently used for crops). Up to 55% of the forest may be damaged by selective timber extraction, and in addition a substantial proportion of the non-commercially viable forest is removed for roads and skid tracks. This level of damage can be much reduced through improved harvesting methods. Although logging is a severe disturbance it is short-term compared to other land-uses. Nutrient loss through offtake is negligible, but erosion can be severe.

c) Continuous cropping: Soil properties are drastically influenced by continuous intensive farming, much more so than by shifting cultivation. There is a sharp decline in SOM during the first few years associated with the mineralisation of the active fraction, stabilising around year five. Fertilisation and minimum tillage can reduce SOM decline. Continuous cropping also results in a sharp decline in soil pH, which can be exacerbated by the use of mineral fertilisers. The decline in SOM, soil structure and pH leads to a reduction in CEC and losses of exchangeable Ca and Mg. Using fertiliser to only replace lost macronutrients can lead to micronutrients becoming critical.

Management practices to reduce these negative effects include reduced tillage systems, the use of crop residue mulches, cover crops and short legume fallows. A combination of these with fertiliser can maintain high yields on some soils.

d) Ranching: Clearance for cattle ranching continues at the rate of about 20,000 km^2/year. Soil fertility and pasture yield can decline rapidly after ranching begins, and only a few years of intensive cattle grazing can destroy the physical soil structure. The Ultisols and Oxisols common in Latin America are inherently infertile, and cattle grazing is often not a suitable or sustainable use of converted forest land. However there are also reported cases of beneficial effects on soil chemical properties after several years of cultivated pasture. Phosphorus suffers the biggest decline after burning, and after five years becomes the critical nutrient for sustaining pasture yield. The potential decline in pasture productivity can be avoided through: P-fertilisation, establishing a legume-grass mixture, and restricting grazing to the optimum level. Legume introduction to native pastures in sub-Saharan Africa has proved difficult due to communal grazing land rights. In Latin America pasture species have to be able to tolerate Al toxicity, low P availability, water stress, insect and disease attack and burning. Despite CIAT (Colombia) having identified suitable species, it is estimated that at least half (10 million ha) of the forest converted to pasture in Brazil has reached the advanced stage of degradation. Appropriate technology for this situation includes mechanisation, improved forages, fertilisation, and weed control - and once introduced continued investment is necessary. In the face of this opening up new land is seen as a cheaper option. A form of "shifting pasture cultivation" has developed, which poses a great threat of ecological damage, in terms of biomass, diversity, soil and water losses and possibly global climate change.

e) Perennial tree crop plantations: Both perennial tree crop plantations and plantation forestry lead to a loss of biodiversity compared to natural forest. However the long-term effects on soils are not as drastic as conversion to arable crops or pasture. Susceptibility to erosion is reduced markedly if bare soil is protected by a cover crop such as *Mucuna* or *Pueraria.*

Extractive plantation or tree crops have significant effects on nutrient dynamics at harvest through removal of crucial cations. This is further aggravated as the rate of soil nutrient return to the topsoil in monoculture plantations is less than the nutrient uptake by the vegetation.

Fruit plantations with a sustainable economic yield have been developed in several tropical regions without using a fallow period or fertiliser. This has been possible when the crop is grown together with other trees, commonly nitrogen-fixing legumes.

In some instances forest plantations are seen as a means of rehabilitating abandoned and degraded soils in tropical ecosystems.

f) Agroforestry: Agroforestry is a "land use system in which woody perennials are deliberately grown on the same piece of land as agricultural crops and/or animals in some form of spatial arrangement or sequence". Many claims are made for agroforestry, and Sanchez (1995)[8] listed 16 hypotheses, with their current status. These are presented as Table One.

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[8] Sanchez PA. 1995. Science in Agroforestry. Agroforestry Systems 30:5-55

Table One : The Agroforestry Hypotheses (Source and citations from Sanchez PA,1995)

Hypothesis	Status and references
1. Agroforestry systems cannot control soil erosion.	1. Proven in contour hedgerows and multistrata systems (Roose, 1970; Lal, 1989, Young, 1989b; Alegre and Fernandes, 1991; Banda et al., 1994; ICRAF, 1994, Juo et al., 1994; Kiepe & Rao, 1994)
2. Agroforestry systems can maintain SOM at levels satisfactory for soil fertility	2. Not proven. Too simplistic, since there are no reliable SOM levels related to satisfactory soil fertility. SOM increase has been detected temporarily in sandy soils under alley cropping (Lal, 1989; Kang et al., 1990) but not for other soils (Rao in press). Relevant proof should be in terms of functional SOM pools in relation to system nutrient uptake and overall productivity.
3. Agroforestry systems maintain more favourable soil physical properties than agricultural systems	3. Partially proven for soil under contour hedgerows in relation to adjacent cultivated fields (Van Noordwijk et al., ICRAF, 1994)
4. N-fixing trees can substantially augment N inputs in agroforestry systems	4. Proven (Ladha et al., 1993). Limited quantification of N-fixation by legume spp. and subsequent biomass N accumulation and return to the soil via litter.
5. Trees in agroforestry systems provide deep nutrient capture from subsoil layers that are inaccessible to crop roots	5. Proven for deep rooted nitrate capture in oxic subsoils with positive charge (Hartemink et al., in press; ICRAF, 1995). Not yet proven widely and unlikely to be relevant in other infertile subsoils.
6. Agroforestry systems can lead to more closed nutrient cycling and to more efficient use of nutrients and less leaching losses	6. Not quantitatively proven. Highly probably in many systems, but data not available.
7. The cycling of bases accumulated by trees in agroforestry systems and returned to the soil as litter can help reduce soil acidity.	7. Proven for litter high in Ca and Mg in non-agroforestry systems (Sanches et al., 1985). Decomposition of leaf litter produces metabolic organic products that temporarily complex Al in the short soil solution, thus decreasing soil acidity, for short time periods (Davelouis et al., 1991; Wong et al., in press)
8. Agroforestry is a useful component of systems for the reclamation of degraded soils.	8. Too general, probably will be proven in many circumstances. Proven for saline and alkaline soils (Singh et al., 1994). Proven for N depleted soils of Eastern Zambia with Sesbania fallows (Kwesiga * Coe, 1994).
9. The role of tree roots is as important as that of above-ground biomass in soil fertility maintenance.	9. Not proven. An important research topic.
10. Shade from tree canopy improves soil biological activity and N mineralization.	10. Proven (Wilson, 1990; ICRAF, 1993).
11. Roots of N-fixing trees have more nodules when in close contact with roots of non N-fixing plants. This may lead to direct transfer to the non-nodulating plant.	11. Not proven. High controversial.
12. Annual crops are unable to use all water stored in the soil.	12. Proven for shallow rooted crops (Ong et al., 1995)
13. The combination of trees and crops generally enhances rainfall water use.	13. Proven (ICRAF, 1994; Ong et al., 1995)
14. Because agroforestry systems use more water than annual cropping systems, they should increase primary development.	14. Being tested, depends on competition.
15. There is less competition between tree and crop species that develop canopies at different times.	15. Proven (Dalal, 1974).
16. Competition for water in agroforestry systems can be reduced by modifying the spatial arrangement of trees.	16. Proven (ICRAF, 1994)

Conclusions and recommendations (taken directly from the review)

The foregoing review of literature serves to illustrate the complexity and diversity of the Forest/Agriculture interface, and perhaps provides an indication of why there have been only limited attempts to summarise the behaviour of the soil at this interface. The interface includes a wide range of activities, which vary to a considerable degree in the relative importance of trees and agricultural crops, the spatial and temporal extent of the interface, and the extent to which the systems are to be maintained with or without external inputs. The types of activity vary from the basic short-term clearance of forest for a limited duration cropping phase, followed by abandonment, with possible return at some time long in the future; through agricultural encroachment at the forest edge for continuous production; management of woodland spatially discrete from agricultural crops, such as the Miombo woodland of southern Africa; the tree gardens widely found in south east Asia; agroforestry practices such as alley cropping; and tree management systems such as plantations where agricultural crops are mixed either spatially or temporally. Most of these activities would conveniently fall under the broad heading 'Agroforestry', and it is important to note this, as frequently the term appears to be used in the very narrow sense to describe alley cropping. The practice of alley cropping is just one of the many activities called agroforestry, and experimental plots apart, is probably not of major importance when considering farmers in the tropics and sub-tropics.

In attempting to develop land use and management strategies for the Forest/Agriculture interface, it is imperative that the broad characteristics of the trees and agricultural crops are clearly identified. Further, the very nature of the interface requires that these strategies must take account of the interactions between the two components. These characteristics of the individual components and the nature of the interactions must be identified above and below ground.

The decline in soil fertility is a significant feature of many smallholder farming systems at the Forest/agriculture interface in the tropics and sub-tropics. This process of decline must be addressed and solutions identified if attempts to increase agricultural production from these systems are to be successful. In many cases the smallholder systems include no external inputs of nutrients and, as a consequence, their ability to maintain agricultural production is dependent upon the inherent fertility of the soil, the ability of the perennial (tree) root system to 'mine' nutrients from deep in the profile, and possibly some biological nitrogen fixation. As much of the land currently occupied by smallholder farmers and areas likely to be incorporated into agriculture in the future are underlain by soils such as Oxisols and Ultisols with inherently low fertility, the time period during which crop production might be maintained from internal nutrient sources alone is likely to be relatively short (indeed this is the driving force behind shifting cultivation). In many systems there is little knowledge of the nutrient pool available or the nutrient export in crops, it is therefore virtually impossible to predict the time taken for unsustainability to occur.

Nutrient depletion and consequent poor yields is often the precursor for other negative effects to occur. The reduction in yields will be accompanied by a reduction in associated residues which may result in lack of fodder for animals, and an unprotected soil surface resulting in an increased vulnerability to erosion. If the land is abandoned because of this degradation further land will need to be brought into production, with the likely consequence that this will be subject to the same degradation processes.

Identification of gaps in our knowledge and research foci

The gaps in our understanding of the systems and the research priorities are presented under broad headings:-

General Comments

1. Sanchez (1995) presents 16 'Soil Agroforestry Hypotheses' (see Table one). Evidence to support these hypotheses is exceptionally limited both in amount and in regional scope.
2. The soil is the basic resource of the Forest/Agriculture interface system, attention must focus upon the direct measurement of soil processes within the soil if the system is to be managed efficiently and successfully.
3. Sustainability is a long-term consideration, it is therefore essential that long term monitoring of soils under systems at the Forest/Agriculture interface be established. These studies should focus on both the potentially vulnerable soils and soils which are expected to support long term sustainable production, with a range of tree-agriculture combinations.

4. An alternative to long-term monitoring is the use of computer based models. At present it would appear there is insufficient understanding of the processes involved and as a consequence a scarcity of information which might be used to validate such models.

Principal researchable constraints

a) Soil nutrients:

-There is a need to more fully understand: a) the dynamics of P in the inorganic-organic soil system; b) to consider the application of a wide range of rock based P sources.

- There is a need to investigate the process of "deep nitrate capture" and to identify the nature of rooting systems required to optimise the efficiency of these systems.

- There is a need for a more complete understanding of nutrient budgets for systems at the forest/agriculture interface.

- There is a need to monitor the changes in soil nutrient pools in the post-clearance phase (especially for Oxisols).

- There is a need to establish extensive field trials to consider the optimum management of organically-based and fertiliser-based nutrient inputs.

b) Roots:

- To investigate the morphology and nature of tree root systems necessary to optimise the roots' role in "closing the nutrient cycle".

- There is a need to understand the distribution, decomposition and nutrient release patterns of both perennial tree and annual crop root systems.

- To investigate under field conditions the nature and dynamics of the interaction between tree and arable crop root systems, both under normal and stressed conditions. The different root architectures and nutrient and water capture strategies must be identified.

c) Soil organic matter

- There is a need for mechanistic research of the release and immobilisation of nutrients in organic residues added to the soil both as soil surface and below-ground additions.

- To characterise the nature and composition of plant residues with respect to their "liming" effect, and to investigate response in both field and laboratory environments.

- To characterise the nature of tree plant residues, the rate of breakdown of the residues, and the release of nutrients during this breakdown, and to synchronise these releases with the needs of the crop plants and soil system.

- To investigate the beneficial effects of fallow tree species and identify the extent to which particular trees may be used for ameliorating soil with respect to particular nutrients. To develop a management strategy on this basis.

- To monitor the nature and dynamics of soil organic matter and plant litter decomposition over seasons and longer time periods.

Development issues

Deforestation leads to a loss of biodiversity and the degradation of natural resources, especially soil and water. Unsustainable practices such as destructive slash and burn agriculture, low-input ranching and destructive logging methods are using forest resources wastefully and causing irreversible damage to the environment.

Good husbandry principles such as minimum tillage, cover crops, judicious use of fertilisers and the wise choice of species mixtures (as in agroforestry) can reduce the negative effects associated with conversion from natural forest to managed productive agriculture.

Due to the complexity and dynamic nature of the changes that take place at conversion, further understanding is required of the processes occurring at this time in order to determine suitable management strategies.

12. Morse K 1996 A Review of Soil and Water Management Research in Semi-Arid Areas of Southern and Eastern Africa. Chatham, UK: Natural Resources Institute

Geographical Area: Africa (Southern and Eastern)
RNRRS Production System: Semi-arid

Introduction
This review was commissioned under the Semi-arid Production System of the Natural Resources Systems Programme of the ODA RNRRS to consider the potential for improving farming systems in the semi-arid parts of southern and eastern Africa particularly through research and application of soil and water management techniques.

Summary of main conclusions
Concern over production levels and environmental impact of arable and pastoral farming in the semi-arid parts of sub-Saharan Africa has been expressed for many years. The cropping system which used to exist was subsistence arable agriculture based on shifting cultivation and livestock production, and this appears to have supported those who used it for many generations. However the unsustainable nature of shifting cultivation was a feature of reports from the beginning of this century. Population pressures, land tenure and sedentarization have combined to replace shifting cultivation, and continuous cropping is now the norm. The continual cultivation of a piece of land without replenishing nutrients and organic matter will eventually lead to the decline of productivity to a low level. The reality is that an increasing number of people will depend on this environment, and it is vital that there is adequate preparation to meet their requirements.

The most important constraints are high temperatures, poor soils and low and erratic rainfall. With the exception of some fibres and oilseeds few commercial crops can be grown profitably under rainfed semi-arid conditions, and the opportunities for irrigation are limited.

The capture of water by the soil, its utilisation by the crop, and decisions and interventions which can influence these activities, are the lynchpins of any discussion of the technical management of the semi-arid environment. Both water and nutrients are limiting factors, and though they are not usually limiting simultaneously, some interplay is present. If water can be appropriately managed then other problems, such as soil erosion, can be overcome or at least reduced.

Components of water management are: the balance between rainfall and harvested water on the one hand and evaporation, transpiration, soil storage, runoff and leaching on the other. Water capture, storage and utilisation are important, but so also is the disposal of excess water to prevent waterlogging, erosion and downstream sedimentation. Various interventions or decisions can be made by the farmer to ensure that water in the soil is best used by the crop. These include: selection of varieties, selection of crop density and crop management practices (e.g. timing of activities, rotations, nutrient supply, tillage).

Research results from the semi-arid zone can be very difficult to analyse due to high variability of climate and soils. On poor soils small changes in P-Bray or clay content can give rise to large differences in the relative availability of nutrients and hence large differences in plant growth. Farmers use the variability (e.g. variations in topography and fertility) as part of a risk aversion strategy. It is important for research to be conducted in such a way that they reflect the reality of bad, average and good years.

It is also important that research acknowledges the constraints to adoption (other activities of farmers, their perceptions and their resources). An example is the use of mulch, FYM or compost materials, for which there may be limited supplies, limited labour and competing uses to soil and water conservation or soil fertility maintenance.

Crop growth modelling provides the potential to reduce the time required to obtain sufficient results for valid comparisons between options for intervention (e.g. for intercropping options), and the integration of the responses to climate, soil and agronomic parameters provides a good opportunity for inter-disciplinarity. However, the variability problems discussed above could make the modelling process complex, and involve a high proportion of (scarce) available resources.

The review considers the agricultural conditions pertaining in 5 countries of eastern and southern Africa (Botswana, Kenya, South Africa, Tanzania and Zimbabwe), assesses past and present research, and gives some pointers towards future research in the area of soil and water management. In all of the countries reviewed there has been a move towards meeting the research needs of smallholder farmers. However there was concern over the apparent repetition of research and the lack of progress in some countries. There seems to be an assertion that anything older than 20 years is outdated and irrelevant, and information flows into and within some countries and institutions is far from ideal. Methods of research are changing, with the partnership between research and farmers, and the need to integrate social and economic issues, far more discernible than it was in earlier publications. The move to on-farm research is a positive one, given the often misleading results from on-station trials. However, it has to be recognised that on-farm research is expensive in terms of researcher-time and recurrent expenditure.

Botswana: Research in Botswana (dominated by mechanical tillage research) highlights the need for trials over the range of poor and good seasons, and the complexity of research in semi-arid conditions, with poor establishment due to the climate and soils, and high coefficients of variation preventing or weakening the (statistical) analysis of results. Low water holding capacities of many soils appears to be the main constraint, preventing any impact of management interventions which aim to conserve or concentrate water. Mulch has not proved to be a useful method of improving soil moisture, and tillage research has been somewhat inconclusive over the last 25 years. The need to reduce soil compaction and increase infiltration has been illustrated by a number of researchers. However, as the only significant improvements in yield have resulted from the use of implements other than the (commonly available) mouldboard plough, the adoption of new techniques seems unlikely. The aim of any tillage operation in Botswana should be to enhance establishment and alleviate excessive soil strength by reducing bulk density. Strategies which include the mouldboard plough to increase the movement of water into the soil and reduce weeds may prove to be the most useful in the long term. Further examination of the relative economics of tractor and animal draught should be undertaken. Cropping in Botswana's difficult conditions is an opportunistic practice. It is concluded that the selection of appropriate crops and varieties will probably be the most effective route to increased crop production.

Kenya: In Kenya some 80% of the land is considered marginal for crop production, and yet the number of people living on that land is expected to reach 11 million by the end of the century. Expansion of arable farmers impacts on natural resources, and on pastoralists. Research historically concentrated on the high potential areas and cash crops. The migration of people along a gradient of decreasing rainfall, and a recognition of the importance of smallholder farming , has changed the emphasis of research. Kenya now has an increasingly comprehensive record of research into soil and water management in marginal areas. Although most research has been on-station, on-farm research - and the application of existing knowledge to the farming situation - is becoming more common. However, adoption by farmers of techniques proved by researchers to be effective has been slow, and they remain largely unconvinced of the value of relatively sophisticated and dynamic management approaches (e.g. response farming) and labour intensive conservation measures and water harvesting techniques. More collaboration between farmers, extensionists and researchers could bring dividends.

The agroforestry programme has made an important contribution in Kenya, and long-term work on the practical and economic implications of agroforestry should continue. More attention should be given to the practicality and applicability of the agronomically proven mulching techniques and static/shifting trashlines, so that widespread adoption can become a reality. The use of computer modelling offers interesting possibilities for predictive recommendations, but more work is required to incorporate farmer practice (e.g. intercropping) into these models. For this to be achieved, a detailed understanding of water relations and cropping patterns in intercropping systems has to be developed.

South Africa: In South Africa the vast majority of research has been directed towards commercial farming, and the smallholder sector was neglected. Much of the (excellent) research for semi-arid areas has been conducted at institutions of the Agricultural Research Council in Orange Free State and the Transvaal, and has concentrated on monocultures. Erosion is a problem through much of South Africa, but effects on yields have not been quantified. Nor is it clear if smallholder farmers see it as a problem. Control has concentrated on mechanical measures. The understanding of soil-plant-water relations under dryland and irrigated conditions is advanced in South Africa. Much of this work has been incorporated into crop-growth models which are used as management tools by researchers and (commercial) farmers. As example is the MAIZEMAN model (an adaptation of the CERES-MAIZE model. It may not be possible to apply the model directly to smallholder conditions, or allow farmer preferences for maize varieties. In the present climate of greater priority given to the smallholder sector, emphasis should be given to soil and water management practices, although it must also be realised that agriculture for many is a low priority, low prestige activity.

Tanzania: Agricultural research spending in Tanzania is about 20% of that considered to be necessary by FAO, and has focused on cash and export crops and areas of relatively high potential. During an extensive survey of agricultural literature Smith (1990)[9] stated that "there is very little interest in water use and soil and water engineering aspects, relatively few references to cultivation and soil husbandry techniques and increased, but rather low, activity in soil erosion and conservation studies in recent publications. It should be commented that a great deal of the literature is general in nature".

It seems that demand for land in the semi-arid areas will increase, and that this will adversely affect pastoralists unless use is optimised in order to minimise the impact. Research has been highly dependent on donor support, and this is likely to continue. There has been an emphasis on agrometeorological analysis, the conclusions of which have little to offer to farmers. Financial infrastructure to support research in semi-arid areas is weak, and farmers resources are very limited for the adoption of measures requiring capital or labour. Therefore any interventions will have to be low cost and have minimal impact on the many other aspects of farming. Assessment of the existing farming methods, and the soil and water management systems already used by farmers in the region, might be a useful starting point for any research.

[N.B. since this review a Collaborative Environment Research Project (ERP) has started in Kenya, Tanzania and Uganda supported by ODA with project management by Silsoe Research Institute, the purpose of which is: *The provision of adoptable technologies, based on indigenous practices, for improved water, soil and fertility conservation on sloping lands under conditions of water deficit; project emphasis given to resource-poor farmers.]*

Zimbabwe: In Zimbabwe, most of the research relevant to small farmers started in the 1980s, mainly under the Department of Research and Specialist Services (DR&SS) and the Department of Agricultural Technical and Extension Services (AGRITEX). A committee for on-farm research and extension (COPFRE) was formed in 1986 to co-ordinate between the two. Soil loss is a serious concern in Zimbabwe, mostly attributed to poor cropping technology and inappropriate livestock management. Farmers in communal areas might lose up to 50t/ha/yr. of soil. In addition a recent survey found that 80% of fields in Natural Regions II-IV showed symptoms of nitrogen and phosphorus deficiency.

Most research to date has concentrated on crop management practices and physical means of preventing water and soil loss. Previous enforced soil conservation measures were deeply unpopular. If they are presented as methods of keeping water within the field, as well as providing fodder for livestock contour bunds and grass strips may be better received after the droughts of the early 1990s. The creation of micro-environments for fruit and fodder trees should be investigated, and intercropping may help to reduce soil loss by developing more of a canopy earlier in the season. Mixed cropping in the form f relatively narrow strips and no-till cultivation has shown promise in higher potential sites, and now needs to be assessed in more marginal environments. Biological methods of controlling soil erosion should be more thoroughly investigated. This is happening with some NGOs and research organisations looking at the integration of trees and fodder crops in mixed and arable farming systems.

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[9] Smith PD. 1990. An evaluation of past agricultural studies in Tanzania. Bangor:, UK: University College of North Wales, Centre for Arid Zone Studies

Principal researchable constraints

- Biological methods for soil and water conservation; e.g. hedgerows and trashlines that are cheap and can be modified with experience.
- Varietal development, particularly to ensure good establishment at the start of the season
- Moisture conserving tillage operations using draught animals or hand hoes. Methods that can combine operations, as in Zimbabwe, should be tried elsewhere.
- Agroforestry has shown promise, but still needs to be proved.
- Rainwater harvesting may be valuable, but it is extremely site specific, can take up valuable land area (the run on area) and requires skilled management to avoid erosion, leaching and waterlogging.
- Environmental niches such as dambos, sodic lands and termite mounds should be exploited in a sustainable way.

13. ODA/World Bank 1996 Soil Fertility Management in Sub-Saharan Africa: Final Report of a Regional Study Funded by ODA and Managed by the World Bank

Geographical Area: Sub-Saharan Africa
RNRRS Production System: Various, but particularly relevant to Semi-arid,

Introduction
This report is a critical review of the technical, economic and institutional constraints to improving soil fertility in sub-Saharan Africa, and actions recommended to address them. The report is a synthesis of four country action plans prepared for Ghana, Kenya, Malawi and Mali, together with selected additional documents. The action plans were formulated by country researchers to identify ways to improve soil fertility in their respective countries. The work was financed by the ODA, and managed by the World Bank.

Summary of main conclusions
Declining soil fertility is regarded by some as the most fundamental impediment to agricultural growth, and a major reason for slow growth in food production in sub-Saharan Africa (SSA). Soil degradation is hastened by extremely low use of mineral fertilisers, averaging only 12kg/ha in 1993 (c.f. 72 kg/ha in India) and stagnant during the last decade. Population growth has resulted in a demand for more food, extending cropping to more marginal lands. The per capita arable land area has dropped by 2% p.a., and traditional bush fallows have been dropped in favour of continuous cropping, with a consequent downward spiral of soil fertility, declining yields and increased soil erosion.

Traditional agricultural techniques, increasing use of marginal lands, continuous cropping, over-grazing and deforestation are direct causes of land degradation. These are driven by economic, social and political forces. Constraints to improved soil fertility management include: technologies not adapted to local conditions; poor returns to agricultural products dependent on rainfall; the low price of outputs relative to the price of inputs and weak market development of agricultural inputs and outputs.

Soil nutrient depletion, caused by plant uptake and subsequent plant removal, leaching beyond the crop root zone and surface runoff, is considered the fundamental bio-physical limiting factor responsible for slow growth in food production. The estimated net loss has averaged about 700 kg N, 100 kg P and 450 kg K per hectare during the last 30 years over about 100 million hectares of cultivated land in SSA.

Nitrogen has been characterised as the second most important crop production after water, while Phosphorus is equally important in some areas. There is comparatively little knowledge of the micronutrient status of SSA soils. Soil acidity, measured by a decrease in pH, is commonplace in Africa and reported to be increasing.

Despite the above, recommended fertiliser application rates are frequently unattractive to SSA smallholders, as they ignore local conditions, practices and resources and are static in the face of changing economic environments. One suggestion is that more precise fertiliser recommendations can be formulated by modelling soil nutrient dynamics and crop growth using geographic information systems (GIS).

Although there is a need for more localised identification of soil nutrient status, most government facilities are suffering from insufficient investment to maintain adequate soil testing services. Heavy workloads, low human resource capacity and long delays in getting results out characterise most existing services.

An action-research approach developed in Mali by a farming systems team, with farmer participation, has been successful in classifying soil fertility constraints and identifying improved organic fertilisation methods for farmer use. Recommended fertilisation practices are differentiated according to their need for land, labour and cash resources. An experimental programme is underway to determine locally adapted alternative practices (Defoer et al 1995)[10].

The efficiency of on-farm fertiliser use, as measured by yield response to N and P additions, is often low. Timing and placement of the fertiliser, timely planting and weeding, moisture availability and the correct

[10] Defoer T, Kante S, Hihorst T and de Groote H. 1995. Towards more sustainable soil fertility management. Paper presented at the Nutrient Cycling Project Workshop, FARM Africa/IIED Arba Minch, Ethiopia, 24 Nov. - 1 Dec.

choice of variety can enhance the efficiency. Moisture availability is a major constraint, and the high risk of poor response to fertiliser in dry years is a primary cause for little or no use in semi-arid areas. A partial solution can be found in "response farming", where fertiliser use (and other husbandry practices) are adjusted to evolving rainfall patterns through the season.

Subsidies on fertilisers is a controversial issue. By 1994 16 out of 29 SSA countries had either reduced or eliminated fertiliser subsidies. This often coincided with market liberalisation and the devaluation of national currencies, complicating the analysis of the consequences. Some are of the opinion that getting the right fertiliser to the right place at the right time is just as important as price in determining the growth of fertiliser consumption. Pan-territorial pricing and maintenance of buffer stocks by government and the conditions imposed by donors on type, origin and transportation of in-kind fertiliser aid all combine to reduce the impact of market liberalisation.

Only small quantities of fertiliser are manufactured in SSA. However the cost of importation is high, and a drain on scarce foreign exchange. Several countries have deposits of rock phosphate, limestone, gypsum, sulphur and magnesium. Of these rock phosphate exploitation looks to be the most promising, and could contribute to the long-term upgrading of soil phosphate reserves.

Soil degradation is also a consequence of falling SOM levels. SOM maintenance and management is central to sustainability of soil fertility on smallholder farms in the tropics. There are two approaches to improved soil fertility management. One is to meet plant requirements with mineral fertilisers, and the second relies on biological processes to optimise nutrient cycling. A more sustainable middle path is Integrated Nutrient Management which combines organic and mineral methods of soil fertilisation with physical and biological measures of soil and water conservation. It integrates technologies that are adapted to site-specific agronomic and socio-economic circumstances to redress nutrient imbalances and SOM deterioration more effectively. It requires and provides an improved understanding of the inter-related problems and solutions associated with soil fertility management, and builds on farmer management practices and knowledge which allows for incremental, rather than wholesale, change.

There are four general categories of organic methods for increasing soil fertility and SOM: agronomic (composts, mulches, crop residues, planting legumes and green manuring), crop and soil management practices (including fallowing and reduced tillage), integration of crops and livestock, and agroforestry. The benefits and status of research of these are considered briefly in the report. It is concluded that agroforestry benefits are likely to be long term in nature - and that many of the claims made have yet to be substantiated.

The problems of soil erosion and low soil-water retention are highly correlated. Soil erosion and low water retention are directly related to the destruction of vegetative cover, exposure of the soil and increased runoff. The effects can be severe. Pieri (1989) estimated the annual losses in Mali as 23 kg N/ha, 1-4 kg P/ha and 7-50 kg K/ha as a result of erosion. Problems of soil erosion in grazing lands is primarily associated with severe denudation. Many measures to increase soil water retention and decrease erosion require a catchment basin approach. It is necessary to tackle these problems on a community basis and to design incentives to encourage individual participation in communal works.

Principal researchable constraints

The approach of Integrated Nutrient Management is suggested as the most appropriate framework to provide short-term plant nutrient requirements and restore SOM in the long-term. A combination of complementary research station and farm-level approaches is required, including the active participation of farmers and extension agents. Specific research topics suggested are:

- Improving fertiliser-use efficiency
- Micro-nutrient research (of the type developed in Malawi)
- Organic fertilisation methods: combinations of organic/inorganic (INM); means to produce organic manures under low fertility, land, labour and capital constraints; labour management between seasons; adjusting fertility management according to climate
- Develop and test methods for evaluating returns to investments in organic technologies that provide long-term and multiple benefits
- Where necessary establish new soil testing and calibration facilities
- Conduct a comprehensive review and synthesis of unpublished research on mineral and organic fertilisation and soil and water conservation practices
- Develop a GIS capacity to model and monitor stocks and flows of nutrients, the effectiveness of fertiliser recommendations and the growth of major food crops
- Implement a technical and economic research programme to evaluate the long-term residual benefits from the use of local mineral resources (e.g. rock phosphate and limestone)
- Initiate research to understand the basic processes of soil nutrient stocks and flows, and to track the consequences of crop and soil management strategies.

Institutional actions to complement research

- develop and implement participatory, action research programme to identify key soil fertility constraints and technology or management practices to address these constraints (see Defoer et al, 1995)
- Expand the CIMMYT/Rockerfeller model of soil fertility research and extension to other areas of Africa
- Articulate and develop national environmental policies which incorporate a comprehensive soil resource management programme
- Create national multidisciplinary research teams to monitor soil fertility status an develop new programmes and strategies to improve soil fertility
- Develop research and extension institutions that promote greater involvement by farmers
- Develop closer linkages and co-ordination between national, regional and international centres and NGOs.
- Promote community-based land-use planning
- Involve communities in determining alternatives to food as an incentive to participate in communal soil and water conservation projects
- Revise laws to private land ownership, where needed
- Commit substantial resources over extended periods of time to implement a successful technology development and transfer process.

Development issues

In addition to research, it must be recognised that a primary constraint to improved soil fertility management is the low level of smallholder cash income. Accordingly, research must be accompanied by a general rural development strategy that includes policies and investments to increase the efficiency of output markets, improve agricultural extension services, and promote savings through cash generating projects.