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Edited by: P. J. Gregory
C. J. Pilbeam
S. H. Walker

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Increasing productivity in high potential systems: The role of integrated nutrient management in sustainable soil fertility improvement

M. Wood, A.F.E. Palmer and P.J. Gregory
The University of Reading

Introduction

This paper will consider high potential production systems in developing countries where there are high population densities and agricultural research is aimed at resource-poor smallholder farms. The priorities are to increase food production and improve soil fertility through the development of sustainable production systems involving integrated nutrient management. There is a growing body of evidence that in many such systems yields are reaching a plateau or, in some cases, actually declining. With human populations continuing to grow and little scope for expanding crop area in Asia and only limited scope in Africa, productivity per unit area must be increased. Integrated nutrient management will have a pivotal role to play if productivity and production increases are to occur. The following high potential production systems will be considered in this review.

- Wetland rice production systems (flooded anaerobic soils) in Asia.

- Alternating wetland and upland production systems (alternately anaerobic and aerated soils) such as the rice-wheat rotations employed in Northern India, Pakistan, Nepal, Bangladesh and north-central China.

- Rainfed, largely maize-based, production systems (aerated soils) in the Highlands of East Africa and parts of Central and South America.

When reviewed in the light of the latest projections for human population (Fischer and Heilig, 1997), sustainability of productivity and production of crops in the high potential areas of Africa, Asia and Latin America take on critical dimensions. The following five countries will have the largest contributions to population growth 1995-2050:

India	603 m	China	296 m	Nigeria	227 m
Pakistan	221 m	Ethiopia	156 m		

There are always uncertainties with such projections but even the lowest scenarios are alarming in terms of sustainability of crop production and productivity especially in the countries with the highest projected population growth (Tribe, 1994). The high potential production systems included in this document are important in all of those countries.

The burden of producing the food for these extra mouths will largely fall on the high potential production systems where farmers tend to produce surpluses to their subsistence needs as compared to more marginal environments. Most, but not all, of the above systems are located in the tropics so, before considering the production systems, a brief summary will be given of the biophysical resources (soils and climate). Because of the diminished importance of shifting agriculture in relation to settled agriculture (a process that will continue), this review will only consider high potential agricultural systems in settled agriculture.

Biophysical resources

There is great variation in the physical, chemical and mineralogical characteristics of tropical soils, which relate to geological history, geomorphological characteristics, climate, vegetation and other biological factors including man. In order to compare and extrapolate data between regions it is necessary to avoid misleading and inaccurate terminology (Sanchez, 1976); this report will use the USDA Soil Taxonomy classification.

Soils of moderate to high fertility (Alfisols, Vertisols, Mollisols, Andisols, alluvial Entisols and high base status Inceptisols) cover 33% of humid tropical Asia, but only 12% of tropical Africa and 7% of tropical America. However, most of the fertile soils in Asia are already under cultivation, and 'problem' soils with severe management limitations are widespread (22%) (Sanchez *et al.*, 1989). The interaction between climate (rainfall and temperature) and soils is a key determinant of potential crop productivity.

Universal Tropical Soil Infertility?
Many generalisations have been made about tropical soils that suggest that tropical soils, when compared to temperate soils, are lacking in diversity, fertility, soil organic matter *etc.* Today, it is recognised that tropical soils are as diverse as temperate soils (see Box 1) and that this diversity must be taken into account in decisions about the agricultural management of tropical soils (Lal and Sanchez, 1992).

Box 1 Myths and Science of Soils of the Tropics

Sanchez and Logan (1992) dispel the myth of "universal tropical soil infertility" on the basis of soil fertility levels, clay mineralogy and soil organic matter contents.

- Generally fertile soils (Alfisols, Mollisols, Vertisols and Andisols) cover a similar proportion of the temperate region (27%) and of the tropics (24%).
- Variable charge minerals (e.g.. kaolinite, iron oxides) are a feature of tropical soils (60%) but are less common in temperate soils (10%) where permanent charge minerals are common.
- Soil organic matter (SOM) content is a function of inputs from plant litter and the decomposition rates. The range of SOM contents found in the tropics is as variable as that in temperate regions.
- Tropical soils should be considered in terms of specific soil fertility constraints:

Soil-related constraint	Africa (1555 M ha)	Asia (1205 M ha)	America (1879 M ha)	Tropics (4638 M ha)
% Long drought stress	67	72	45	60
% Aluminium toxicity	26	24	43	32
% Steep (>30%) slope	22	51	32	34
% High P fixation	11	20	32	22
% Saline	1	2	1	1

In a given climatic region, where growth of crops is controlled by temperature and rainfall, soil adds a further constraint through (a) the availability of nutrients and (b) depth, stoniness, texture and structure. These soil factors together determine soil fertility (Rowell, 1994).

Nutrient Budgets

Soil fertility is sometimes (wrongly) viewed simply in terms of the supply of plant nutrients: the macronutrients N, P and K; the secondary nutrients Ca, Mg and S; and the micronutrients Fe, Mn, Cu, Zn, B, Mo, Co, Na, Si and Cl.

Nitrogen and phosphorus are often primary limiting factors for crop production. N exists largely in unavailable forms in the soil and the atmosphere with a small proportion present in available forms in the soil. The available forms may be lost from the system in some cases with deleterious environmental effects and negative economic consequences for the farmer. Because of the mobility of certain forms of N, losses are inevitable to some extent and can be balanced by inputs from biological nitrogen fixation and fertilisers.

In contrast, there is no atmospheric input of phosphorus and potassium, and inputs must be either from weathering of minerals or from fertilisers. When P is added either as relatively soluble forms such as the common phosphate fertilisers or as the less soluble rock phosphate, only a portion of the P will be available to plants immediately due to fixation in the soil.

Nutrients other than N and P can become limiting under intensive cropping and if deficiencies are encountered can be remedied by additions to N and P fertilisers. It is reckoned that 30% of the chemical elements are essential for life; some of these such as Na and K are concentrated in the earth's crust, whereas others such as Ni and Cu are found in the deeper mantle. Fyfe *et al.* (1983) offer an interesting global perspective on rates of geochemical weathering and hence nutrient supply from parent rock. If a plant extracts a nutrient at a faster rate than minerals can supply then, assuming no other inputs, complex clays (smectites) will be drained of essential nutrients and will be degraded towards kaolin, and water retention and ion exchange capacity will be reduced. Fyfe *et al.* (1983) advocate the use of finely-ground rock to supply sufficient micronutrients to intensively cropped soils.

Wetland rice production system (anaerobic soils)

Rice-based agricultural systems dominate in much of Asia where more than 90% of global rice supplies are produced and consumed (Cassman *et al.*, 1995). Irrigated rice systems account for 55% of total harvested rice area and 76% of global rice production (IRRI, 1993). About 40 million ha of irrigated rice are harvested each year in tropical and sub-tropical Asia, of which twenty-eight million ha at present produce two or three rice crops per year on the same land. Approximately 12 million ha are in a double-crop rotation of irrigated rice and wheat in Northern India, Pakistan, Nepal and Bangladesh (Cassman *et al.*, 1995).

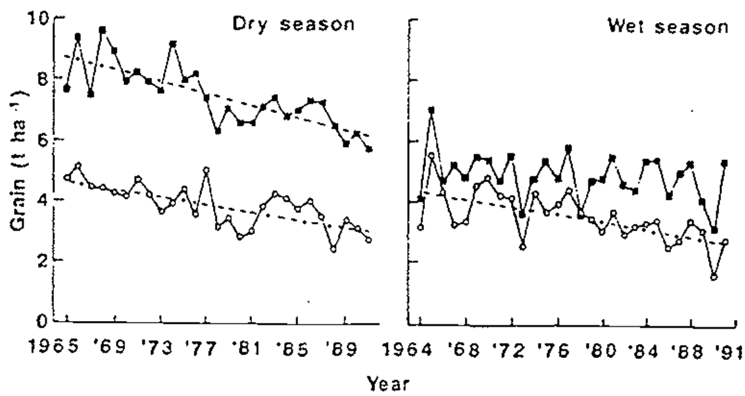
Since the 1960's, the wetland rice systems have intensified with the use of modern short duration, high-yielding varieties. These are the most intensive cereal crop production systems in the world. Besides full irrigation, high nutrient inputs and some pest control measures are employed. The International Rice Research Institute (IRRI) estimates that rice production must increase by more than 50% by the year 2020 (IRRI, 1993) to feed the growing population. This increase must come from existing irrigated land that has been intensively farmed for two or three decades often after many years of less intensive cultivation. A net increase in land for irrigated rice cultivation is not anticipated.

Although the long history of rice farming indicates that the system is sustainable at a relatively low level of productivity, it is not certain whether the high levels of productivity achieved following the Green Revolution are sustainable (Greenland, 1997; see Box 2). On a regional basis the rate of increase of rice yields for Asia fell from 2.86% $year^{-1}$ (1973/75 to 1981/83) to 1.32 % $year^{-1}$ (1985/87 to 1991/93). Greater declines have been observed for China.

Box 2 Long-Term Continuous Rice Experiments: Yield Declines (After Cassman *et al.*, (1995))

- IRRI agronomists have carried out a series of long-term experiments at research stations in the Philippines to monitor the changes brought about by the introduction of Green Revolution technologies.

- With few exceptions, these experiments have demonstrated declining yields over time:



- The quantities of nutrients removed in each tonne of grain are :
  10-15 kg N   1-5 kg P   1.5-7 kg K

- Nutrient balances can be estimated for different levels of production; these indicate the importance of application of inorganic fertilisers and efficient use of rice straw.

Causes of Yield Decline in Wetland Rice Systems

The long-term productivity declines in the continuous wetland rice systems have been attributed to various factors. The high offtake of nutrients in the rice crops, normally two crops per year and sometimes three crops per year, can lead to negative nutrient balances (see Box 2). Yields have declined in spite of high use of N and P fertilisers and there appears to be a problem of N uptake late in the crop cycle (during grain-filling).

Sulphur is often removed from rice soils in larger amounts than are supplied in irrigation water and other inputs (Greenland, 1997) and deficiencies have been reported in a range of Asian countries. The amounts of micronutrients such as Fe, Mn, Zn removed by crops are often balanced by inputs from irrigation water, rainfall and sediments causing little mining of soil reserves. Zinc is the micronutrient that is most commonly reported to be deficient particularly in soils of pH >6.8 and organic matter contents >3% (Greenland, 1997).

Identifying the causes of the yield decline phenomenon at IRRI will require a better understanding of the processes that govern the N-supplying capacity of intensively-cropped wetland rice soils, in particular the regulation of N cycling processes by the soil biota and the interaction between biological and physical processes.

Cassman *et al.* (1996) have reported that acquisition of applied N by the rice crop is typically less than 40% in farmers' fields. Measurement of the components of N-use from indigenous N in the soil-floodwater system and from applied N (partial factor productivity) have indicated considerable variation in indigenous N supply in both the IRRI long-term experiments and farmers' fields. This may be due to variation in soil conditions and management during the fallow period. The degree of soil drying, aeration, microbial activity, tillage, residue management and subsequent effects on N mineralisation-immobilisation and retention of available N in the root zone are key factors (Cassman *et al.*, 1995; Gaunt *et al.*, 1995; Kundu and Ladha, 1995).

At present, rates of N applied by farmers are not related to indigenous N levels. Hence, Cassman *et al.* (1996) conclude that there is a need for field-specific N management to optimise N-use efficiency of lowland rice systems in Central Luzon, Philippines and perhaps for tropical lowland rice systems in general. This implies moving away from blanket fertiliser recommendations for large recommendation domains towards more precise methods at the farm-scale.

Rice-wheat production systems of south Asia and China (northern India, Pakistan, Bangladesh, Nepal and north-central China)

Rice-wheat cropping systems cover 12 million ha in the Indo-Gangetic and Brahmaputra flood plains and in the foothills of the Himalayas (Hobbs and Morris, 1996). It is estimated that 32% of the total rice area and 42% of the total wheat area are under rice-wheat rotations. These rotations include other crops (oilseeds, pulses, fodder crops) and the farming system generally includes livestock. There is little scope for expansion of the area of this cropping system.

Wheat is grown in the cool dry winter season and rice during the warm humid summer. Both crops receive supplemental irrigation. The relative importance of rice and wheat varies between countries. In Bangladesh rice is the main food staple and in Pakistan wheat dominates. Soils in the areas of this production system are diverse; the calcareous soils of the Indo-Gangetic flood plain are generally alkaline whereas the non-calcareous soils of the Brahmaputra flood plain are more acidic (Hobbs and Morris, 1996). Nitrogen and P are the major nutrients required with micronutrients (*e.g.* Zn) required in some areas.

Cropping intensity is usually two per year and in the most densely populated areas is 3 crops per year. Wheat and rice areas have increased markedly since 1960 but yields per capita have declined and total arable land has barely changed. So, the increased areas of wheat and rice have occurred through intensification, generally by the introduction of a second cereal into the cropping sequence. This has been facilitated by the use of irrigation and the development of short duration, non-photosensitive varieties. The modern varieties being semi-dwarf in stature could respond to greater amounts of fertiliser and their adoption also stimulated increased investment in irrigation in the 1960's and 1970's.

Yields of both wheat and rice increased at 2% per year from 1960-1990 following the introduction of Green Revolution technologies. India and Pakistan were the first countries to benefit and increase in rice and wheat yields in Bangladesh and Nepal did not occur until the mid 1970s. There is now evidence that these earlier increases in yield have halted and the yields of both crops may have started to decline (see Box 3).

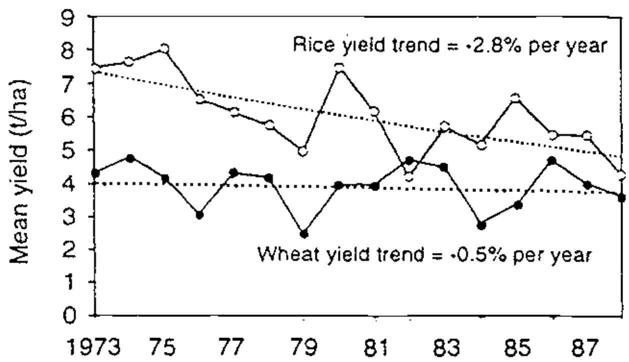
The factors implicated in declining yields in continuous rice systems considered above may also be involved in the rice-wheat system e.g. ability of the soil to release N for crop growth (Cassman *et al.*, 1995). N fertiliser use efficiency is also low, around 30%. However, there could be additional causes for the apparent productivity declines (Hobbs and Morris, 1996).

The long-term productivity declines in rice-wheat systems have been attributed to nutrient deficiencies, especially N and P, because of the amounts of nutrients removed from the soil in the rice and wheat crops (see discussion on continuous rice). However, it has been difficult to establish clear links between soil fertility levels and declining yields of wheat.

Box 3 Long-term Rice-Wheat Experiments: Yield Declines
(After Hobbs and Morris, 1996)

- A number of soil fertility trials have measured the yields of rice and wheat in continuous rice-wheat cropping systems and shown decline in yield.

- Long-term trials at Pantnagar, U.P., India (1973-88) have shown declining yields of rice (-2.8 % $year^{-1}$) and wheat (-0.5% $year^{-1}$) in intensive systems when inputs are constant:



- Trials carried out a six stations in the lowland Terai in Nepal have shown annual declines in wheat yield of 4.3-6.8%.

- At Faizabad, U.P., India yield declines have occurred across a wide range of fertiliser application rates indicating a degradation of the natural resource base. This feature has been generally masked by farmers applying higher rates of fertiliser to maintain yields at lower fertiliser use efficiencies.

Soil physical properties are important in rice-wheat systems due to the alternating wetland (anaerobic) conditions for rice and the upland (aerobic) conditions for wheat. The puddling process for wetland rice breaks down soil aggregates, reduces pore sizes and leads to the formation of a plough pan. The resulting poor growth of wheat roots following rice may be a cause of the observed declining wheat productivity.

Soil biological factors may also contribute to the productivity declines for rice and wheat. Root nematodes have been implicated in poor rice growth in Nepal and the supply of N from soil may be important as discussed for rice-rice systems.

Expansion of the irrigated area and intensification of cropping systems have increased the demand for irrigation water throughout South Asia. In north-western India the water table has dropped at a rate of 0.2-1.0 m year $^{-1}$ during the past decade. This raises questions about the long-term sustainability of rice-wheat systems. More farmers are using tubewell water to supplement canal water, often with a deterioration in quality due to the presence of salts. Use of such water can cause salinity or sodicity especially in areas where water is insufficient to adequately leach out salts.

Phalaris minor is a grassy weed that is a severe problem in wheat, and has become a major problem in the continuous rice-wheat systems. Weeding by hand is ineffective and it must be controlled by herbicide. However, there is evidence for resistance to isoproturon, the most extensively used herbicide in India. Similarly pest and disease problems sometimes emerge in this intensive rice-wheat systems.

The rice and wheat crops compete for time in the ground. If one crop is late planted or involves a longer maturing variety, it may delay the planting of the subsequent crop. This is particularly true for wheat after rice where the field must be changed from wetland to upland conditions. Any delays in planting date for wheat adversely affect yield and hence fertiliser use efficiency.

The history of wheat yields in Pakistan since the green revolution has been reviewed by Byerlee and Siddiq (1994). The yield trends are of concern particularly in relation to projected population increase. The major inputs into wheat production in Pakistan have been modern varieties (virtually 100% adoption in irrigated areas) and increased fertiliser use (up from 10 kg nutrient ha^{-1} in 1966 to 130 kg nutrient ha^{-1} in 1986 in irrigated areas). Initially nitrogenous fertilisers were used, but by 1986 40% of fertiliser use was phosphatic fertiliser although this has subsequently decreased. The winter season water supply (when wheat is grown) doubled in the period 1964-76 but growth in irrigated water supplies then slowed. In spite of these inputs, wheat yields in the Pakistan Punjab have stagnated. In addition to the factors described above farmers are applying less manure to their fields, and reduced inputs of organic material, due to competition between its uses for manure and fuel, may lead to a range of fertility problems.

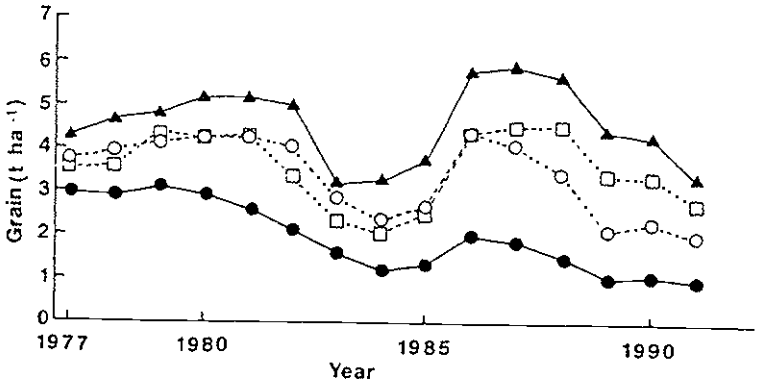
Upland cropping systems (maize-based) in Sub-Saharan Africa

Maize-based cropping systems are prevalent in much of sub-Saharan Africa especially in Eastern and Southern Africa. Maize is grown on 16 M ha in sub-Saharan Africa (CIMMYT, 1994) and there is great diversity of cropping systems in these high potential systems. In recent decades there has been a strong trend from shifting cultivation to settled agriculture brought about by population increases. With present population projections suggesting up to a tripling of population in Africa in the 1995-2050 period this trend must continue (Fischer and Heilig, 1997).

Evidence for declining yields over time as cropping intensities are increased and fallow periods are eliminated has been accumulating (Qureshi, 1990; Swift *et al.*, 1994; Singh and Goma, 1995). These declines are often rapid resulting in very low yields of less than 500 kg ha^{-1} when no fertiliser inputs are used (Kihanda and Wood, unpublished). Even where fertilisers have been applied, yields have often been maintained for several years but have then declined (see Box 4).

Box 4 Long-Term Upland Maize Experiment: Yield Declines

There are a few long-term data sets for continuous cultivation of maize in high potential areas. Data for Nigeria (Greenland, 1994), Tanzania (Singh and Goma, 1995) and Kenya (below) (Swift *et* al. (1994) all show declining yields despite inputs of NP (O), FYM (□), NP+FYM (▲) or no inputs (●):



Data for the response of maize to NP fertiliser (50 kg ha^{-1} NP $year^{-1}$, farmyard manure (5 t ha^{-1} FYM $year^{-1}$) and lime (500 kg ha^{-1} lime $year^{-1}$) averaged over 9 years at two sites (Embu and Kavutiri) in central Kenya show the benefit of integrated nutrient management for improving productivity (grain yields per season in kg ha^{-1}):

Site	No fertiliser	+NP alone	+FYM alone	+NP + FYM	SE
Embu	1648	2560	2009	3026	153
Kavutiri	878	2675	2056	3673	219

(Kihanda *et al.*, 1996) (SE standard error of mean)

Long-term experiments reported by Swift *et al.* (1994) show that high productivity cannot be maintained by use of inorganic fertilisers alone. Therefore there is a trend to recommendations that combine inorganic and organic fertilisers (Swift *et al.*, 1994). Similarly there is evidence that organic manure alone cannot sustain high crop yields (Williams *et al.*, 1995) again reinforcing the recommendation to use a combination of organic and inorganic fertilisers.

^{15}N fertiliser recoveries reported for central Kenya and Zimbabwe are 20-30% (Kihanda *et al.*, 1996; Kamukondiwa and Bergstrom, 1994). These values are disappointingly low and indicate significant potential for leaching of nitrate. Such low fertiliser-N recoveries indicate that opportunities exist for reducing the losses of N from the cropping system and improving nutrient use efficiency. The use of deep-rooting crops may allow some of this nitrate to be captured within the soil profile (Shepherd *et al.*, 1996).

Kumwenda *et al.* (1996) conclude that declining soil fertility is the most widespread limitation to maize yields and to the sustainability of maize-based cropping systems of eastern and southern Africa. Productivity increases are disappointing even where modern varieties are used and fertiliser is applied. In southern Africa N deficiency is ubiquitous and deficiencies of P, S, Mg and Zn are common in the sandy soils

Continuous cropping with insufficient organic inputs causes a decrease in SOM (Woomer *et al.*, 1994). As for the other high potential cropping systems, organic inputs to maintain SOM appear to be critical but are generally insufficient to halt the decline in SOM. For example, in central Kenya (Andisol, pH 4.2-4.5) following continuous cropping of maize with no inputs for 7 years the soil organic matter content decreased from 3.76% to 2.09%. The addition of farmyard manure at 5 t ha^{-1} $year^{-1}$ had only a small impact on this decline resulting in a soil organic matter content of 2.35% (Kihanda and Wood, unpublished). However, all possible sources such as farmyard manure, crop residues, legumes, leaf litter and prunings from trees, composts should be utilised as efficiently as possible with judicious use of inorganic fertilisers.

High potential systems - common features and solutions

All the high potential production systems considered above have the following features in common:

- Relatively good moisture supply either from rainfall or irrigation.
- Potentially fertile soils.
- High human population densities with high growth rates.
- Intensive cropping systems already in place.
- Little scope for expanding the acres of crops.
- Germplasm is available for most crops (especially the cereals) with higher yield potential than is being achieved by farmers.
- Low N fertiliser use efficiency (<50%).
- A slowing down in the annual rate of yield increase.

In addition, there are problems of physical deterioration of soil properties, particularly in the rice-wheat system where the combination of poor soil structure following puddling and poor root growth has a major effect on wheat yields.

One common thread is the low efficiency with which N is used by rice, maize and wheat. N is the nutrient that is probably causing yield plateaux or even declines in some cases. This is not meant to imply that other nutrients are not sometimes limiting even at present yield levels or that they will not become limiting when nitrogen supply/uptake is adequate. Crop yield per unit of N must be improved and this is most likely to be done through combined use of organic and inorganic fertilisers and through crop management (*e.g.* Kumwenda *et al.*, 1996). Such an increase in resource use efficiency should also lead to environmental benefits.

In order to manage N fertiliser additions to achieve synchrony of crop demand and N supply, it is necessary to be able to monitor N-mineralisation rates and probably also immobilisation of mineral N. Measurements of *net* N mineralisation may provide an indication of the availability of N to a crop, but improved management of N will require an understanding of the *gross* rates of N processes (Powlson and Barraclough, 1993). This, together with provision of simple tests of these processes for use by farmers in high potential production systems, would appear to be a major challenge to soil scientists. Can simple tests be developed for use by resource poor farmers for monitoring these complex processes (Snapp *et al.*, 1996)? Alternatively, can management routines be developed using precise measurements of these processes by researchers for the major soil types/environments so that near-optimal management recommendations can be made to large recommendation domains (target groups) of farmers?

For all the cropping systems of high potential areas studied, location-specific data are required for improved integrated nutrient management to achieve the goal of higher nutrient use efficiency. In the case of N this incorporates fertiliser N use efficiency and in part it involves more efficient use of soil organic N, added organic manures, biological nitrogen fixation, crop residues, etc. This overall situation is extremely complex and adds to the management intensity of crop production for the farmers concerned. How does a farmer obtain the information he needs to make decisions on use of inorganic fertilisers? The provision of such simple information as decision support tools may, when combined with the farmers' knowledge and experience of his fields, help him or her achieve improved synchrony and nutrient use efficiency. This will lead to an increase in the intensification of farming systems in terms of the knowledge and resources required resulting in increased productivity, whilst minimising the environmental impact.

During the past 30-40 years the farmers in these high potential production systems have demonstrated that they can change their crop production methods to achieve higher yields (adoption of new varieties, use of fertilisers, use of pesticides, use of machinery, change of time of planting, plant population, tillage methods etc.). More research is needed to provide the key information that farmers need to make the day-to-day management decisions required to improve their integrated nutrient management. This research should be participatory involving farmers, extension and research personnel.

Conclusions and recommendations

This review has highlighted the key role of soil physical, biological and chemical factors in determining crop productivity in high potential systems. There are large areas of fertile soils in these areas with good rainfall or access to irrigation water.

In all cases, modern varieties of the principal cereal crops have been developed and adopted by a high proportion of farmers. Use of inputs has increased during the past 40 years especially fertilisers but also pesticides. As a result there have been large yield increases but in many cases yields have reached a plateau. Productivity is apparently declining with apparent degradation of the soil as part of the natural resource base. Fertility depletion and degradation of soil physical characteristics are linked to soil organic matter, but this is far from being understood.

Sustainable soil fertility management should involve use of all the organic sources available as efficiently as possible in terms of timing, method of application to strive for synchrony of nutrient release and crop demand. This should be combined with use of inorganic sources of specific nutrients to provide nutrients during periods in the crop cycle of nutrient supply shortfalls relative to crop demand.

Such integrated nutrient management requires site-specific information-intensive management on the part of the farmer when compared with the energy/input intensive management of the post-

Green Revolution period. It requires different approaches to research in order to investigate the productivity of use of inputs instead of just yield *per se*. This requires research programmes of a long-term nature and multi-disciplinary and site-specific orientation (Lynam and Herdt, 1989).

In summary, for the high potential areas considered in this review, the following research themes are highlighted:

- Soil organic matter transformations and the role of soil organisms as they relate to availability of N, and synchrony of N mineralisation/immobilisation with the nutrient requirement of the crop.

- Use of organic materials (manures, composts etc.) to achieve maximum synchrony of nutrient supply with crop demand and to improve soil physical properties.

- Use of inorganic fertilisers (macronutrients and micronutrients) to supplement organic manures on a site-specific basis to increase nutrient use efficiency.

- The effect of intensification of crop production systems on soil physical characteristics particularly in relation to seedbed formation, root growth and water supply for the dryland crop in the rice-wheat system.

Attention should also be drawn to the importance of the quantity and quality of the irrigation water in relation to the sustainability and productivity of rice-based systems.

The above research priorities all concern soil science but cannot be viewed in isolation. There are strong interactions with crop agronomy, water management, entomology, pathology, weed science etc.

Hence, we strongly recommend the need for integrated multi-disciplinary research approaches with a long-term perspective in research programmes and funding to address the priorities identified above.

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Working Group on High Potential System

Integrated Nutrient Management on Farmers Fields: Approaches that work

Chairman: Dr Eric Craswell
Rapporteur: John Gaunt
Keynote Paper: Dr Martin Wood

Introduction

Constraints to the improvement of productivity and soil fertility vary from farmer to farmer and field to field. Thus overcoming these constraints requires participatory research that involves farmers and is site specific, underpinned by strategic and basic research. However, if this research is to benefit farmers, other than those in the specific location where the research is conducted, we have to establish mechanisms to transfer knowledge from one farmer to another and between agricultural systems.

Knowledge transfer is a major constraint to achieving improved production. Such transfer requires determination of limits for extrapolation. These limits are determined by socio-economic factors as well as environmental factors.

Classifications on the basis of cropping system, or agro-ecological zones (AEZ's) that do not take account of socio-economic factors are likely to be only partially successful for the purpose of establishing extrapolation domains. For example socio-economic constraints to production are likely to differ between rice wheat rotations of the Indo-Gangetic Plains and north-central China. Further, AEZ's as defined by the FAO, do not define irrigated (wetland or upland) areas. Thus they are of limited value in identifying extrapolation domains for irrigated crops. The concept of Resource management domains that integrate climatic, production and social constraints to define extrapolation domains is currently being developed within the CG system, lead by IBSRAM.

The current production level of high potential systems, can be considered with respect to the yield response curve (fig. 1). The potential yield where environmental factors (water, nutrients, pests and diseases) are not limiting is, determined by climate. Yield potential may be increased through plant breeding efforts.

Most agricultural systems are constrained by environmental (resource) factors. The type of management changes required will depend on the site specific constraints ie. the point on the 'response curve' at which the site falls. High potential systems occur at all points on the response curve. Sites at A, which are characterised by low external inputs tend to be responsive to 'green revolution' type packages, whereas at B, solutions will require knowledge intensive management to overcome resource constraints occurring despite a high level of supply.

Resource constraints, associated with soil fertility were generalised as:

1. Unbalanced and inefficient use of fertilisers (macro and micro nutrients)
2. Decline in soil fertility associated with the interaction between organic matter nutrient supply and soil physical problems
3. Acidity associated with fertilisation
4. Soil and water quality and the efficiency of its use
5. Pollution impacts on yield

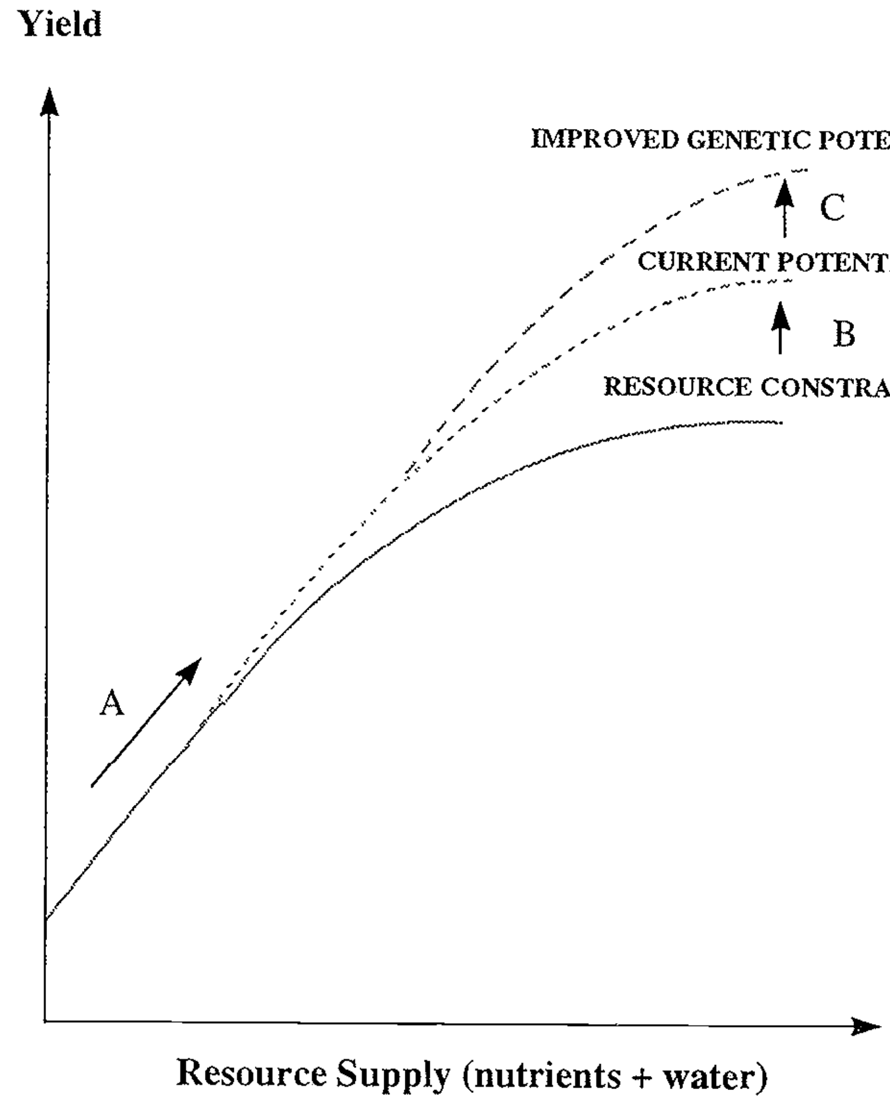


Figure 1. Constraints to high potential production systems

Of these constraints, unbalanced and inefficient use of fertilisers and decline in soil fertility associated with declining soil organic matter status emerged as generic issues, irrespective of the position on the 'response curve'.

The research required to increase productivity and improve soil fertility is summarised below. Although the research methodologies and tools are not fully developed. Their development will involve participatory approaches. This does not preclude basic research, such as that required to improve the simulation of soil processes, but defines the purpose for which the models produced must be suitable.

1. Site specific research
    - construction and use of nutrient balances
    - development of methods to better use inorganic fertilisers and manures & other organic inputs
2. Knowledge transfer
    - definition of resource management domains
    - role of participation in the transfer of knowledge
    - decision support tools, models (eg. process, static, rules based) and associated diagnostic tools
3. Better understanding and simulation of SOM dynamics, nutrient supply and interactions with soil physical properties.
    - process based research and modelling
    - relations between SOM and soil physical properties

Within this framework, specific constraints and research opportunities were identified for the following high potential systems:

Production system	Region
1. Continuous Rice	Asia
2. Rice - Upland	Asia
3. Irrigated upland crops	Asia
4. Rainfed upland	Asia / Africa

Research Opportunities

1. Continuous Rice cropping systems in Asia

Demand (Constraint)
Application of knowledge intensive management tools to reverse declining yield and improve nitrogen use efficiency

Priority Issues
- Testing, through model simulations and field trials, of management practices that reverse trends in declining productivity and soil fertility associated with near continuous flooding of rice soils.
- Development and testing of management practices that lead to increased nitrogen use efficiency.

Suggested Project
Participatory research to test appropriate methods to reverse declining productivity in continuous rice and improve efficiency of nitrogen use.

2. Rice / Upland system (Rice/Wheat system, Indo-Gangetic Plains)

Demand (Constraint)
To understand implications of changes in tillage and nutrient management in rice / wheat systems

Priority Issues
- Impact of new tillage systems on soil fertility in all phases of the rotation, including changes in crop establishment, management of water, crop residues etc.
- To develop a package of practices for new tillage options and accelerate adoption of these practices
- introduce management practices to improve the integrated management of nutrients

Suggested Project
To develop, introduce and accelerate adoption of new tillage and integrated nutrient management practices in the rice wheat systems of the Indo-Gangetic Plains.

Verification of the performance of proposed management practices and identification of resource management domains, suitable for technology transfer requires examination of the implications (in soil fertility, policy and socio-economic terms) of changed tillage and residue management (including crop, manure and legumes). Having identified extrapolation domains methods to enhance transfer of knowledge can be employed.

3. Rainfed Upland, Eastern India

Demand (Constraint)
Need to increase agricultural production in Eastern India

Priority Issues
- Improvement of fertiliser use efficiency and resource management
- Improved management of water resources, including drainage
- Introduction of improved plant genotypes suited to socio-economic and environmental constraints

Suggested Project
To identify and analyse improved management practices for Eastern India, that combine introduction of plant genotypes, soil and water conservation and integrated nutrient management. Quantify the performance of these systems, both in terms of productivity and sustainability and identify appropriate resource management domains for knowledge transfer.

4. Rainfed Upland, Africa

Demand (Constraint)
Transfer of knowledge related to management of soil fertility

Priority Issues
- Understanding of the impacts of residues on both short term nutrient supply and the contribution of residual organic matter to the build up of SOM.
- Improving nutrient use efficiency
- Development of techniques to facilitate adoption and knowledge transfer

Suggested Project

To develop options for the combined use of organic and inorganic nutrient sources, that take account of the circumstances of individual farmers. Providing as an output diagnostic tools that can be used by farmers, those involved in extension and researchers for assessing different ways of using resources to improve productivity and maintain soil fertility.

The third dimension: soil fertility and integrated nutrient management on hillsides

Dr Rita Gardner
Royal Geographical Society (with The Institute of British Geographers)

Introduction

Hillsides of 10 degree slopes and above account for only a small fraction of the world's total farmed and cultivable land, but nevertheless their importance far exceeds their physical extent. This is so for two main reasons. First, it has been estimated that over 50% of the world's population rely either directly or indirectly on water resources generated on sloping terrains, and none more so than in the Hindukush-Himalaya. Furthermore, the soil eroded from such susceptible terrains by the water can be both a beneficial source of nutrients downstream and a threat to engineering installations and livelihoods. Secondly, sloping agricultural lands are home to many of the world's poorest farmers.

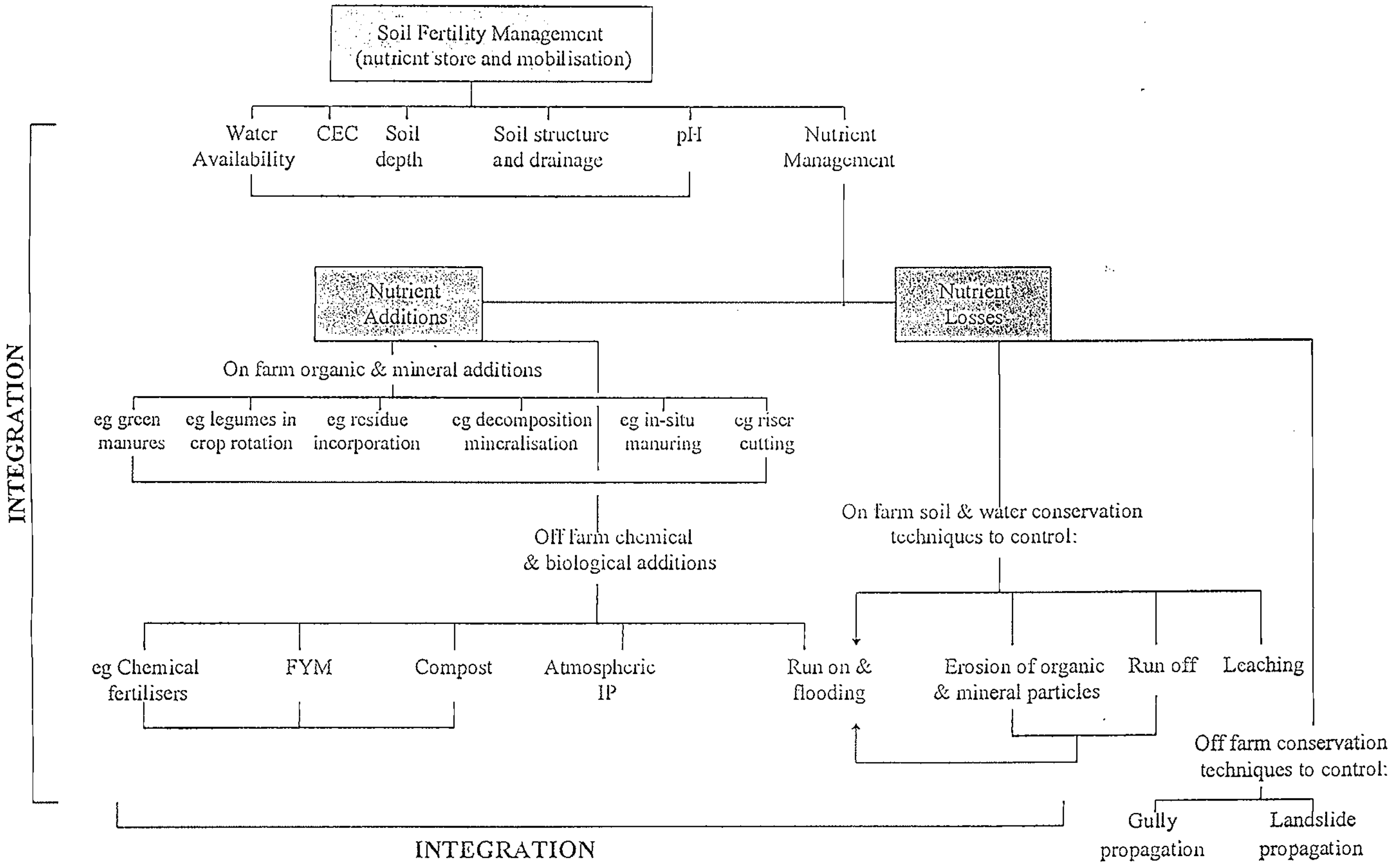
The hillslope adds a third dimension to the study of soil fertility and nutrient management. It does so through the force of gravity, through the sensitivity to change and a slopes' ability to transmit change readily to other areas, and through the complex patterns of spatial variability and interdependence within social, natural and agricultural systems This inherently spatial dimension tends to pose either additional or enhanced challenges to those arising simply out of the first two dimensions alone - namely the socio-economic / institutional environments and the natural environment within both of which all farming systems operate.

It is on the 'added factors' introduced by sloping lands that this paper will focus in its discussion of soil fertility and integrated nutrient management. It will draw heavily on examples from Nepal as this is where the authors expertise lies, but many of the generic points are also more widely applicable to hillsides from temperate to tropical terrains in less well developed countries.

The integrated nutrient management concept

A stylised diagram of the components in integrated nutrient management, based loosely upon that typical of the subsistence mid hill farms of Nepal, can be seen in Figure 1. There are three main elements. The first is the maintenance of soil properties that enhance, as far as possible given the inherent character of the soil and the parent material, the storage and mobilisation of nutrients. This is seen as an essential component to integrated nutrient management; these broader elements of soil fertility management cannot be divorced from nutrient management. The second major component deals with the management of avoidable nutrient losses through indigenous (and other if appropriate) soil and water conservation technologies. The third deals with nutrient additions: the nature, qualities and amounts of on and off farm sources of nutrients available to the farming system. As the initial character of the soil is modified by agricultural practices, the latter two components will increasingly describe the potential nutrient pool, only a proportion of which will be available at any one time; and the former will influence the extent to which the potential nutrients and water can be retained and made available.

Figure 1 The components in soil fertility and integrated nutrient management



Integrated nutrient management strikes at the heart of both soil and water conservation and soil fertility maintenance and development. There is inevitably integration and feedbacks between all three main components identified above; a change in any one of which will to some degree affect the others. The integration is especially important on warm humid hillslopes which are arguably the most susceptible especially when rainfall and cultivation patterns are highly seasonal. In such environments rates of decomposition are high, water is readily available to detach and transport particles and their adsorbed nutrients and to leach, and the forces of gravity carry the removed substances inexorably downwards often through a series of complex stores. In such environments both soil conservation and fertility management through high nutrient inputs are potentially required, and certainly so in the more intensive farming systems. All hillslopes, whether in dry or humid areas, power up the potential for nutrient loss, although the particular combination of moisture availability and nutrient status will influence the most appropriate types of soil and water conservation techniques, as illustrated superbly in the many examples in Reij *et al.* (1996).

While an understanding of nutrient cycling and other chemical and physical processes that underpin integrated nutrient management is clearly important, so too are the household characteristics, and the wider social, economic, political and environmental characteristics. These constrain the range of elements within an integrated regime that are available to the farmer, and affect his or her choices. It is generally believed that in resource poor farmers this choice will be made primarily so as to maximize short term returns. But there is also usually a well developed understanding, even if a constrained ability, among the farmers of the need to maintain soil fertility in the longer term.

Integrated nutrient management concepts are inherent in the traditional farming systems of the mid hills of Nepal, where there is a well documented reliance on the combination of livestock, forest products and crops (e.g. Carson, 1992; Vaidya *et al.* 1995). In this respect it serves as a useful example both of what can be achieved and, at the same time, of how far there still is to go. Nepal will be used below to consider more systematically the ways in which the characteristics of hilly areas can add to the not inconsiderable difficulties of effective integrated nutrient management in poor, largely subsistence economies.

The characteristics of hilly areas and the general implications for integrated nutrient management

a. Population change, poverty and subsistence agriculture

Nangju (1991) characterised steepland areas as having a set of diagnostic characteristics which can be classified broadly into those relating to the problems of inaccessibility and remoteness, and those stemming from a range of external economic, social and institutional pressures. Among the latter group, a high population density with high rates of population growth (2.5 to 5 % per annum), widespread poverty, and subsistence agriculture is a common set of circumstances in the hilly regions of Asia although clearly not unique to hilly areas, and less common in other mountain regions. Many observers have argued that this combination led to forest degradation, increasing use of marginal land with thin and degraded soils (Pandey *et al.* 1995), increasing intensity of land use with multiple cropping systems, and resulting declining soil fertility (Shah and Schreier, 1995; Pradhan *et al.* 1992). This was reflected in static or decreasing productivity and production in the staple crops (Figure 2). According to Pandey *et* *al.* (1995) management of soil fertility and plant nutrition is the key to improving and sustaining agricultural productivity. Less recorded but equally as important in a Nepalese setting is the decline in soil quality in the degraded forest areas.

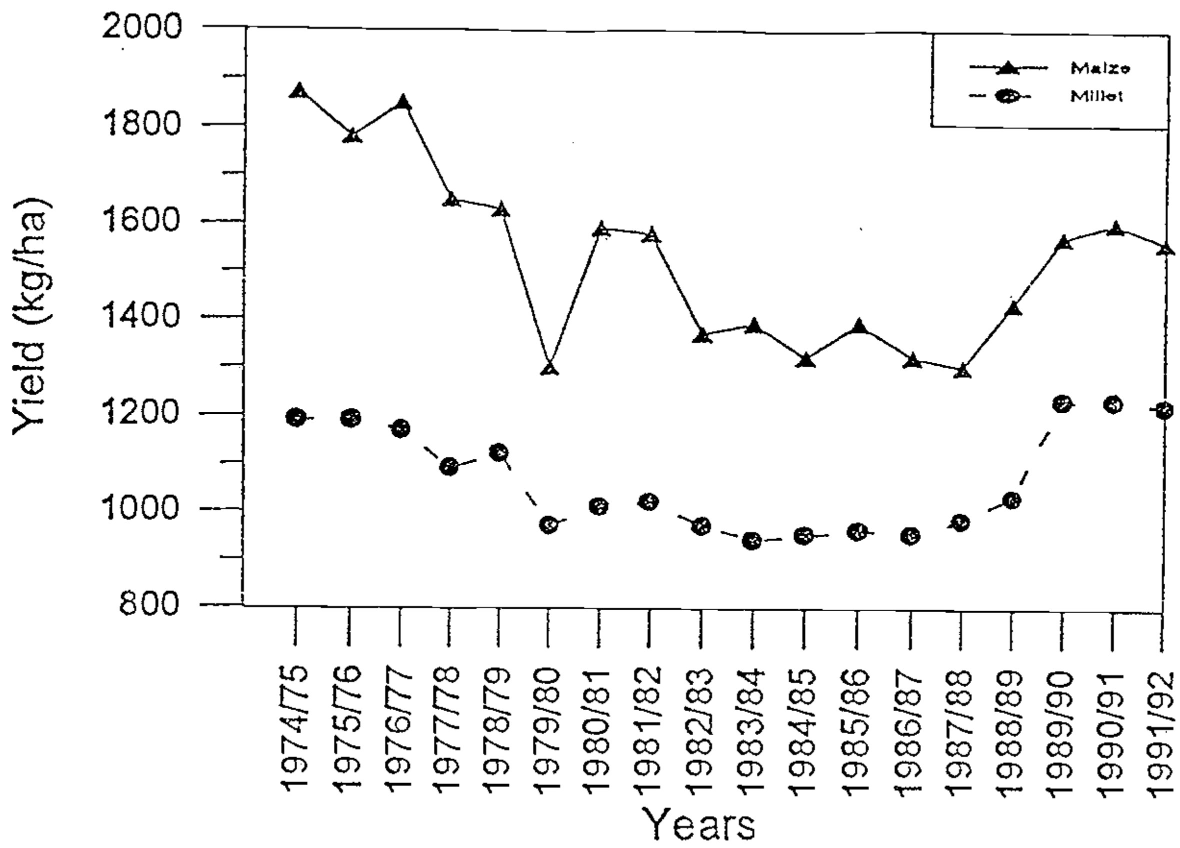


Figure 2 Maize and millet production trends in Nepal Mid Hills (from Pandey *et al.* 1995)

Farmers in a recent detailed survey in western Nepal also agree that declining soil fertility (65% of those interviewed) is a major problem (Vaidya *et al.* 1995). Combined with a relatively poor nutrient status and thin depth of the acidic soils developed on gneisses, schists and phyllites, it implies that some farmers are facing the need to cope with declining fertility at times of increasing need to improve outputs. However, the major reasons cited by farmers for the decline in soil fertility in western Nepal were decreasing FYM supplies, soil erosion, reduction in forest resources, and changes in soil characteristics following use of chemical fertilisers (Table 1). Declining FYM related partly to reductions in livestock numbers owing to lower labour availability as a result of off-farm employment and higher levels of school attendance. This illustrates the negative effects on nutrient management that declining size of farming household may impart in intensively managed systems. In some cases less FYM was also attributed to reduced fodder resources following forest degradation. However, the effects of very recent trends in increased community forest management and tree planting on private land (Gilmour, 1991; Gardner and Jenkins, 1995) await to be seen.

Table 1 Reasons given by farmers for changing soil fertility in western Nepal (from Vaidya *et al.* 1995)

Reasons for changes in soil fertility	Soil fertility trend on bari		Soil fertility trend on khet	
	increase	decrease	increase	decrease
Use of chemical fertilizer	26	71	33	77
Change in crop intensity	19	31	28	53
Change in FYM application	63	165	50	114
Labour availability	32	59	17	46
Change in livestock mgmt practices	10	85	2	46
Soil erosion	1	229	0	103
Moisture/climate	17	16	22	19
Change in forest resources	1	102	0	60
Change in livestock population	0	25	0	17
Land improvement practices	2	1	1	0
Other soil fertility mgmt practices	5	0	6	1
Miscellaneous	0	4	0	0

There is a further interpretation for declining production; one that is argued as being the farmer's perspective rather than that of the scientists and aid workers (Tamang, 1993). It is suggested that production has declined simply owing to land being taken out of production by the farmers as a result of labour shortages, and that generally increasing productivity on land under cultivation has been insufficient to offset the decline in cultivated area. In a setting where detailed information of this type is in short supply, and where the variability in socio-economic and farming systems is enormous owing to the very nature of the hilly terrain, such seriously different interpretations of the causes of declining fertility and production leads to considerable uncertainty. There is urgent need for diagnosis and clarification as to whether all interpretations are correct within highly site specific circumstances or whether one, and if so which, has a much wider applicability.

Unfortunately, the historical change and current rates of change of soil fertility and nutrient status are largely unrecorded in the predominantly acidic soils, other than by proxy productivity data. This is at best a poor indicator as productivity is not solely a function of soil fertility. Reliable baseline soil analytical data are remarkably few, and analyses of current nutrient status are restricted. In the recent detailed study of 340 samples from rainfed sloping lands in the western area, organic carbon averaged 3.2+-% 0.06; total N 0.27+-% 0.1; available P 174+- ppm 13.4; and exchangeable K 0.44+- meq/100g 0.02 (Vaidya *et al.* 1995). Goldsmith (1981) also reported low total nitrogen and CEC in the eastern region. Only exhcangeable K was in adequate supply in the Dhulikhel area (Shah and Schreier, 1995). Little is known of micronutrients. While it is perhaps less important to know the starting point, the current rates of change under different farming systems would be most helpful in assessing the overall sustainability of current practices. This would require a longitudinal study of some years duration.

b. Political isolation and political priorities in hilly areas
Political isolation is also seen as a diagnostic characteristic (Nangju, 1991), and together with the poor extension services that often exist in remote areas, it can affect the priority given to scientific research as a whole, the perceived research priorities, and the dissemination of information to farmers. Within Nepal the importance of soil fertility maintenance has at last been recognised. In the eighth fifth year plan policy is "to increase integrated agricultural production which is in harmony with ecological and environmental conditions". Until recently soil fertility research was focused in only three centres, two of which put great emphasis on farmer participation and knowledge. With increasing interest in this topic, the relevant research programmes in different ministries and across different donors and research centres could benefit greatly from information exchange and integration so as to maximise benefits to the hill farmers. The reality is that they are unlikely to be so. Meanwhile the extension system remains weak at best.

An example of enhancing the limited scientific knowledge base is found in the current project co-ordinated by Reading University in which long term experiments will be established to examine nutrient cycles within treatments involving combinations of organic and inorganic sources of fertiliser. While the conceptual basis of the system has been reported (Tamang, 1993), there is little quantified information, and current recommendations of fertiliser usages are generalised and largely derived from studies in the terai. Together with the quantified information on nutrient losses from erosion, runoff and leaching gained in the ongoing bilaterally funded project between Lumle Agricultural Research Centre (LARC) and Queen Mary and Westfield College London, this will provide the first detailed study of nutrient budgets, specifically nitrogen, in a farming system in Nepal. It will also help to assess if the present system of integrated nutrient management is sustainable. While much development activity is soundly based around farmer first and farmer participation strategies, there is still a need for underlying quantified data on key topics, so as to establish the nature of a potential problem in absolute rather than relative terms.

Political priorities also at times impact directly on the nutrient management system. Chemical fertiliser use in the mid hills is still low at well under 10,000 tons NPK in 1991, although it has been rising steadily since the 1960s. However a substantial reduction in government subsidy on fertiliser in 1993 has caused a reduction in use. The analysis by the Soil Survey Division in the 1980s has indicated yields could be increased by 55-60% if correct amounts of fertilisers were used, but in view of the long term potential problems, more assessments are needed (Pandey *et al.* 1995). There are reports from farmers that chemical fertiliser use alone has negative effects on soil structure, acidity, and productivity after some years (Sherchan and Gurung, 1995), and chemical fertilisers are usually used in combination with organic manures and indigenous techniques. Used alone the residual effects of chemical fertilisers are also low (Sherchan and Gurung, 1995). The combined approach is supported by the Nepal Agriculture Perspectives Plan (1995) and has been shown to be effective in increasing yields over short term studies (e.g. Gurung and Neupane, 1991, Sherchan and Gurung, 1995). The study by Vaidya *et al.* (1995) showed that the dominance of FYM as a nutrient source varies across different agro-ecological zones, being the highest in the less accessible and high hill areas. The introduction of chemical fertilisers has also been shown to change the management towards less integrated styles, for example in Chambas it has led to the cessation of in-situ manuring (Vaidya *et al.* 1995). Further studies to elucidate and evaluate the sustainability of other management responses are required in this dynamic environment. Improved fertiliser supplies is one of the unique challenges in the hills identified in the Agriculture Perspectives Plan (1995).

c. History of settlement and indigenous knowledge
The long history of settlement in many mountain regions, has often enabled a well developed indigenous knowledge of soil fertility maintenance and of soil and water conservation (swc) techniques to have been developed (Moldenhauer *et al.* 1991; Reij *et al.* 1996). There is considerable evidence in Nepal that this is the case and much effort at LARC over the past 10 years has been devoted to understanding indigenous soil fertility systems and practices. The continuing importance and recognition given by the farmer to the use of farm yard manure and composts to maintain fertility is well documented, and improvements in the efficiency of manure production and use are a high priority as are sustaining the sources of materials for FYM and composts in the face of rising demand. A range of other techniques for organic nutrient inputs is also included in farming systems, but the effects of individual techniques on the balance of fertility maintenance is unknown.

The studies to date on indigenous knowledge and methods are very encouraging and reinforce the now widely held view that the development of indigenous techniques have much to offer future strategies for sustainable agriculture. For example the incorporation of only partially decomposed compost seems to maximise nutrient release at the time when they are most required by crops and less likely to be removed in leaching and runoff (Tripathi, pers. comm. 1997).

Erosion and decline in soil fertility are the main reasons cited by farmers in the western Nepal study for the increasing demand for FYM. In terms of current soil conservation strategies in Nepal (Table 2) the widespread use of terraces substantially reduces runoff and soil loss, and there is a clear understanding among farmers in the Likhu catchment of the need to control water runoff so as to prevent build up on the agricultural land but at the same time not to increase infiltration so as to lead to terrace failure (Gardner and Jenkins, 1995; also reported from elsewhere by Tamang, 1993). Knowledge of the complexities of hillslope hydrology - although not expressed in such a way - is not ubiquitous across all farmers but certainly present in those farming khet and lowland bari. Any future development of enhanced conservation strategies, which are certainly needed in some areas of Nepal, will not simply be able to adopt technologies in use elsewhere but will need to pay careful attention to the possible negative effects of increasing infiltration on terrace failure.

Table 2. Current main strategies that directly and indirectly affect surface soil conservation on rainfed agricultural land in the mid hills of Nepal

Conservation techniques (indigenous)	*Conservation as by-product of fertility enhancement*	*Conservation as by-product of other functions*
Level terraces	FYM/compost application	Weed growth under crops
Sloping terraces	Mulching	Intercropping
Run-off ditches	Cutting terrace risers	Algal growth under crops
Earth bunds	*In situ* manuring	Riser ditches
Stones bunds	Leguminous crop cover	
Gully check dams	Ploughing in residues	
Tree planting on unstable slopes		
Water control through khet		
Run-on barriers		
Stone risers		

A wide range of supplementary soil and water conservation measures are also used in indigenous systems (Gill, 1991), but less commonly so and knowledge of the reasons for their adoption and their effectiveness are generally lacking. Improved understanding of indigenous techniques and the circumstances in which they are applied will be most valuable alongside the development with farmers of appropriate additional conservation measures. Furthermore, measures to increase soil fertility through vegetative inputs are recognised by farmers as having conservation value through improving the soil structure (Vaidya *et al.* 1995). Lastly, there exists those farming practices that are undertaken for purposes other than SWC or nutrient inputs, but which nevertheless have a significant effect in reducing soil and water losses. The growth of weeds during the monsoon and pre-monsoon is one such practice (Figure 3) whereby soil losses are reduced to less than 10% of the weed-free values at times of low weed cover. It is unknown whether the farmers value the weed cover for this purpose, for if not, changes to the farming systems for other reasons may negatively impact on SWC.

d. Land tenure, land holding size and incentive

It is well argued on a theoretical basis that tenure arrangements may affect the willingness of farmers to invest in long term fertility improvement (Tamang 1993) and there is some evidence of relaxation towards the end of the tenancy (Joshi, 1994). However, this is a complex area and tenure arrangements are highly variable both in terms of length, payback and conditions. Specific studies relating tenure and land holding size to fertility maintenance and use of soil and water conservation methods are very rare. Vaidya *et al.* (1995) did not find a relationship between tenancy and trends in soil fertility in western Nepal, where 26% of farmers were involved in some form of tenancy arrangements. This is an area in need of further clarification given the large scale of tenanting.

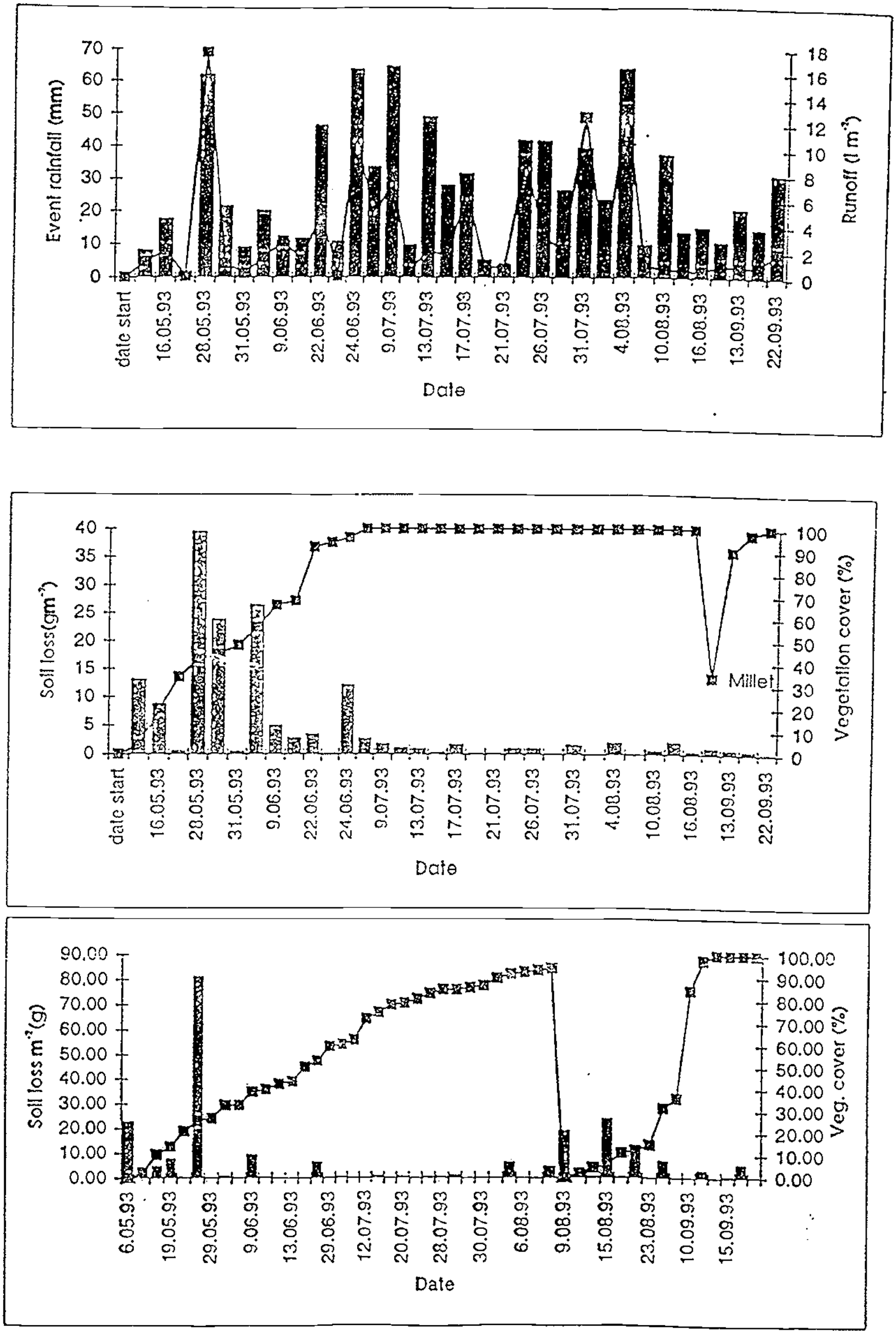


Figure 3 Soil losses in relation to ground cover on bari land in the Likhu catchment (from Gardner and Jenkins, 1995); (a) event rainfall and runoff for selected events; (b) soil loss in relation to ground cover across the same events.

e. Remoteness and poor accessibility

Remoteness and poor accessibility is strongly associated with inadequate communications, poor distribution of chemical inputs, poor potential for marketing of goods and typically, limited potential for local off farm employment. In terms of the nutrient management system, limited availability and poor timing of availability of fertiliser is a common problem in the hill areas of Nepal, as are problems of fertiliser transport. In the western hills study 85% of fertiliser users lived within two hours walk of the road (Vaidya *et al.* 1995). The road building programme has given rise to corridors of accessibility that are increasingly linked to a market economy and in which chemical inputs are much more widely used. Elsewhere, the low income generation in the agricultural sector also reduces the capacity to purchase inputs. This may be offset by out migration of the younger male population, but this itself can create further stresses by changing the gender distribution of the workforce. Combined with the increasing uptake of education among children, the balance of labour available for nutrient management and soil conservation management is inevitably shifting.

The implications are seen in terms of livestock numbers that can be managed by the household and hence perceived declining FYM additions in some areas, and in reductions in cultivated land. Impacts, if any, on the conservation and fertility management methods are unknown. Traditionally the male members of the household manage water control techniques, in situ manuring, and purchase and apply chemical fertiliser, while the women are responsible more for the organic parts of the system, including composting, collecting and carrying organic matter for composting and bedding, and collecting, carrying and spreading FYM. Lack of labour may also affect the trend towards increasing FYM and compost application on fields nearer the house at the expense of those further away, enhancing the variability in soil nutrient status of different parts of the land holding and ultimately depleting the long term nutrient status of some areas. While these instances are reported from discussions with farmers, little scientifically documented data is available.

f. Sensitive physical environments with strong spatial linkages

This characteristic is one of the most distinctive in mountain areas worldwide. There is no doubt that hilly environments are highly sensitive and, some would argue, fragile owing to the combination of steep slopes and high kinetic energies. Mountains and hills are, by their very nature, designed to be eroded, and their relief and complex drainage pathways ensure that the patterns of interconnectedness down hillslopes are highly variable. There is a tendency to ignore the hillside scale, as falling between that of the farmers' fields and the whole catchment, and yet it is at this scale that sediment, soil and nutrient pathways are capable of affecting farmers differentially. For example, hillslopes have often had complex geomorphological histories of denudation, which leave remnants of flatter terraces on which soils preferentially accumulate to greater depths, with steeply sloping hillsides as sites of preferential erosion in between.

In humid hilly areas landslides are common, but they will vary in their distribution according in part to the subsurface drainage pathways and position on the hillside (Gardner and Jenkins, 1995). They also vary in the extent to which they are connected into the hillslope drainage patterns (Gardner and Jenkins, 1995) and hence in the extent to which the eroded soils and sediments are removed from the hillslope. It is normal for landslides in agricultural areas in the middle hills of Nepal to be reterraced and brought back into cultivation within 5 to 6 years (Gardner and Jenkins, 1995), thus limiting long term soil losses. Although large scale land loss by landsliding is more obvious and devastating for those affected, rainsplash detachment together with overland flow and rill erosion are the processes by which the majority of the fertile topsoils are eroded .

Farmers in the Lumle research command area showed an awareness of the importance of erosion losses (Vaidya, 1995) as the major cause of declining soil fertility but the majority when further questioned in groups felt there was little that could be done to prevent overland flow - it was accepted as an insidious fact of life. Clearly this is not the case and indeed some preliminary studies are being undertaken by ICIMOD, NARC and in the Likhu catchment on agro-forestry and other intervention measures. Methods of diverting water flows and conserving soil through live barriers, mulching, or simple ditching in the few high intensity storms in April and May in Nepal, before ground cover has developed, or if possible developing early cover crops, are a priority.

A combination of steep slopes with high and intense rainfall inevitably leads to high runoff, high erosion potential, seasonal variability in such erosion and a high landslide hazard. For example extremes of soil losses in excess of 300 t/ha have been recorded in hills in Guatemala, Trinidad, Bangladesh and Malaysia (Craswell, 1993). The relative relief of the hillslopes, the erodibility of the soil, the amount of disturbance, and the timing and intensity of rain in relation to the cropping patterns and soil cover will determine to a large extent how the system responds.

Reliable erosion and associated nutrient loss data in Nepal are few (Table 3) and they are highly variable depending in part on real spatial differences in the above characteristics, but also on widely differing methodologies and periods of measurement. Of particular importance is the fact that few studies on outward sloping rainfed terraces (bari land) have used natural areas or have included into their calculations annual inputs of soil from, for example, riser cutting and ditch clearing. Storage in riser base ditches in the Likhu catchment accounted for an equivalent soil loss of over 20 t/ha from the terrace above. Thus, direct comparisons are not to be recommended, but overall the impression is of high variability on cultivated land between levels of loss that are acceptable to those that are clearly not, no matter which of the many general definitions of tolerable levels of soil losses are used (Morgan, 1986). Erosion affects not only nutrient levels, but also has negative effects on general soil fertility parameters such as bulk density, rooting capacity, and water retention (Craswell, 1993).

Table 3a Runoff and soil erosion estimates from erosion plots and small catchment studies on cultivated land in the Middle Hills

Location	Management	RO %	Soil loss t/ha/yr	Details
Fakot				
	Terracing - improved	7-12	1.3-4.4	One 240m² plot; inward & lateral slope (1979-80)
	+ mulch	4	0.2	Same plot (1981)
	Terracing - poor	23-34	2.8-4.9	One 310m² plot; outward & lateral slope
	Natural grass	3	2.1	Same plot
Nagarkot:				
Chisipani				
maize-soyabean	Conventional tillage	4	0.6	10x5m plot; 12 collections in 1990; level terrace
1940m asl	+ fertilisers	5	1.2	same
SL-LS	Minimum tillage	5	0.2	same
2154mm ppt	+ cover crop	10	0.3	same
Chyandanda				
maize/millet or soyabean	Conventional tillage	19	14	10x5m plot: 18 collections in 1990: level terrace
1385m asl	Alley crop			
SL-LS	(grass hedge)	24	105	same
2154mm ppt	Alley crop			
	(banana trees)	21	54	same
	Hillside ditch	15	94	same
	Strip cropping	24	2.1	same
Kulekhani				
maize/wheat	Tradn cultivation	19	1.5	Outward slope; 16x5m plot
1800m asl	+ contour ridging	20	2.2	1985-1990
SL-CL	Tradn cultivation	19	1.4	Inward slope; 16x5m plot
	Hillside ditching	24	2.1	
Bhandar				
maize	Tradn cultivation	11	9	7x2m plot; 1758mm ppt
2180m asl	Tradn cultivation	<3	1	7x2m plot: 1836mm ppt
Bamti				
maize/millet	Tradn cultivation	11	3	7x2m plot; 1551mm ppt
1995m asl				
Pakhribas				
1200m asl	Cultivated fallow	32	25	Inward slope; 18m² plot
red soil	Maize/millet tradn	32	35	same
	Maize/millet improved	27	24	same
	One crop maize	30	30	same
	+ min tillage & mulch	23	18	same; Banmara mulch

Table 3b Nutrient loss through rainwater erosion

Land type/Land use	Nitrogen kg/ha/yr	Phosphorus kg/ha/yr	Potassium kg/ha/yr	Sources
Maize/millet, bari	55.0	2.53	7.88	Gurung, 1993
Maize + soyabean khet	0.43 - 0.83	.002 - .003	0.07 - .17	Maskey, 1991
Rainfed bench terrace	3.8	5.0	10	Carson, 1992
Rainfed marginal land	15	20.0	40.0	Carson, 1992
Grazing land degraded	75	100	200	Carson, 1992

Soil losses from heavily degraded forest were found in the Likhu area to far exceed those from traditionally-managed agricultural rainfed terraces. This is a matter of considerable concern given the already poor fertility status of forest soils, the degradation of forest ground cover, and the harvesting of litter for composting, mulching and bedding. Estimates vary as to the extent of the nutrient transfers. Kiff *et al.* (in press) for example report amounts of litter removed for composting varying from 7% to 50% of annual production. However, conservation of forest productivity receives less attention than that of cultivated land, but it is arguably no less important given the need for increased FYM and compost within the traditional integrated farming systems.

In general, applied erosion and associated nutrient loss studies are at a very early stage. The current programme of research jointly between Lumle, NARC and QMW/RGS-IBG is partly aimed at predicting areas and terraces of high risk for which enhanced soil conservation measures would be a benefit, as well as informing these relative assessments with quantitative measurements of nutrient losses by erosion, runoff and leaching in the identified high susceptibility areas. It is also considering for the first time in Nepal the evidence for differential erosion and deposition over a medium time scale on whole hillsides, using ^{137}Cs technology. Taken together, the understanding of process and cause engendered by these analyses, are a precursor to working with farmers to develop improved conservation technologies. Unfortunately, much soil erosion research in Nepal, as elsewhere, is hampered by the absence of records of rainfall intensity - a critical variable in assessing annual and seasonal patterns of erosivity. Furthermore, no previous studies in Nepal have calculated the nutrient losses from erosion taking note of the differential effects of erosion in moving the nutrient retentive finer particles and organic matter. In addition, leaching losses at the field scale are being examined for the first time in this project. These comments illustrate the need for further research and on farm conservation measures to "mitigate surface erosion as well as to minimise nutrient losses" (Sherchan and Gurung, 1995), including the effects of current changes to farming regimes in the light of the pressures previously discussed.

Hillsides, more than any other landscape units have strong spatial links - the hillslope is merely a form for transfer of material and energy. Basal processes such as river erosion and landsliding can propagate upslope, and upslope processes can extend downslope. There is through this a huge potential for nutrient redistribution - either to khet land in drainage waters

(Shah and Schreier, 1995); to the river and subsequent capture in overbank deposits or floodwater retention schemes, or to the next fields down in the terrace cascade. The accretion of soil and nutrients in the first khet terrace in the irrigation system is very well known, but redistributions within the terrace sequences over medium term periods are only just being studied for the first time using ^{137}Cs technology. Applications of this technology to the hilly areas of China have been successful in recommending soil conservation development (Zhang *et al.* 1994).

g. High spatial variability in physical, farming and socio-economic systems
The last major generic characteristic of hillsides is spatial variability in the natural and in the human systems. For example in one hillslope in the Likhu catchment there may be largely Chettri and Brahmin farmers in the basal areas cultivating irrigated paddy/winter wheat on relatively large land holdings with a self sufficiency in forest products and an ability to pay for hired labour. At the other extreme towards the top of the hillslope may be a recent Tamang immigrant, far less knowledgeable about the farming system, occupying a small area of already substantially degraded marginal land with low inherent soil fertility, and reliant on communal forest resources. He may need to hire his own labour out in order to help to bridge the hungry season and he will therefore have less time to devote to fertility maintenance and soil conservation matters (Blaikie, in Gardner and Jenkins, 1995). His crops will be poorer and the ground cover therefore less; he will suffer accelerated erosion and high levels of runoff from his land. Moreover, in the interconnected hillslopes, there is the potential for not easily reversible environmental damage to be started by poor management in one area and to propagate to others nearby. Some of the most sensitive positions are near the top of the system, close to the drainage divides, where gullying once set in can be difficult to control. It is in precisely these locations in Nepal that the resource poor farmers with reduced capacity to adopt conservation measures tend to live, and on already highly degraded land, as described above. This is but one illustration of the many interactions between class, land use and soil erosion that are widely explored in Blaikie (1986).

The spatial diversity may be accompanied by close interdependence such as with *in situ* manuring by large herds, or in irrigation system management, or in terms of use of commonly managed land as in the forests, and in sharing labour to repair landslide failures, all of which exist in Nepal. It is interesting to note that while farmer to farmer relations are well developed in some such areas of agricultural enterprise, they are far less so in terms of soil conservation. The most effective conservation measures will take account of the hillslide as a whole rather than as a set of unlinked individual fields. A concern at the hillslope scale which encompasses areas of privately and publicly managed land, lies at the heart of catchment planning which is the ultimate way of enhancing the soil and water resources, and the environment, for everyone (Carson, 1992).

Tackling gaps and issues

As most development is an evolutionary process rather than a revolutionary one, we should seek ways of enhancing and developing through participatory methods the current farming systems and approaches to integrated nutrient management. It is both practically and ethically difficult to target just the poorest of the poor farmers, and thus developments in integrated nutrient management should be capable of offering something to everyone. Rather than focus explicitly on the poorest of farmers we should perhaps ensure that he/she is fully included and that some if not all the improved practices and technologies are appropriate to him/her and have been developed through him/her.

Viewed in such a broad way, the gaps, developments and improvements in integrated nutrient management on farmer's fields fall into six groups.

1. Those diagnosing an issue or clarifying a key problem. The analysis above has highlighted uncertainty over some key issues, including that of the causes of declining production. Such uncertainty is exacerbated in hill environments owing to the inevitable spatial variability and complexity of systems in such areas.

2. Those understanding the constraints and opportunities faced by farmers in nutrient management, and in particular the socio-economic constraints at the household level. Integrated nutrient management and soil fertility management cannot be considered purely as a scientific set of issues.

3. Those understanding an essential scientific process and its timing and magnitude within the farming system, and indigenous knowledge of it and responses to it. The understanding of the nitrogen cycle within bari lands is a classic example.

4. Those seeking to replace or enhance a source of nutrients at a field scale so as to improve availability, amounts, quality, timing etc; those seeking to develop or enhance methodologies for reducing soil and associated nutrient losses at the field scale; those seeking to improve the general soil environment for nutrient retention at the field scale.

5. Those that operate on a hillslope or catchment scale to maximise benefits to all farmers therein by co-operating in the management of nutrient losses and the supply of nutrient inputs at this scale.

6. Those that work at higher levels to relieve the political, social, economic and infrastructure constraints characteristic of hill regions and to improve the institutional systems supporting agriculture; and through this liberate capital, labour, know-how and incentive.

Given the diversity of hill regions, in most instances the gaps and the issues within those gaps will be area specific. Arguably developments in one category alone may not be sufficient to bring about major improvements, and the project focus will often be multi-disciplinary. For example, the remarkable changes documented from the Machakos District, Kenya (Tiffen & Mortimore, 1996) are testimony to the driving force of an ability to generate income through off farm employment and through improved accessibility. Other improvements, such as in soil and water conservation, facilitated, strengthened and possibly speeded up the processes but they were not in themselves driving forces for major change.

Future strategies for integrated nutrient management and research have been identified as part of wider strategies for soil fertility research and development in the mid hills of Nepal by several authors including Pandey *et al.* (1995); Sherchan and Gurung (1995); Silsoe Research Institute (1997); Kiff *et al.* (in press); and Gregory (1996) and Nepal Agriculture Perspectives Plan (1995).

These authors and the author of this paper highlight the following research needs to support integrated nutrient management in the Middle Hills of Nepal. Those in bold are perceived to be the most urgently in need of attention.

These authors highlight:

Group 1

1. **The causes of declining productivity and production across agro-ecological zones and farming systems.**

Group 2

1. The need to identify potential areas that could benefit substantially from the use of chemical fertilisers.
2. Understanding farmers choice of strategy to maintain soil fertility from among the many available, and the reasons for such a choice.
3. **Understanding local knowledge and its spatial and cultural variation in relation to soil and water conservation methods and nutrient sources.**

Group 3

1. Rhizobium innoculation of legumes to improve their nitrogen-fixing capability.
2. **Understand and quantify the integrated nutrient flows, including erosion, leaching, nutrient additions, and recycling, and their sustainability in typical farming systems or recommendation domains.**
3. A long term fertility experiment to determine the rate of mineralisation of incorporated organic matter.
4. **Establishing the relative rates of change in soil fertility, especially on rainfed land.**
5. **Improving knowledge of organic matter nutrient dynamics, including the reasons for indigenous methods of FYM management.**

Group 4

1. The importance of improvements to organic sources of plant nutrients, particularly in the supply of fodder and forest materials, and second in good production and application techniques for compost/FYM.
2. The application of biofertilisers to bari land systems.
3. Legumes for the provision of additional nitrogen and as cover crops
4. **Development of appropriate additional soil conservation methods, taking note of localised redistribution of soil across hillslopes, on both field and hilllslope scales using indigenous knowledge and scientific understanding.**
5. Trials with inorganic fertilisers

Group 5

1. Adopting a watershed management approach.
2. **Forest productivity; the assessment of the implications of the new community forest management programmes for fertility maintenance on agricultural land.**

Group 6

1. Strengthening of the technology transfer system so as to improve the level and speed of adoption rates.
2. Rural road building programme to improve accessibility for inputs and to markets.

3. Co-ordination across donors, governments and ngos of the research priorities and their fulfilment so as to maximise the returns on the investments.

Conclusion

This brief review has focused on the particular problems of soil fertility maintenance and integrated nutrient management faced by one of the classic areas of hillslope farming systems in the world - Nepal. The discussion is set within the wider context of the generic characteristics of hilly areas; and it suggests the characteristics that differentiate hilly areas consistently from many others are, first, the spatial interdependence and interconnectedness of the physical processes that lead to nutrient losses and redistributions. This suggests that we ignore at our peril the hillslope scale of research and development endeavour; a concentration on individual farmers fields alone is too narrow, and on whole catchments is arguably too broad to manage effectively. Secondly, there is the interdependence, complexity and diversity of biophysical and socio-economic conditions, and of fertility and nutrient maintenance issues and regimes. Such complexity inevitably means that much research is locally focused. Such diversity requires clear prioritisation of research and development needs, and co-operation between different groups and projects so as to maximise synergies and returns. This is particularly important across the two key research areas of nutrient cycling and soil and water conservation. Finally it is worth remembering that applied research invariably benefits from focusing on the product rather than on the processes alone (Stocking, 1993).

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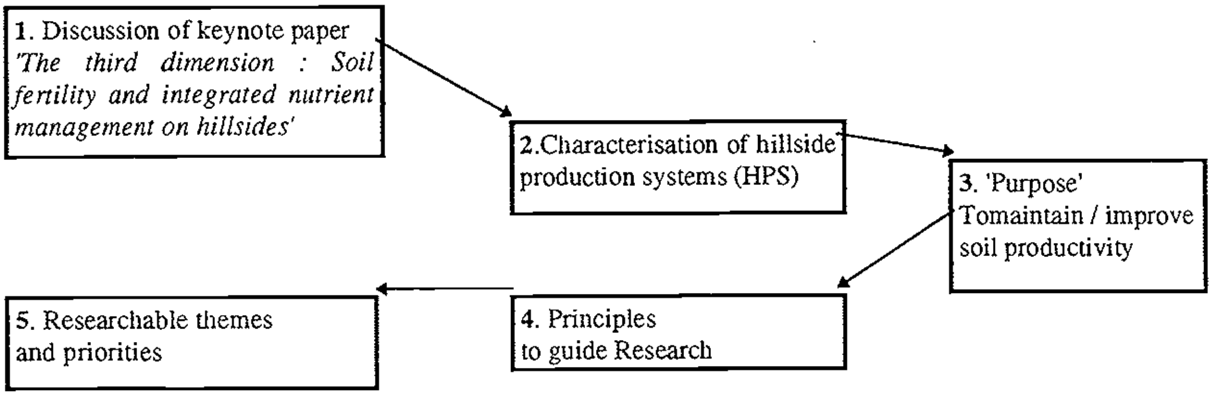
Working Group on Hillsides Production System (HPS)

Chairman: Prof Mike Stocking
Rapporteur: Dr Stephen Briggs
Keynote Paper: Dr Rita Gardner

An excellent and comprehensive keynote paper titled *'The third dimension : Soil fertility and integrated nutrient management on hillsides'* was presented to the working group for discussion by Dr. Rita Gardner.

This provoked discussion and the process shown below which worked through a process of; characterisation of aspects which are special to hillside environments; definition of an overall research purpose; definition of a set of principles which should be used to guide research into hillside research (these are also cross cutting themes), and finally arriving at four main researchable constraints / priorities for research.



HPS working group process to obtain researchable constraints / priorities

Discussion of keynote paper

The working group examined the following important differences of hillside production systems which differ from other systems and which may help in directing appropriate future research activities. The basis of the framework is drawn from the keynote discussion paper using a series of headings based on experience from Nepal.

i) Population, poverty and subsistence agriculture.
Population growth and decline variation from high > low densities in HPS
Farming operations vary from Plantation/cash crop/market driven scale > subsistence agriculture in HPS
Wealth resources vary from high > low in HPS

ii) Political isolation & priorities
Variation from political integration > isolation within HPS
Political priorities are often linked to economic importance of HPS locations

iii)History of settlement & indigenous knowledge (ik)
Variations in HPS from low levels of ik in newly settled areas > high levels of ik in long settled areas, linked with out-migration from HPS and the loss of ik.

Recognition that outside knowledge can have an effect on ik from low effect > high effect in HPS

iv) Land tenure, holding size and incentive
Complex tenancy arrangements operate in some HPS
Greater level of fragmentation of land ownership / usage in HPS
Land tenure affects nutrient management strategies in HPS

v) Remoteness & poor accessibility in HPS
The presence of road access corridors varies considerably from poor > high
Poor access limits access to inputs, products and to market driven farming operations

vi) Sensitive physical environments and spatial linkages.
Variation from catchment approach > collective approach in HPS
High levels of spatial variability in physical and climatic environments, farming systems, and socio economic status in all HPS. HPS include high potential, semi-arid, forest agriculture and peri-urban production systems.

Characterisation of aspects which are special to hillside production systems

The working group discussions can be summarised as:

- Hillsides are areas with a high level of poverty which are often inaccessible and remote in location and suffer from political isolation.

- There is a huge variation in hillside environments (climatic/physical/socioeconomic), both spatially and in connectivity, making it difficult to achieve generic research approaches. More appropriate may be to utilise generic research approaches combined with site specific approaches which integrate social and biophysical science. A recognition that understanding these systems is a long term process.

- In recognising the spatial links of HPS, there is a need to move the focus of hillside research from plot or farm scale towards a hillside or small catchment scale.

- Hillside slopes add a 'third dimension' which are highly sensitive to change, effects of gravity and transmission of problems down slope or down catchment. These susceptible environments have the potential to 'power up' or excelerate the potential for soil nutrient losses.

- Land tenure, incentives and tenancy arrangements are highly variable in hillside environments making it difficult to generalise

- A long history of settlement in some hillside areas has built up a wealth of indigenous knowledge of environmental and socio-economic conditions. Local knowledge of hillside soil hydrology is of particular importance.

- There is conflicting evidence as to the status of productivity within hillside environments, which is not helped by the lack of baseline information.

- In hillside environments moisture is often limiting during critical periods of the growing season, and excessive during other periods of the year, needing careful and dynamic management.

Purpose

The working group agreed that the main purpose of HPS research should be:

"To maintain, or where possible, improve soil productivity"

Recognising that:

- To improve soil productivity, external inputs into a farming system may be required.

- A synergy between soil fertility / soil erosion research as one discipline, with closer integration of crop and livestock interactions, is needed.

Principles to guide research

The working group defined a set of principles which should be used to guide further hillside research. These principles may also be cross cutting themes within other production systems. The Principles are:

- Explore / build on local knowledge wherever possible (with particular attention to hydrology in HPS)
- Embrace participatory approaches
- Base research on hillside / catchment scale processes
- Ensure flexibility in project design for course adjustment
- Increase the observability and economic importance of problems at farm level for producers
- Validate the social and economic viability of outputs / interventions
- Closer integration of socioeconomic and biophysical research with a development of a common language is needed. This has implications for scaling up of projects, with better identification and an increased use of farmer recommendation domains.
- Commitment from donors to longer term studies to understand the processes involved in hillside environments is required.

Researchable themes and priorities

Three main research themes together with the recognition of their interactions were identified by the working group and are as follows:

- A) Combat soil nutrient loss (leaching and erosion)

- B) Reverse the decline in organic matter content of soils

- C) Improve water management (for both surplus and deficit conditions)

- D) Interactions between soil nutrient loss, OM decline and water management

Within these themes the priority issues in HPS are:

- *A - Combating nutrient losses -*

- Understanding nutrient flows in ' typical' farming systems, building on existing and ongoing research incorporating flexibility into project design
- Devise / test / modify / adapt interventions with options for producers based upon and using experience of :
  - Live barriers
  - cover crops (paying attention to impacts of soil N buildup)
  - mulching
  - reduced tillage
  - physical structures
  - crop / livestock interactions
  - reduction of burning

- *B - Reversing soil OM decline -*

- Compost composition analysis of materials and management
- Farmer decision making re. The use of organic materials
- Incorporating outputs from nutrient loss research into farmer practice
- Alternative organic sources as OM inputs (*i.e.* TSBF programme)

- *C - Improve water management (for surplus and deficit conditions) -*

- Increase water availability at critical times of season for plant growth by devising / testing / modifying / adapting interventions with options for producers based upon and using experience of :
  - OM management
  - tillage/cultivation
  - mulching
  - physical structures

- Management of surplus water by devising / testing / modifying / adapting interventions with options for producers based upon and using experience of :
  - tillage/cultivation
  - mulching
  - physical structures

- *D - Interactions between soil nutrient loss, OM decline and water management -*

- Little is documented on local technologies for soil nutrient management. This should be addressed in any new project design. The basis of any new project should build upon what farmers already know and use, farmers being fully involved in development of existing or new technologies.

- A need for a greater understanding of knowledge systems as to how and why farmers make decisions regarding soil management, with the development of methodological steps in project design to incorporate farmer decision making understanding

- Given the variability in hillside environments interpretation of biophysical and socioeconomic data using quantitative and qualitative techniques needs to be addressed.

Hillside production system (HPS) links to socio economic methodologies (SEM) component.

Linkages from the HPS to the SEM component of the NRSP are important in the following areas:

- Common property / common access resource issues in hillside scale interventions between ; gainers and losers : collective action (e.g.) water management issues

- Indicators of impact at hillside / catchment scale

- Local knowledge : methodology : coping with variations (Sillitoe *et al.* Bangladesh on going)

Agricultural production systems of the peri-urban interface: soil fertility issues

C Quansah[1], P Drechsel[2] and R D B Lefroy[2]

1. Department of Crop Science, University of Science and Technology, Kumasi, Ghana.
2. International Board for Soil Research and Management (IBSRAM), Bangkok, Thailand.

Abstract

Increasing population and urbanisation have necessitated the intensification of agricultural production systems at the peri-urban interface. Intensive crop production without additional external nutrients to replace those removed through crop harvests and other output pathways results in soil fertility decline which, in turn, adversely affects crop yield and food security. Soil fertility replenishment is therefore a prerequisite for sustained crop production in the peri-urban interface. While this goal may be achieved either by the use of mineral fertilisers or organic inputs, integrated plant nutrition provides a more efficient production environment.

Factors which constrain the acquisition and the use of mineral fertilisers and organic inputs have been examined and appropriate measures are suggested to deal with them. Success stories of soil fertility replenishment through the use of organic inputs have been documented in four case studies. The need for intensive peri-urban interface production systems to embrace the five pillars of sustainability (productivity, stability, viability, acceptability and protection) is stressed.

Introduction

The world's urban population is expected to increase from 2.76 billion in the year 1995 to 5.34 billion in the year 2025. Out of this figure more than half, 2.72 billion, are expected to reside in Asian cities. Within the same time frame, the populations of African and South and Central American cities will also increase. In 1960, about 14% of the population of West Africa lived in cities. This figure rose to 40% in 1990 and the estimated value for the year 2020 is 60% compared to 50% in sub-Saharan African cities (Snrech, 1994; Schippers, 1995).

This rapid process of urbanisation has caused some specific changes in both agricultural production systems and rural-urban interactions (Gould, 1988). The changes include:

- Increasing demand for food and other primary products in urban centres.
- Increasing flows of goods from production to urban centres.
- A reduced force of available labour in agricultural production centres.
- Increasing cash flows from urban to rural areas (remittances).
- Increasing numbers of female-headed households when males take up urban jobs.
- Increasing nutrient export from rural areas to urban centres.
- Limited return of organic materials to agricultural production centres.
- Increasing amounts of urban wastes from household, industry and sewage systems.

In an apparent response to the increasing urban population, peri-urban interface production systems have emerged. These, as defined in the Renewable Natural Resources Research Strategy (RNRRS), are:

> "characterised by strong urban influences, easy access to markets, services and other inputs, ready supplies of labour but relative shortage of land and risks from pollution and urban growth" (Holland *et al.*, 1996).

Although studies of urban and peri-urban farming systems in developing countries are scattered and scanty there is evidence of the following characteristics:

- Smaller towns are surrounded by intensively cultivated land, while larger urban centres have conspicuous inner and outer zones where cultivation of food crops and market gardening are vigorously pursued.
- A wide spectrum of production systems ranging from household subsistence to large scale commercial farming can be found around these major towns.
- In general, there is a tendency toward more intensive production systems.
- Vegetables and fruits are grown on land unsuited for building purposes and on undeveloped public and private lands.
- Intensive production of livestock and poultry for meat, milk and eggs are operational around city limits.
- Currently, limited external inputs are used in peri-urban agriculture and the precarious land situation resulting from the highly dynamic city boundaries creates uncertainty about long-term viability, hence peri-urban farming receives hardly any government assistance.
- Mismanagement of intensive crop production systems, particularly in vulnerable areas may lead to declining soil fertility, increased erosion and depletion of water resources. Conversely, the ingredients for a process of sustainable intensification of production in the peri-urban interface (fertilisers, agrochemicals, nutrient export in urban wastes, etc.) are potentially present in the urban centres.
- Significant returns to input, diversification to high value and marketable crops, and income generation activities outside agriculture may lead to increased financial returns to agricultural production and permit investment in soil improvement measures and nutrient replenishment techniques.

The interaction of these characteristics with the specific changes caused by rapid urbanisation have important implications for the management of soils in the peri-urban area for sustainable agricultural production. Among these, this paper discusses issues relating to soil fertility depletion and replenishment, and sustainable land management for peri-urban areas.

Soil fertility depletion

The magnitude of the problem

The magnitude of nutrient depletion in Africa's agricultural land is enormous (Smaling, 1993). Although nutrient depletion in peri-urban production systems has not been precisely researched, depletion from cultivated land in sub-Saharan Africa has indicated annual rates of 4.4, 0.5 and 3 million tonnes of N, P and K, respectively (Stroovogel and Smaling, 1990; Sanchez *et al.*, 1997). These rates are several times higher than Africa's annual fertilizer consumption - excluding South

Africa - of 0.8, 0.26 and 0.2 million tonnes of N, P and K, respectively (FAO, 1995). Intensive crop production in the peri-urban interface without external inputs may even reveal higher localized depletion values. Assessing nutrient depletion through the various output pathways in peri-urban production systems vis-a-vis the dynamic nature of the peri-urban environment should therefore form an important base for developing sound soil fertility management practices and replenishment strategies.

The process of soil fertility depletion

Pressure on land for agriculture, due to urbanisation, results in land fragmentation and reduced farm sizes which leads to continuous cultivation for lack of new lands to move to and to satisfy the increasing demands for staple food and vegetables by urban dwellers.

As production is intensified, most of the traditional soil fertility maintenance strategies - such as long fallow periods and clearance of new lands - break down (Quansah, 1997; Sanchez *et al.*, 1997). The consequence is that the soil nutrient capital that once supported such settlements is gradually depleted through harvest removals, leaching and soil erosion (Sanchez *et al.*, 1997; Quansah and Baffoe-Bonnie, 1981). The problem is exacerbated by the inability of most farmers to sufficiently compensate these losses by returning nutrients to the soil via crop residues, manures and mineral fertilisers (Quansah, 1996).

Effects of soil fertility depletion

The decline in soil fertility is almost always associated with a reduction in soil organic matter which correlates with a loss of structure, lowered water infiltration, increasing compactibility, soil crusting , increasing erodibility, leaching and a decrease in nutrient retention capacity (Greenland *et al.*, 1994). These effects, in addition to less cover to protect the soil, increase runoff and erosion losses which may cause off-site siltation of reservoirs and in some cases eutrophication of rivers and lakes (Sanchez *et al.*, 1997).

The major consequence of soil fertility depletion is a marked decline in crop yield and food security. Soil fertility replenishment could therefore contribute significantly to the resolution of most of the problems of depletion.

Soil fertility replenishment

A practical goal in the maintenance of soil fertility is to return to the soil most of the nutrients removed from it through harvests, runoff, erosion and other loss pathways (Aune, 1993; Quansah, 1996). The pathways for soil fertility replenishment include mineral fertiliser application, maintenance of soil organic matter (animal manure, plant residue, municipal waste, raw or processed into compost) and accompanying technologies (soil conservation, sound agronomic practices).

Fertiliser use and constraints to its use

Mineral fertiliser application is the most obvious way to overcome soil fertility depletion.
In spite of its benefits in food production improper use may cause detrimental environmental effects (FAO, 1972). Detrimental effects are usually due to application rates in excess of plant needs or to improper management practices (Dudal and Byrnes, 1993). The main negative effects

of higher fertiliser applications are occurrences of serious nutrient imbalances and toxicities that affect yields or crop quality and off-site effects from leaching and erosion of nutrients particularly N and P (Lefroy and Craswell, 1996).

In peri-urban areas fertiliser is often applied to high value crops such as vegetables while food crops receive little or no fertilisers (Ofori *et al.*, 1997; Quansah and Sarfo-Mensah, 1997).

Most smallholder farmers in Africa and those operating within peri-urban areas, in particular, appreciate the value of fertilisers but are seldom able to apply them at the recommended rates and at the appropriate time. The constraints to fertiliser use include:

- High cost and delivery delays largely due to poor road and market infrastructure.
- Blanket recommendations of fertilizer rates irrespective of crops and soil types do not meet the demands of intensive cropping and the shift to high value crop cultivation in peri-urban area.
- Lack of access to institutional credit is a major problem. A strategy which will channel credit to small-scale farmers to enable them to purchase fertilisers will increase the effective demand for fertilisers.
- A policy that is restrictive in the type of fertiliser imported deprives farmers of more cost-effective fertilisers.
- Institutional constraints include land tenure arrangements, research extension linkage, institutional lending, distribution of inputs and output market linkages (MOFA, 1996).

An effective research-extension-farmer linkage would ensure that research addresses farmers' priority needs and problems, farmers and extension workers keep abreast of research developments, available technologies are adapted to suit local agro-ecological and socio-economic conditions, and feedback on the relevance and performance on improved technologies aids performance of the system.

Maintenance of soil organic matter

There are several aspects of organic matter management which are often not considered in using organic materials in peri-urban production systems. Neglect of issues relating to quality, decomposition, etc. may lead to immobilisation of nutrients and reduction of crop yields.

Quality, decomposition and synchrony

A detailed review of these issues has been given by Woomer *et al.* (1994) and Myers *et al.* (1994). Organic inputs may be of low or high quality. Materials that have a high C/N ratio and immobilise N as they decompose are of low quality (*e.g.* cereal straw, woody materials and other waste products such as sugar cane bagasse). High quality materials have a low C/N ratio and release nutrients rapidly during decomposition (*e.g.* many legume residues, green manure, animal manure, compost, some crop residues and agricultural waste products). The faster organic materials decompose, the less remains as soil organic matter. Thus the two functions of organic materials in supplying nutrients and increasing soil organic matter content cannot be optimised at the same time (Janssen, 1993).

The choice of organic residues should therefore be such that residue decomposition results in nutrient releases that match crop demands or achieve the desired changes in soil organic matter. If release is not in synchrony with demand, surplus nutrients are free to leach below the root zone or become unavailable through chemical or biochemical processes. If nutrients are leached below the rooting zone, groundwater quality may be jeopardised as well as nutrient recovery reduced (Lefroy and Craswell, 1996). Synchrony of N release with crop demand may be achieved through management of N, lignin and polyphenols (Myers *et al.*, 1994; Lefroy *et al.*, 1995). This concept is the basis for the useful organic matter management decision tree for N produced by Swift (1997).

Sources and use of organic materials

The sources of organic materials used in peri-urban production systems include animal manure, poultry manure, plant residues, compost (municipal waste, crop residues, etc.). These materials vary in both their contents of nutrients and quality. The value of urban wastes to peri-urban agriculture are well known and have been used for intensive agricultural production systems in China and East Asian countries for centuries. Awareness that recycling of compostable waste can reduce the volume of refuse that must be incinerated or placed in landfills necessitates the streamlining and testing of systems for collection, sorting, composting and distribution.

Although precise figures for the use of organic materials in peri-urban agriculture are difficult to obtain, the general observation is that these materials are under-utilised. Some examples of the use of organic materials in peri-urban production systems are presented in case studies later in this paper.

Integrated plant nutrition

The need for integrated plant nutrition has been echoed by several researchers. Combined use of organic and inorganic inputs results in higher yields, increased nutrient use efficiency and greater residual effects than when either source used alone (Swift, 1997).

Sound soil fertility management should therefore use available livestock and poultry manures and crop residues wherever practical, taking appropriate nutrient credit for these materials and using mineral fertilisers to balance the crops nutritional requirements for realistic yield goals (Quansah, 1997). The challenge in peri-urban production systems in developing countries is to study in detail the interaction between organic and inorganic sources of nutrients and to develop replenishment strategies that require few external inputs and are consistent with the needs and aspirations of the smallholder farmers and the dynamic nature of the peri-urban boundary (Ofori and Fianu, 1996).

Constraints to the use of organic inputs

In spite of the benefits of organic matter in sustaining crop productivity, there is limited use of organic materials in peri-urban crop production due to the following constraints:

- The large quantities often required may not be available
- Manure is present only in areas of livestock and poultry production
- The logistics of transporting and handling the bulky organic materials which may be of low

quality to farms not situated in the immediate vicinity of production pose a major problem.

- Purchase of organic inputs may be costly.
- The handling of organic inputs is often labour intensive
- Urban wastes may cause heavy metal contamination
- Poor characterisation of organic inputs in relation to quality and nutrient content makes their use risky.
- Knowledge of handling and usage of organic materials by both farmers and extension officers is poor.

Accompanying technologies
Soil fertility replenishment requires a set of accompanying technologies and policies if it is to be effective in raising and sustaining food production (Sanchez *et al.*, 1997). These practices include the correct choice of crop variety and management, adequate disease, insect and weed control, and, most importantly, soil conservation and water utilisation techniques. In most peri-urban areas agronomic measures of erosion control are sufficient to achieve the conservation goal (*Quansah, 1990;* Quansah *et al.*, 1991; Kiepe and Rao, 1994).

Sustainable land management in intensive Peri-urban production systems
To be sustainable, the management of land in peri-urban areas for intensive crop production must embrace the following pillars of sustainability (Smyth and Dumanski, 1993; Syers *et al.*, 1996; Greenland *et al.*, 1994):

- maintain or enhance productivity (productivity)
- reduce the level of production risk (stability)
- protect the environment (protection)
- be economically viable (viability)
- be socially acceptable (acceptability)

Lefroy and Craswell (1996) applied the concept to intensive agriculture in peri-urban areas with emphasis on intensive vegetable production and observed that the protection of the resource base and the prevention of degradation of the soil and water quality is the pillar that is frequently given least attention in many intensive agricultural systems. In many cases, recognition occurs only after the other four pillars of sustainability have been affected.

The misuse of agrochemicals and their detrimental effects on the environment were stressed. The maintenance of environmental quality requires that these chemicals are used properly.

Case studies in the use of organic materials for soil fertility replenishment

The use of poultry manure, plant residues and mineral fertilisers in maize-cassava intercrops in the Atwima District of Ghana - an IBSRAM/UST AFRICALAND management of upland soils project.
Intensive poultry production in the Atwima District of Ghana, 20 km west of Kumasi, has resulted in the production of large quantities of poultry manure. It is estimated that out of the many poultry farms in the district, two farms alone can produce about 25,000 tonnes of manure per

year. At an application rate of 4 t/ha, this is enough to fertilise 6,250 ha of land for maize production.

However, it is not uncommon to come across mounds of manure at roadsides or in the bush, sometimes on fire. This haphazard disposal of poultry manure poses a major environmental pollution problem in the district. Current usage of poultry manure in the district is mainly for vegetable production and for a few food crops. Access to manure is no problem. Depending on the distance, farmers pay up to 10,000 cedis (about 5 US dollars) to get a truck load of about 2 tonnes of manure.

Through the participatory on-farm research approach of the IBSRAM AFRICALAND Project, some farmers have started using poultry manure on food crops.

Their trials involve the following treatments: residue + no external input (T_0); residue + 4 t/ha poultry manure (pH 7.6; 3.5% N, 0.73% P and 1.18% K; 66.72% OM - T_1); residue + 4 t/ha poultry manure + low NPK fertiliser (30-20-20 kg/ha) (T_2). The results in a maize-cassava intercrop showed the trend of maize grain yield to be T_2 (3.62 t/ha) > T_1 (3.16 t/ha) > T_0 (2.18 t/ha). Mean cassava tuber yield was in the order of T_1 (22.13 t/ha) > T_2 (21.6 t/ha) > T_0 (10.74 t/ha). In both cases T_1 and T_2 out-yielded T_0, but the yield difference between T_1 and T_2 was not significant.

A simplified financial analysis indicated net returns in cedis of 1,003,302 (US $502) for T_0, 2,112,859 (US $1,056) for T_1 and 2,115,334 (US $1,058) for T_2. The percentage marginal rate of return to additional investment was 98 for T_0 to T_1, 85 for T_0 to T_2 and 1.4 for T_1 to T_2. This analysis indicates that while it is profitable to change from T_0 to either T_1 or T_2, the magnitude of the marginal rate of return to investment is greater for T_0 to T_1 than either T_0 to T_2 or T_1 to T_2.

Farmers use of urban waste in Kano

Urban soil waste, principally street sweepings and household refuse, is used on a large scale as a minimally composted fertilising material by the near urban (15 km range) farmers of Kano in Northern Nigeria. This use has developed over several centuries as a means of retaining and enhancing the productivity of the soil in this densely populated and intensively cultivated area (Lewcock, 1995).

Until 20 years ago farmers collected the waste themselves, exchanging it for fuelwood brought into Kano on donkeys. More recently, they have become dependent on municipal tipper lorries to deliver the waste. As the tippers have deteriorated, from 40 to 50 operational vehicles to 5 or 6, so access to the waste has become more difficult and more expensive. The introduction of transport of waste by tipper lorry greatly reduced the previous drudgery of carting thousands of donkey loads of waste from the city. The subsequent breakdown of administration of the waste disposal system has now, however, trapped the farmers in a very difficult situation.

The farmers, at present, find great benefit in roughly composted materials. It may be that greater value could be obtained through improving the waste quality. The question is whether the extra cost of sophisticated collection and composting systems would be affordable or add a great deal to current productivity levels. These issues need to be addressed if agriculture is to play its important role in resource flow management which, in this case, is waste management.

The compound farming system in the Guinea and Sudan Savanna zones of Ghana

One of the efficient methods of soil fertility maintenance in traditional agriculture is practised in the "compound" farming system by farmers in the Guinea and Sudan Savannah zones of Ghana. The areas surrounding their homesteads are intensively cultivated and soil fertility is maintained by applying crop residues, household refuse and animal manure. The practice has resulted in the build up of relatively high soil fertility for continuous cropping and yields from these fields (3,000 kg/ha maize grain) are much higher than the 'distant' farms (700-1,000 kg/ha maize grain) which in some cases are still under a bush-fallow rotational system.

Shallot farming in the Volta region of Ghana

The most advanced traditional soil management system practised in Ghana in the cultivation of annual crops is that seen in the shallot growing system at Anloga in the Volta Region (Ofori *et al.*, 1997). The soils are sandy soils with inherently very low nutrient holding capacity. However, farmers through their own management practices have been able to cultivate the same site for over a century and yields of shallots cultivated three times a year are still averaging 6 /ha.

The main sources of nutrients to maintain soil fertility have been of organic origin namely: bat manure, cow dung and fish. With recent economic constraints, fish is replaced by poultry manure. Green manuring and residue management are also two important aspects of soil fertility maintenance practised by these farmers. The successful and sustainable soil fertility build-up in the shallot industry is not independent of other factors, namely: land reclamation, water management, cropping systems, heavy application of organic fertilisers and skilful labour management.

Conclusions

Increasing population and rapid urbanisation exert pressures on agricultural production systems in the peri-urban interface. Intensification without complementary external inputs results in soil fertility depletion to the detriment of crop yields. Soil fertility replenishment is necessary to break the soil depletion spiral.

However, the acquisition and use of the needed mineral fertilisers and organic inputs are constrained by several factors including high prices, poor road and market infrastructure, lack of capital and land tenure issues. Removal of these constraints and the creation of the necessary policy and economic environment will enhance soil fertility replenishment for sustained crop yield.

Integrated plant nutrition is more efficient than either mineral fertiliser or organic inputs alone in the production cycle.

Crop production systems in the Peri-urban interface can contribute immensely to the management of urban waste. Soil fertility replenishment requires a set of accompanying technologies and policies to be effective in sustaining food production. These include, among others, soil conservation, appropriate water utilisation and judicious use of agrochemicals.

The five pillars of sustainability (productivity, stability, viability, acceptability and protection) should be considered at all stages of land management in the peri-urban interface.

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Working group on peri-urban interface production systems

Chair: Professor P Harris
Rapporteur: Mr C Lewcock
Keynote Paper: Dr C Quansah

In discussion the following main issues were discussed:

Some brief discussion took place on what is peri-urban. The peri-urban definition was criticised since in fact there were often labour shortages for farmers because of competition from urban employers. The long distance effects of urban areas were noted.

As urbanisation progresses there is pressure for a more intensive, commercial, cash economy. This gives greater incentives to produce, it in turn may give greater incentives to, e.g. increased inputs such as fertiliser.

Other changes come in train:

- pressures on land, smaller holdings, reduced fallows but the need to maintain returns militates against more extensive options (but some degree of flexibility/extensification may b possible e.g. through seasonal migration, distant land holdings etc.);
- crop production changes in response to less room, *e.g.* intensification of vegetable production, increased nutrient demands, fertilisers, pesticides etc.;
- livestock production also changes, trends to zero-grazing, buying in of fodder and feeds (from outside urban area?), possibly greater integration between crop and livestock, important manure management issues;

In and near urban areas there is a whole different variety of available nutrient sources. Commercial inorganic fertilisers may be more available, wastes of different nutrient value: market waste, dairy cattle, pigs, poultry, agro-processing (mix varies with location), sewage sludge, waste water generally.

There are opportunities to upgrade the wastes , *e.g.* by recycling through livestock. The farmer will need to make trade-offs. To understand the system requires an integrated approach with the farmer at the start and the consumer at the end.

Urban waste has a value and costs. It may be <u>very</u> low grade. There are differentiated markets for the waste. Costs, for transport or labour for processing may be considerable (especially for bulky, generally low value materials). Specialised systems for access may be developed, e.g. Hubli-Dharwad, farmer auctions for waste, Kano, large-scale dumping of urban waste (for payment).

Generally speaking there is a much greater institutional separation between the farmer and the nutrient source than in rural areas, e.g. municipal "suppliers" of urban rubbish and (say) industry or other premises controlling supply and quality.

There are important links in the urban context between nutrient management and environmental management: there may be health issues e.g. from heavy metal accumulation and pollution from both solid and liquid waste. There is air pollution, with possibly very dramatic impacts. One question which arises is whether a bit of phosphate/nitrate in local streams from inorganics is any worse than nitrates from poultry manure.

One possible question is whether the most important consideration in the use of urban organic materials is for nutrient content or, in particular, soil organic matter properties, especially water moisture retention. Contrasting experience of Kumasi and Kano may be indicative, i.e. different agro-ecological conditions - or maybe it is cultural?

Not surprisingly there can be a lot of ignorance for farmers, extensionists and scientific community about any particular nutrient source and how/when to apply it separately or in combination. Baseline data on, e.g. soil nutrient deficits in urban areas are missing.

There is difficulty in clearly specifying the beneficiary for any peri-urban soil fertility research. There is a whole range of options:

- vegetable farmers seeking to intensify there land use. In some cases they may be poor young men getting as much as they can out of the land; having raised capital moving onto something less taxing. These "hit and run" farmers could have serious implications for soil mining). Or maybe farmers with a genuine long-term commercial idea in view.
- Subsistence farmers, *e.g.* women around Kumasi, trying to keep the household going in a situation with reducing plot size and decreasing soil fertility;
- speculators in land, maybe, as around Hubli-Dharwad planting low labour input, but sub-optimal, tree crops;
- this years peri-urban lands are next years housing estate - what happens to the farmers, who is responsible for the long term sustainability of the soil? One policy option could be to mine the near-urban areas much harder since they will be "lost" anyway whilst protecting more fertile areas further out (town planners probably need greater understanding of natural resources?)

Is lack of security of tenure a disincentive to investment by farmers?

There are clearly differences between peri-urban areas, *e.g.* soil, rainfall in Hubli-Dharwad and Kumasi.

Summary of overheads

Some Characteristics of Peri-Urban Interface vis-à-vis Nutrient Management:

There are <u>pressures on land</u> leading to smaller holdings, reduced fallows, fertility decline.

Nearby <u>markets for produce</u> give incentives to intensify and use more nutrients.

A greater variety of nutrient sources are found, both organic and inorganic, some highly specialised.

There is a greater separation between farmer and nutrients via municipal and other waste gatekeepers (a whole series of complex nutrient exchange relationships is possible).

The speed of urbanisation means the best strategy can be to mine soil where land is to be lost imminently.

There can be highly concentrated adverse environmental impacts associated with use of both inorganic and organic nutrient sources.

"Urban areas are vast nutrient sinks. It should be our responsibility to ensure that this resource is not wasted" - David Powlson IACR Rothamsted.

Issue areas for research:
City-regional perspective:
Managing (getting rid of) wastes (this includes non-soil-nutrient options, e.g. for energy or feed or for dumping, landfill).
Maintaining environmental quality.
Maintaining agricultural productivity/soil fertility.
This last is generally a very low priority for the urban manager!

The researchable needs arising from this are:

- the need to explore and understand the institutional perspectives of the waste managers/urban policy makers, what is important and why. A key issue is valuation of the various sources of urban nutrients (organic and inorganic) for agricultural production. The lever or entry point is likely to be on the environmental or pollution impacts of various options.

Inventories of available nutrient resources, quality, accessibility etc. will be needed. Some work is available on particular wastes but not all and not how they interact with each other or in the soil.

Farmer perspective
What are the farmer's fertility strategies?
What are the opportunities seen by the farmer? There may be many different opportunities with similarities to the rural options, *e.g.* livestock, mixed cropping, green manures etc. Likely to be at the same time more tightly constrained, *e.g.* very limited fallow, but with wider range of choice, *e.g.* variety of nutrients.
The issue doesn't just relate to nutrients, inter-related with pest management, breaking pest cycle on higly intensive holdings etc.

We cannot neglect the labour implications, *e.g.* the time to create compost, the employment provided by waste sorting.

The researchable needs arising are:

- The need to develop decision trees/choice pathways for nutrient management.
- To achieve this there is a need to categorise the beneficiaries, including "hit and run" farmers (e.g. short term intensive vegetable producers), longer term vegetable farmers needing long term fertility, subsistence household farms, urban dairy keepers etc.. We cannot just deal with the poorest farmers, we may miss opportunities to "upgrade" farming systems.
- It is also important to know much more about the long/short term nutrient release and interactions of the various available materials.
- Studies are needed of cultural issues e.g. farmer attitudes to use of poultry manure and sewage waste.

Environmental issues

These include

- soil and water pollution from both organics and inorganics.
- problems of food safety for consumers and health for producers.
- various confounding factors, e.g. air pollution impacts on productivity.

Two other important points

Apart from the general considerations above, research is likely to be very site specific, with agro-ecological and cultural differences and differences in nutrient mixes between urban areas.

When exploring issues about soil nutrients we can also be exploring health related pathogens.

Can semi-arid areas ever be self-sufficient? Can they survive without subsidies?

J. K. Coulter
DFID

Introduction

Semi-arid production systems, as defined by the Natural Resources Research Strategy of DFID, are those areas with mean monthly temperatures above 18 degrees C, mean annual rainfall in the range of 400-1200mm and one or more seasons with evapotranspiration exceeding precipitation. Clearly this definition covers a very wide range of farming conditions, many with dense populations; such areas would be more generally defined as "drylands". Table 1 shows a break-down of such lands into four different zones; the production systems of the NRRS thus cover both the semi-arid and the sub-humid zones and the 1200mm rainfall limit, in its definition, is obviously at the high end of the sub-humid zone.

Table 1 Characteristics of Dryland Zones (from Dixon *et al.*, 1989)

Zone	Vegetation	Potential land use	Annual rainfall (mm)	Inter annual rainfall variation
Hyper-arid	Little perennial except some bushes	Agriculture and grazing usually impossible	<100	Up to 100%
Arid	Scattered vegetation may include small shrubs	Light pastoral use, no rainfed agriculture	100-300	50-100%
Semi-arid	Savannahs and tropical scrub	Grazing; rainfed agriculture possible but hazardous	300-500	25-50%
Sub-humid	Tropical savannahs	Suitable for rainfed agriculture	500-800	<25%

An obvious reason for the importance of drylands is that they cover one-third of the earth's surface and 850 million people depend on them for a living (MacRae, 1987). Population is rapidly increasing and in Kenya, for example, there will be over 11 million people living in its marginal lands by the end of the century - more than the total population of the country at independence. Drylands have long been regarded as particularly subject to degradation through increasing animal and human populations. Hence the statement, considered by some as contentious, that drylands are fast being reduced to wastelands through man's use and abuse. Major concerns about environmental degradation in countries such as Kenya were expressed as long ago as the 1930s (Pereira, 1997). The degradation was real enough but what was not appreciated at that time was how farmers, given the right circumstances, could react to such conditions and develop sustainable farming systems (Tiffen *et al.*,1994).
Integrated nutrient management from stall-feeding of livestock, some fertiliser use and planting of fuel and fodder trees has played a part in this but it has taken place with a maximum of self-help and a minimum of outside investment; there is now considerable

information from this and other areas on how farmers cope with these conditions. This has led to suggestions that land degradation may be only a passing phase in the transition to different land use. Thus land rotation, the basis of sustainable farming in much of dryland agriculture, has now disappeared in land-scarce areas to be replaced to some extent by crop rotation, such as happened in the UK a couple of centuries ago.

Farmer-led improvements based on simple observations followed by practical tests, rather than an analysis of the scientific principles involved, can probably sustain growth rates in the range of 0.5 to 1.0 per cent per annum but the growth in demand in these dryland areas is of the order of 3.0 to 4.0 per cent per annum. Even if farmer-led innovations are widely applicable over a broad range of ecological and economic conditions, a productivity gap must arise which will need to be filled, either by transfer of food from other areas or reduced by emigration.

A second but related reason for increasing attention to drier areas is the alleviation of poverty, a particular focus of donors; the migration of people from the poorer lands to the urban areas is of major concern to governments. The question that needs to be addressed in this forum is the role of research in dealing with these problems and thus its contribution to poverty alleviation. With it comes the question of how to combine farmer innovation with scientific advances to improve productivity, both per labour day and per unit area, with the essential proviso that the economic conditions are conducive to innovation. We should also question the reality of productivity growth reaching 3.0 to 4.0 per cent per annum in these drylands, the potential contribution of research to such rates and the needs for additional resources for investment.

In addressing this question the paper reviews some of the research that has been done on dryland management and the knowledge that has been gained from experimental work and from farmer innovation. In discussing the economics of dryland management and its improvement the paper looks at some of the policy issues that need to be addressed and how the specific focus of the workshop could be helped by these. It is worth emphasising here that we need a combination of science, farmer innovation and favourable economic conditions to achieve improvements in productivity. There is a lesson to be learned from the UK; agricultural science was active from the middle of the 19th century but yields of the major crops scarcely changed until the 1940s.

Research on dryland management

Experimental work on dryland management can be divided into four broad categories, soil and water conservation, nutrient management, cultivation techniques and plant breeding. Clearly these are interrelated; tillage affects soil and water conservation; nutrients affect the efficiency of use of water and *vice-versa*.

Soil and water conservation

The excellent review of soil and water management research in the semi-arid areas of Southern and Eastern Africa by Morse (1996) provides a wealth of information on the results of this work. The experimentation covered a wide range of techniques for soil and water conservation - cultivation, fallowing, land shaping, mulching and trashlines, agronomic research on rotations, spacing and time of planting, hydrological and rainfall studies and agroforestry. However the review also points out that the same kinds of experiments on soil and water conservation have been carried out for the past four decades. Tied ridging is given as an example of a technique that has been researched for several decades in several countries.

There have been changes in the degree of emphasis of the research - in earlier days on on-experiment station experimentation and more directed towards cash crops, latterly on on-farm experimentation and thus a much closer partnership with farmers. In the more recent experiments more sophisticated instrumentation e.g. neutron moisture probes and automated weather stations have been used. .

The common theme throughout the research programmes centres around the questions of how to preserve the soil resource base and decrease the vulnerability of the farmers to highly variable rainfall in the semi-arid areas. The research does provide technical answers to these questions - soil and water can be conserved, yields can be improved by most of the techniques which were researched, some times spectacularly, particularly if they were used in combination. But it is **availability** that is the critical factor for farmers - availability of mulching materials, of manure, of labour, of capital, that mostly prevents the implementation of the research findings by farmers.

As noted above farmers' indigenous systems for soil and water conservation have received much more attention in recent years. Farmers often use soil variability, based on micro-topography, as an insurance against excessively wet or excessively dry conditions. Shedding or collecting areas for rainfall are partly responsible for the variation in growth but nutrient levels also play a part. Willcocks and Critchley (1996), for example, describe several soil conservation systems used in Kenya, Tanzania and Uganda, some for centuries. Broadly these are trash lines or stone lines, soil pits and across-slope ridges. The soil pits - the *ngoro* system in Tanzania is very labour intensive and it is stated that there is a general belief that decreased fallow periods are leading to low yields and that this, with the high cost of labour may be rendering the system uneconomic (Ellis-Jones *et al.*, 1996). This illustrates once more the importance of the soil and water conservation x soil fertility interaction and underlines the fact that farmer innovation may not be permanent.

Nutrient management and soil fertility

The variation of drought conditions in space and time in dryland areas means that research on soil fertility management has to be long-term but Morse's review emphasises the inability, under present funding systems, to plan and carry out such research. Furthermore the soils are very variable, with small changes in nutrients or micro-topography leading to large variations in crop growth. Detailed measurements of these features are needed to help in the interpretation of results - a factor which adds to the cost of such experiments. In the past there were more opportunities for such experiments and since the 1940s there have been a substantial number of long-term experiments in Sub-Saharan Africa, and previous to that in India (Greenland, 1994). The results of some of these in the drylands, for example, at Serere in Uganda have been summarised by Watts Padwick (1983). These and several others in SSA involved fertilisers, manure, and resting periods under a variety of covers including green manure. Unfortunately the monitoring of nutrient changes was not sufficiently detailed for in-depth information. In the Serere experiment it was possible to maintain quite high yields by applying 12 ton/ha of manure once in each 5-year rotation; while yields of individual crops increased following longer rest periods, these were not sufficient to compensate for the lack of crop from the resting land. It is of interest to note that leguminous green manures were included in several experiments -a factor again being investigated in some present day experiments as a substitute for nitrogenous fertilisers. In Zimbabwe, in the 1950s green manuring and composting were recommended to supply the nitrogen needs of maize. Even with the recommended addition of 225 kg/ha single superphosphate, the commercial farmers' yields averaged about 1.4 tons/ha compared with the 5 tons/ha regularly obtained with fertilisers in recent years (Tattersfield, 1982). We have to be modest in our assessments of what can be achieved by "low-input" agricultural systems.

Phosphorus is deficient in large parts of semi-arid francophone West Africa, and in Niger, for example, 20 kg/ha P_2O_5 doubles the yields of pearl millet (Bationo *et al.*, 1989). Pieri (1992) gives a detailed account of the results of 25 long-term experiments, varying from 6 to 25 years in this region. Much work has been done on the deterioration of soil structure, a very common feature of these fragile soils, and on the behaviour of organic matter. Pieri concludes that the long-term experimentation has proven that "these soils can support in the long-term yields five or six times those which are now obtained by the local farmers" and he continues that the methods are "neither too costly nor too complex". This is certainly an upbeat assessment for a region which typifies the semi-arid zone of SSA.

While much of the attention on soil fertility has been devoted to nutrient management, less emphasis has been given to another important effect of intensification - the build-up of soil-borne pests and diseases. Sandy soils are particularly susceptible to nematode infestation and the impact of these has been reported by Grant (1995) in Zimbabwe. In a long-term trial on continuous maize there were 216 nematodes/g roots in the second year crop and 1008 nematodes/g roots in the fourth year crop. In plots with continuous maize which had received 195 tons/ha manure over 13 years there were more nematodes but also more clean white active roots. The impact of nematodes on yields is illustrated by the effect of soil sterilisation on sorghum and cotton; this increased the yields of the former from 1060 to 2010 kg/ha and of the latter from 630 to 1756 kg/ha. Greenland (1994) has noted the fact that reports on long-term experiments have recorded problems with pests and diseases but no systematic studies have been made. Root damage by pests and diseases may be particularly important in drylands; rotations or resting fallows would be the only practical means of ameliorating this in small farmer conditions but this is an area requiring more attention in future.

These observations confirm the need to monitor a broad range of soil factors in long-term experiments. This would enable us to make predictions about the likely impact of different management strategies into the future.

Cultivation

Cultivation has several functions and there have been many hundreds of experiments on its use - in land shaping, in seed bed preparation, in improving conditions for root growth and in weed control. In the crop calendar in dryland areas the two most crucial times for cultivation are planting and weeding, hence the many experimental results showing the benefits of timeliness of planting. In more humid areas planting can be extended over longer periods with less impact on yields. However the limiting factor for cultivation is the energy source but in SSA human energy provides over 90 per cent of that used in crop production, whereas in India, for example, 70 per cent is provided by animals. The importance of this lies in the fact that whereas a fit human being's energy output is only about 40 watts on a sustained basis, that for ox power is about 450 watts (Table 2).

Table 2 Typical sustainable power outputs of individual animals in good condition

Animal	Working hours per day	Power output(watts)
Ox	6	450
Buffalo	5	520
Horse	10	500
Donkey	4	200
Mule	6	400
Camel	6	650

Within SSA, however, there are substantial differences among countries. The drylands of Zimbabwe use animal draught power extensively whereas Malawian farmers have much less access to such power. Nevertheless, even when power is readily available farmers still suffer from drought. South Africa has had an excellent research system, directed almost entirely at the 60,000 commercial farmers. Much of the country has less than 800mm average annual rainfall, with quite frequent droughts. In spite of the research support, the heavy capitalisation with machinery, and the good infrastructure, the farmers in the drought-prone areas have, on many occasions, had to be saved from bankruptcy by the government.

Without additional sources of energy in chemical, mechanical or animal form, it is difficult to see how the returns per labour day in annual rainfed crop production can be greatly improved.

Breeding for improved crop performance

It is a common feature of dryland areas that farmers, as a risk management strategy, grow several cultivars of each of their major crops. This diversity is obviously more marked where the crops are in their genetic centres of origin, for example sorghum and millets in SSA. However differentiation on the basis of phenotypic characters between different farmer names for the same cultivars and the same names for different cultivars is difficult and the actual numbers may be exaggerated. Because of the important part played by this diversity the question of the role of plant breeding is an important one as this tends to reduce diversity at the farmers' level.

While much emphasis is attached to the potential of plant breeding as a "costless" way of improving farmers' returns in drought-prone environments, it has to be recognised that progress is slow and expensive and that the genotype x environment interaction in such conditions is typically large and apparently non-systematic, (Lawn,1988). Droughts occur over a wide range of space and time in drought-prone environments and involve soil, climate and crop components. Broad adaptation has, as Lawn points out, clear advantages in being suitable over a wider range of environments, having a stable performance and requiring less seed production facilities. On the other hand, high actual yield and stability of performance are, to a large extent, mutually exclusive so there is a potential loss in not using specifically adapted varieties.

Clearly plant improvement for dryland areas is a complicated process - one that needs very clear goals, for example introducing "new" genes for pest and disease resistance. But plant improvement alone will not solve the problems confronting these areas and it must therefore go hand-in-hand with improvements in the environment - in soil fertility and water management.

In concluding this section on biophysical research in the drylands, it is clear that an enormous amount of information has been generated over several decades; could we make better use of this and are there still major gaps in our understanding? I would suggest the proposition that in dryland regions the "fundamental problems of soil and water management are predictable and our understanding of the principles is good but our ability to apply this knowledge to problems in complex local settings is weak". It may be that our understanding of the principles could be improved, which poses the question of the kind of research that is needed but I would suggest that our first priority should be how to apply this knowledge in the complex local settings and that this should define our future research agenda.

The economics of dryland management

Most drylands have a poorer infrastructure than high potential areas and, unlike peri-urban areas they have few markets on their doorsteps. Thus it is essential that potential technical solutions take account of this if there is to be any chance of adoption by farmers.

Economic costs of land degradation

As noted in the introduction there is widespread concern about degradation of the drylands. The rhetoric reflects both pessimistic and optimistic views on the present and future situation. The United Nations emphasis on "desertification", for example the 1977 UN Conference on Desertification, appears to reflect the former, which could be interpreted as a sustained process of degradation for which man is at least partly responsible. The optimists point to examples of farmers being able to reverse the process; in such situations it is clear that the process has not gone beyond a condition in which it either cannot be readily reversed by removing the cause and/or can be easily reclaimed without substantial investment. But, as Nelson (1988) points out, when the process has gone beyond this then the problem of degradation will continue and perhaps accelerate. Thus a distinction should be drawn between readily recognisable short-term damage and that of a long-term nature which may not become apparent until a critical level of degradation has been reached.

There have been various attempts to quantify the cost of land degradation at the national level. In Ghana the current farming systems are calculated to remove the equivalent of 350,000 tons of fertiliser per annum and land degradation and depletion of forests is reckoned to be equivalent to a loss of 4 per cent per annum of GDP. In Malawi the gap between utilisation and restitution of *miomba* woodland is recorded as five million cubic metres per annum, again equivalent to a annual loss of 3-4 per cent of GDP. When these losses are added to population growth, the countries would require their GDP to grow at something like 7 per cent per annum to stand still. Simple techniques such as these of calculating the value of lost nutrients give only a rough estimate of the severity of the problem but they do help by informing policy makers of the economic dimensions of degradation and may guide the establishment of priorities.

A substantial number of cost-benefit analyses of land degradation/soil conservation have been made in both developing and developed countries. Lutz *et al.,* (1994) in their analyses of soil conservation in Central America and the Caribbean advocate the use of this technique to provide a coherent framework for integrating information on biophysical and economic environments. However the authors admit that there is a dearth of hard data in spite of several decades of soil conservation efforts. Consequently the costs and benefits have to be calculated on a series of assumptions which include not only yields with and without conservation but also the rate of uptake of the technology by farmers. Of necessity such calculations must be done over a long time-span, commonly 15 to 20 years. In the drylands of Northern Thailand, Attaviro (1990) shows that after 7 years of exploitive mono-cropping the net benefits are strongly negative whereas those from conservation plus land development are highly positive after the first year. In New South Wales, Sinden (1990) uses a Natural Resource Damage Loss Equation to set the cost of degradation against the value of restoration. The study used a representative sample of farms and estimated the regional costs and benefits of a soil conservation programme in terms of its impact on agricultural incomes. Over a 16-year period the benefit cost ratio was calculated at 1.90.

Farmers' investment in dryland management

While a country is concerned with the economic returns to investment in land conservation the farmer is concerned about financial returns *i.e.* the costs and benefits as perceived by him or her. The discussion in the introduction underlined the strong pressures on farmers to intensify production from their drylands. The need to maintain livelihoods is paramount but this may mean that they are caught in a low income and biological trap from which they cannot escape. There does not appear to be much information on how household incomes change over time with increasing population and intensification. However in countries such as Ghana, for example, the farmers in the dry north are much poorer than those in the humid areas, hence the poverty focus on the former. While various countries have provided grants for such activities as terracing, the intensification in areas like Kano and Machakos appear to have come almost entirely from the farmers' own investments. However, this raises the question of whether farmers' own innovations and investment can sustain their increasing numbers without environmental degradation and a deteriorating standard of living and thus a decreasing self-reliance for the bare essentials of existence. The problem is to develop an approach that will not divert significant resources from current consumption by people at near subsistence levels. Even if they could do this, the corollary is what kinds of additional technical, social and economic investments are needed to move them out of poverty without large capital resources from elsewhere?

Land improvement is the key to intensification but traditionally farmers in SSA have altered their cropping and livestock systems to suit the physical environment rather than investing heavily in changing and improving the environment. Thus cassava replaces other crops as soils are impoverished, fallow periods are shortened to accommodate increasing land pressures, small ruminants replace cattle etc. However there are obviously many examples of SSA farmers investing in land improvement; the Machacos area is a modern example while ancient terracing in Northern Nigeria and islands in Lake Victoria are past examples; use of mulching and transport of manure from stall-fed cattle are also traditional practices in some areas. Nevertheless investments in land improvement in SSA are small compared with those for rice cultivation in Asia or ancient irrigation schemes in the Indian sub-continent or the Middle East.

One crucial factor in farmers' decisions on expensive investments in land improvement must be the quality of that land. In Asia and the Middle East much of the land is highly fertile alluvial or volcanic soils. On the other hand many of the soils in the semi-arid areas of East and Southern and West Africa are deeply weathered and generally chemically poor. Acidity, now or in future, may also be a factor in these well-weathered soils. Thus farmers are unlikely to get an adequate return on their investment in permanent land improvement unless soil fertility is also substantially increased. Thus fertility improvement may be an important lead into other developments.

So what are the financial benefits to farmers from the conservation of water and soil in the drylands and what has been learned from the many hundreds of such schemes?. As Lutz *et al.*, (1994) point out, cases in which returns to conservation are low or negative correlate well with low adoption rates. Many coercive policies have been tried in the past but have failed as soon as the coercion has been removed. This has led to advocacy of vegetative systems for terracing and there are many examples of their uptake by farmers. Nevertheless terrace construction appears to be popular in some areas. Holmberg (1990) states that up to 60,000 farmers per year undertake soil conservation work in Kenya. He describes a programme in the 800 -1000 mm area of Kitui where farmers have constructed *fanya juu* terraces and cut-off drains; 80 per cent of the farmers in the sample area had started some kind of conservation work. His calculation of financial benefits to the farmers from terracing showed that increased yields of traditional crops and production from newly introduced crops (fruit trees) resulted in an increase in net returns per labour day of over 50 per cent. The author remarks that although the returns to investment are high with a rapid pay-back, credit or labour constraints may prevent some farmers from making the initial investments. It may not be possible to generalise too widely from these results for Lutz *et al.*, conclude that, from their case studies, conservation is profitable in some cases but only in exceptional circumstances are mechanical structures profitable - a finding in agreement with the low adoption rates.

There is much fragmented information on the economic aspects of investment in soil and water conservation for land improvement in dry areas but it is difficult to draw a coherent picture from it. Under some conditions there are satisfactory financial returns to the farmer but there is little information on how these would compare with other investment opportunities on or off the farm. In terms of economic returns to the country, the crucial factor would appear to be an ability and readiness to assess the potential longer term damage which may not become apparent until a critical level of degradation has been reached.

The future of the semi-arid areas

The title of this paper raises the question of the survival of these areas. The question is obviously rhetorical since such large numbers of people live in them and it seems almost inevitable that their numbers will increase greatly and perhaps even double in the next two to three decades. If there is substantial emigration, then it is likely to be the younger and more able-bodied people, probably ending up in the urban or peri-urban areas. Nevertheless the fact remains that these dry areas are being decapitalised in terms of the natural resource base but the farmers have very little surplus to invest. Thus the problem, as noted earlier, is to develop an approach that will not divert significant resources from current consumption by people at near subsistence levels. In the developed countries we have the same kinds of problems though they differ greatly in degree. Thus the poorer rural areas are heavily subsidised both directly and indirectly, by the provision of roads and electricity, for example. Few of the countries with extensive semi-arid areas have the financial base to do this. Even countries like India and China, with strong industrial bases have large areas of impoverished drylands and a country like Zimbabwe, with a current budget deficit of 12 per cent of GDP, cannot subsidise its poorer rural areas on any appreciable scale. Even if SSA countries had the resources, they have always to make a choice between investing in the higher potential areas where returns are better, rather than in poverty alleviation of these poorer areas.

Poverty alleviation, as a major objective of development in these drylands, means that there will need to be increased returns per labour day and, in many countries, per unit area. Achieving this will entail a combination of improved technology for existing crops, changes in farming systems to include higher value crops and livestock, greater energy inputs in the shape of chemical, animal and perhaps mechanical energy, additional investments by farmers and by the governments, and/or donors on their behalf. Over the next five years, at least, this will mean adapting and using existing knowledge but the question is how to bring these various factors together more effectively. It would help if we had a realistic assessment of the usefulness of existing information, how and where it is being applied, its sustainability and its profitability. The "right" policy decisions by government(s) will differ for different areas but these decisions must provide the incentives for farmers to change. Somehow the situation has to move from one where the farmers' actions are determined by the need to survive to one where the incentives are the prospects of substantially improved living standards.

There is general agreement that the "Green Revolution" has been technology-led but I think that this is unlikely for the semi-arid lands. I do not think that science can be used to circumvent economic disadvantages even if the "right" kind of research is undertaken. Thus I would suggest that government/donor investment will have to lead the way. How this will operate is a matter for conjecture but investment in infra-structure, including domestic water supplies, small scale irrigation, recapitalising soil fertility, improved processing and marketing, particularly for new, high value crops and, most importantly, farmer education are possible routes.

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Working group on the semi-arid production system

Chair: Prof Keith Syers
Rapporteur: Dr Dave Harris (Mr David Jackson)
Keynote Paper: Dr John Coulter

Discussion

John Coulter began by reiterating the main points of his background paper "Can semi-arid areas ever be self-sufficient? Can they survive without subsidies?" In response the Chairman noted that the paper was very developmental in nature - in line with the current DFID approach to research. It was agreed that returns to land and labour in these areas needed to be improved but that this would not be possible unless soil fertility was maintained or enhanced. A considerable amount was known about crop responses to major nutrients but there were gaps and these lacunae included topics of great relevance to semi-arid areas e.g. the interaction between organic and inorganic sources of nutrients. Finally, the interaction between water and nutrients was seen as paramount in a system that is defined on the basis of the temporal and spatial availability of water. There was general consensus that the widely-used 400-1200 mm/year rainfall definition of "semi-arid" was too broad and that the group would confine themselves to discussing issues relevant to the drier end of this range, i.e. 400-800 mm/year.

The group noted that, again by definition, conditions for crop production in semi-arid areas were marginal and unpredictable. The starting point for discussion was that one of the primary characteristics of semi-arid areas was the high level of risk involved in growing crops without irrigation. Farmers tended to be risk averse (although some rather specialised exceptions were noted, for instance where farmers have little choice but to engage in high risk activities) and it follows that interventions, proposed by researchers on the basis of valid scientific data, but perceived by farmers as being too risky, had little chance of being adopted, at least without outside support (i.e. the "subsidies" mentioned in the background paper). This is a key issue in relation to a question posed in the Introduction to the Workshop - a great deal of research has been done to "improve" (semi-arid) agriculture, why has it been taken up by farmers so rarely and had so little impact?

The idea of "key" technologies was raised and illustrated with reference to the DFID-funded KRIBHCO Indo-British Rainfed Farming Project (KRIBP) in semi-arid India. A "key" technology is a low-cost, low-risk intervention chosen from a "basket of choices" by farmers in a participative exercise involving comparative evaluation by communities of farmer-conducted on-farm trials. Technologies to test are chosen together with researchers and are targeted towards mutually-agreed constraints. Successful technologies raise or stabilise yields, or reduce costs, and experience has shown that these "keys" can induce further investment in improved technology once risk is reduced. In the KRIBP project the targeted constraint was drought and the farmers were offered shorter-duration varieties of their chosen crops in an attempt to avoid the damaging effects of dry spells. In addition, information was provided on how to soak seeds before sowing. This practice improves crop establishment dramatically and shortens crop durations still further. The benefits of these two key technologies were readily appreciated by farmers who have responded by increasing the use of chemical fertilisers (aided by improved access to credit as a result of KRIBP activity). Uptake and farmer-to-farmer spread has been brisk and illustrates that low-risk interventions can be effective and lead to adoption but suggests that, at least in this marginal area, agricultural investment will not occur without short-term gains.

There was much debate about the status of semi-arid areas - were they really in decline? Some participants thought that linear changes and simple "gap" analysis were inadequate for describing the characteristics of these systems and that we must capture the idea of the complex dynamics of change. Consequently, long term research was essential for understanding both the socioeconomic and natural resources aspects of soil fertility. It was noted that this long-term approach was not consistent either with farmers' short-term goals in marginal situations nor with DFID's current funding horizons.

The question of land tenure was debated and it was noted that farmers had little incentive to improve land if there was a risk that someone else would reap the benefits in the future. Such a situation would favour nutrient mining, or at the very most short-term maintenance of fertility and yields. Given the projected rates of growth of population in semi-arid areas (see keynote paper) particularly in Africa, improved soil fertility - not maintenance - is required. In northern Thailand, even when land tenure is secure soil degradation (soil losses of 100-120 tonnes per hectare per year) has not elicited remedial action unless crop yields begin to decline. Is it too late by then? Is remedial action more difficult than it needed to be? The role of trees was discussed briefly here. Planting trees on land in Laos(?) establishes ownership, a benefit in addition to that of improving soil fertility *per se*.

It was clear from presentations earlier in the Workshop that organic matter was the key to improving soil fertility, particularly for resource-poor farmers with poor access to chemical fertiliser. Such farmers are typical of marginal environments in the semi-arid tropics. In addition, the prevalent soils of these areas typically have very low levels of organic matter. Paradoxically, low levels of crop production, and biomass generally, are also characteristic of these areas. Evidence in the literature suggests that biomass is not available in quantities traditionally thought to be effective in maintaining or enhancing soil fertility. Poor and variable quality of organic matter is also an issue and the group welcomed the work previously presented on decision systems for assessing the quality of, and possible uses for, biomass from various sources (in the TSBF/Wye College collaborative Organic Resources Database System). The interaction between biomass quality and manure inevitably involves livestock, so the ownership and use of cattle is a key issue in any research involving the use of organic matter. Since organic matter is in short supply, it was thought important that research should focus on nutrient use efficiency, both within fields and within and between families and communities. Common property resources and community-managed land were also important in this context. Organic matter was a resource like any other and strategies for its best use might very well include trade. The consequences of these nutrient flows for households need to be quantified.

There are a number of paradoxes inherent in soil fertility research. General principles are known governing crop responses to nutrients but practical recommendations for remedial action are highly site-specific and, in a marginal environment, dependent on farmers' household circumstances. Generalisations, then, are not very useful in a developmental context. Attempts to "manage" natural groupings of farmers e.g. in a watershed are a step forward but the individual elements still require individual attention. Nevertheless, there was a feeling that fertility management was not practicable in semi-arid areas without water management. Inherent in this argument was the fact that the water holding capacity of soils increases as organic matter is increased, as well as the obvious interaction between nutrient uptake and water use. There was a parallel here with earlier Integrated Pest Management work - farmer education was the key - but even with IPM, successes tended to be associated with commodity-focused systems e.g. cotton rather than for subsistence agriculture.

Attention was drawn to the link between poverty of farmers and poor soil fertility - locked into a vicious cycle of impoverishment. This was discussed in relation to the view that returns to research investment were always greater (in absolute terms) in higher potential areas. Perhaps cropping in semi-arid areas would always bear too much risk to be sustainable in the long term?

Presentation to Plenary

Issues

Definition of "Semi-Arid" to delimit the Production System area.
Characterised by a large and increasing population, and
Inherently low soil fertility combined with fragile soils.
RISK is a major element, particularly due to low moisture availability.
Low organic matter in soils.
Poverty very widespread.
Not much organic matter available in the system (low biomass productivity).
The trees-crops-livestock interactions are very important.

Research themes:

Topic 1

Researchable constraint;
- limited physical availability of organic materials and the need to manage small amounts optimally.

Priority issues:
- competing uses for limited organic materials (on and off farm)
- optimising use and management

Suggested project:
Appropriate methods to increase the supply of organic materials in semi-arid areas and to optimise the use of the small amounts of organic matter that are available.

Topic 2

Researchable constraint:
Low levels of nutrients and low efficiency of use of added nutrients (particularly P) lead to low and declining productivity in the short and long term.

Priority issues:
- efficiency of use is particularly important in semi-arid areas because the margins for error are smaller in both environmental and economic terms
- use of organic materials to maximise the efficiency of water use and nutrients

Suggested project:
Determinants of nutrient use efficiency at the farm level.

Topic 3

Researchable constraint:
Available nutrients are scarce, and this scarcity is exacerbated by transfers and re-distribution of those nutrients off-farm.

Priority issues:
- the need for quantitative data
- case studies required which are
    - location specific
    - interdisciplinary
    - and methodologically sound
- linkages between differential flows of nutrients and household livelihood levels

Suggested project:
Effects of nutrient flows on rural livelihoods.

Appendix 1

Poster presentations

- **Trashlines in annual crops on steep hillsides**
- **Traditional methods for sustainable soil management**
- **Perennial banana crop mulching practices**

  Stephen Briggs and Jim Ellis-Jones, Silsoe Research Institute

- **Sustainable agriculture on forest margins: modelling soil organic matter transformations and nitrogen availability**

  John Gaunt, IACR, Institute of Terrestrial Ecology, Rothamsted

- **Nutrient budgets in relation to the sustainability of indigenous farming systems in northern Nigeria**

  Frances Harris, Department of Geography, The University of Cambridge

- **Urban agriculture in Havana, Cuba: soil fertility aspects**

  P J C Harris, Henry Doubleday Research Association

- **Adaptation of cover crop legumes to environment**

  R J Summerfield, J D H Keatinge, Aiming Qi, Plant Environment Laboratory, The University of Reading

- **Dry season vegetable production in the forest/agriculture interface, Ghana**

  Liz Kiff and David Jackson, NRI, Chatham Maritime

- **Integrated nutrient management to sustain crop production in the mid-hills of Nepal**

  C J Pilbeam and M Wood, Department of Soil Science, The University of Reading

- **Sustainable agriculture in forest margins**

  Barry Pound, NRI, Chatham Maritime

- **Ecological and economic impacts of soil management on smallholder farms**

  K D Shepherd and M J Soils, International Centre for Research in Agroforestry, (ICRAF), Nairobi

- **Economic and environmental assessment of soil erosion and conservation**

  M Stocking and R Clark, Overseas Development Group, The University of East Anglia

SILSOE RESEARCH INSTITUTE
Wrest Park, Silsoe, Bedford MK45 4HS, U.K.
Tel: +44 1525 860000 Fax: +44 1525 860156

M.A.A.I.F.

Makerere University

Vrije Universiteit Amsterdam

Trashlines in annual crops

On steep hillsides

Stephen Briggs[5], Lynn Briggs[1], Will Critchley[4], J. Ellis Jones[1], Dan Miiro[2], Joy Tumuhairwe[3], Stephen Twomlow[1]
[1]Silsoe Research Institute; [2]Uganda Ministry of Agriculture, Animal Industries and Fisheries; [3]Makerere University; [4]Vrije Universiteit, Amsterdam, [5]DFID

Temporary lines of 'trash' (0.5 - 1 m wide), constructed from weeds with some crop residues of sorghum, maize or sweet potato stems are laid along the contour in annually cropped hillside fields working as mobile compost strips. Trashlines are periodically 'broken up' (after 2, or up to 6 seasons), with the rotted trash (fertility) being locally distributed, before a new trashline is established in a different location during subsequent land preparation.

Trashlines act as barriers preventing soil erosion, slowing rain-water runoff, improving soil water infiltration and trapping a nutrient-rich, fine soil fraction. Trashlines act as zones of soil accumulation immediately upslope of the trashline barrier, encouraging terrace formation.

Benefits

- Reduce soil erosion.
- Increase soil water infiltration.
- Improve organic material management (over burning).
- Reduced labour requirement (compared to *Fanya juu*).
- Trap soil upslope of trashline, providing enhanced soil fertility.

Terraces

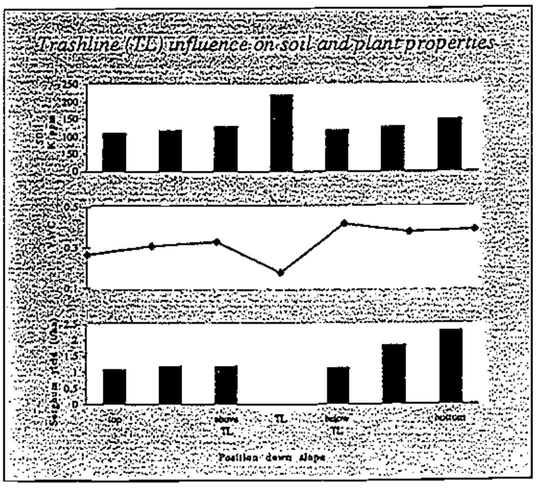
A mobile trashline

Problems

- Weeds spread every time trashline 'broken up'.
- Pests (rats, moles, etc) are encouraged.
- Insufficient residues are available as most are used to mulch banana plantations.
- Declining annual crop yields with insufficient returns of organic material to balance system. Net export of organic materials to banana plantations.

Research focus

- Optimum time for leaving trashlines in one place, before 'breaking up' and spreading fertility.
- Contribution of trashline to soil and water conservation and yields, leading to improvements of local technologies which have been jointly identified by and agreed with farmers and are economically acceptable.



Initial results:

- Preferable to keep trashlines in place for longer.
- Multiple small lines instead of a few, large trashlines.
- Trashline cause a fertility gradient which results in positive returns just above trashline, declining to negative returns furthest from trashline.

Funded by the UK Department for International Development and Uganda Government

SILSOE RESEARCH INSTITUTE
Wrest Park, Silsoe, Bedford MK45 4HS, U.K.
Tel: +44 1525 860000 Fax: +44 1525 860156

M.A.A.I.F.

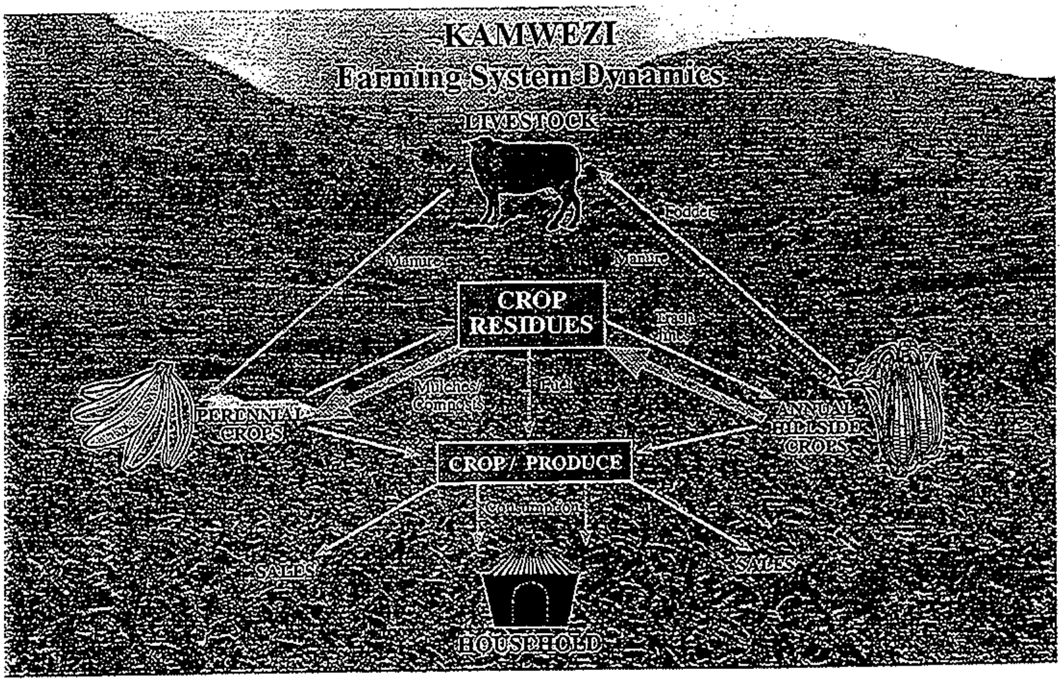
Makerere University

Vrije Universiteit Amsterdam

Traditional methods for sustainable soil management

(The hillside farming systems of Kamwezi, South West Uganda)

Stephen Briggs[5], Lynn Briggs[1], Will Critchley[4], J. Ellis Jones[1], Dan Miiro[2], Joy Tumuhairwe[3], Stephen Twomlow[1]
[1]Silsoe Research Institute; [2]Uganda Ministry of Agriculture, Animal Industries and Fisheries; [3]Makerere University; [4] Vrije Universiteit, Amsterdam, [5]DFID



Physical environment	
Altitude	1400 - 2000 m asl
Slopes	Typically 5 - 40%
Mean rainfall	Bimodal, 832 mm p.a.
Monthly evaporation	125 - 150 mm
Soils	Ferrallitic, Sandy clay loams shallow on hillsides

Socio-economic environment	
Population	193 / km^2
Average farm size	2.2 ha
Tenure	Highly fragmented land parcels of approx 0.25 ha
Farming system	Subsistence level mixed cropping, with a small livestock component
Two main cropping systems	Annual crops on the hillsides. Perennials (banana/plantain) on lower slopes and valley bottoms

Other techniques *(introduced through the project)*:
- rainwater harvesting infiltration ditches
- live barriers
- improved fallow
- improved hedgerows
- stonelines

THE FUTURE

Wide adoption of 'improved' local soil water and fertility conservation technologies in water deficit areas of SW Uganda, with these improvements underpinned by scientific evidence.

Funded by the UK Department for International Development and Uganda Government

SILSOE RESEARCH INSTITUTE
Wrest Park, Silsoe, Bedford MK45 4HS, U.K.
Tel: +44 1525 860000 Fax: +44 1525 860156

M.A.A.I.F.
Makerere University
Vrije Universiteit Amsterdam

Perennial banana crop mulching practices

in valleys and on lower slopes

Stephen Briggs[5], Lynn Briggs[1], Will Critchley[4], J. Ellis Jones[1], Dan Miiro[2], Joy Tumuhairwe[3], Stephen Twomlow[1]
[1]Silsoe Research Institute; [2]Uganda Ministry of Agriculture, Animal Industries and Fisheries; [3]Makerere University; [4] Vrije Universiteit, Amsterdam, [5]DFID

Various materials are used for mulching, mostly stems and leaves of bananas, with additions of stover from annual crops (especially sorghum and beans), applied at rates of between 30-40 tonnes mulch/ha.

Mulching conserves moisture for the shallow rooting banana crop (0-30 cm), in water deficit areas, and is essential to maintaining the productivity of this main food staple and cash crop. Imported mulch materials from annually cropped hillsides replace nutrients removed in harvest, but leaves the hillsides with a deficit nutrient balance.

Benefits

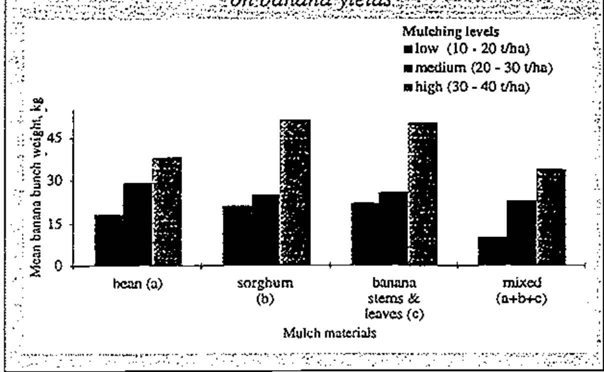
- Conserves essential soil moisture.
- Sustains soil fertility.
- Maintains crop yields.
- Suppresses weeds.

Problems

- 'Steals' nutrients and organic matter from annually cropped hillsides, which are not replaced, causing declining yields on hillsides.
- As annual yields decline crop residue availability for mulch decreases. Farmers have to purchase crop residues to maintain yields of banana crop.

Farmer Research Group discussion on mulching techniques

Effect of mulch material type and application rate on banana yields



Research focus

- Effect of different mulch materials and application rates on soil moisture retention, fertility and crop yields.
- Farmer participation in all research activities.

Initial results:

- High mulch rates increase soil water retention, resulting in improved crop yields, but are unrealistic in terms of material availability.
- Medium and low rates of mulch increase soil water content and yields.

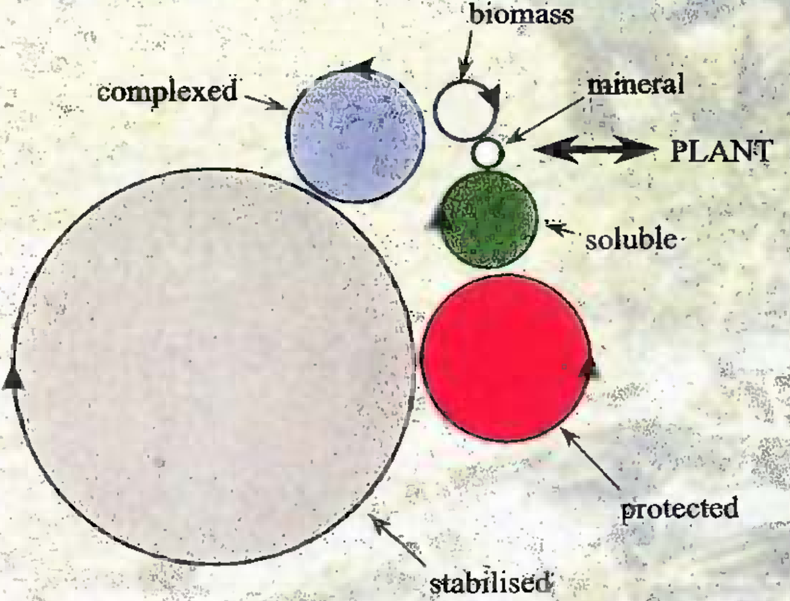
Funded by the UK Department for International Development and Uganda Government

Modelling Soil Organic Matter Transformations and Nitrogen Availability

Productivity declines when irrigated, rice based, cropping systems are intensified. One hypothesis is that intensification interferes with soil organic matter (SOM) cycling, N supply and hence productivity.

Turnover of the "SOM machine", makes N available for plant uptake. If the transformation rates between pools - and hence their sizes - change, the supply of N is altered.

"SOM machine"



The transformation rates are affected by oxygen, and flooding is known to reduce oxygen availability. Yet no current SOM model takes specific account of oxygen. The aim of this project is to create, parameterise, and test such a model.

We shall then use the model to assess the potential impact of various management strategies to ameliorate adverse effects of intensification. Improved management strategies identified through this process will be tested under field conditions in a planned second phase of the project.

IACR-Rothamsted *Integrated Approach to Crop Research* | Institute of Terrestrial Ecology | Centre for Ecology & Hydrology | IRRI

This project is funded by the UK Department for International Development (DFID). It is a collaborative venture between the International Rice Research Institute (IRRI), the Institute of Terrestrial Ecology (ITE) and the Institute for Arable Crop Research (IACR) at Rothamsted.

For further information please contact:
IACR - John Gaunt: john.gaunt@bbsrc.ac.uk; **ITE** - Jon Arah: jarah@wpo.ac.uk; **IRRI** - Guy Kirk: gkirk@cgnet.com - or Yang Haishun: hyang@irri.cgiar.org

Nutrient budgets in relation to the sustainability of Indigenous Farming Systems in Northern Nigeria

Dr Frances Harris
Department of Geography, The University of Cambridge

Poster Abstract

The Kano close settled zone (CSZ) has been the site of an intensive farming system for many years, where crops, livestock and tree products are produced (Mortimore, 1993, Hill, 1977). Over the last 30 years all available land has been under annual cultivation, so there is little or no fallow land to permit crop rotations or grazing. The area supports a rural population density of between 250-500 people/km^2. Observers have wondered at the apparent sustainability of this farming system, but until recently there have not been any detailed studies of soil fertility management in this system. Mean annual rainfall (1906-1985) is 822 mm, although this has declined in recent years. The main crops grown are millet, sorghum, groundnut and cowpea, with smaller amounts of cassava, maize, sesame and peppers. Small ruminants (sheep and goats) are a major feature of this system, and are typically kept tethered in domestic compounds during the cropping season, and roam fields in the dry season. Some farmers keep donkeys or bulls for animal traction.

A two year case study has monitored in detail the soil fertility management practices of three farmers within the Kano CSZ. Inputs from organic manure and inorganic fertiliser, Harmattan dust deposition and biological nitrogen fixation by leguminous crops, and outputs in harvested products, have been quantified at the field level. Chemical analyses of these inputs and outputs has enabled a nutrient balance to be calculated for each landholding. Quantification of the nutrient flows of the three holdings has shown that the balance varied according to the farmers' management of individual fields, and the effect of rainfall on the size of the harvest, which is the main factor determining nutrient removal from the fields (Figure 1). Above average rainfall in 1994 produced bumper crop yields which depleted nutrient reserves, but in the longer term the differences will be smoothed over, with the soil providing a reserve of nutrients to compensate when there is a negative balance and to store nutrients when there is a positive balance, for example, in years of exceptionally low rainfall.

The key to this farming system is the integration of crop and livestock production. Small ruminants consume crop residues, particularly those of groundnuts and cowpea, and weeds, and their nutrients (together with those contained in household waste) are converted to manure, which is transported back to the field. Nitrogen is gained through biological nitrogen fixation by the legume crops. Some grains are sold (in particular groundnut and cowpea), allowing farmers to purchase inorganic fertilisers. Cation nutrients and micronutrients are added to the system when Harmattan dust is deposited on farmers' fields during the dry season.

The results were used to develop a model of nutrient cycling within the farming system (Figure 2). Only a small amount of the material harvested from the fields leaves the area. Much is transported to the compound for storage, but the nutrient it contains is returned to the soil, either via livestock, who convert it to manure, or via the cooking fire, where coarser crop residues, wood, pods and chaff are burned. The ash is added to the manure. Some nutrients are retained by the growing livestock, or lost in burning (especially nitrogen), but most are returned to the soil.

There is no doubt that this farming system is labour intensive. This means that the system can only develop from an extensive system when labour availability is increased, as population density increases. Bourn and Wint (1994) noted that livestock density increases when population density increases. Thus the livestock necessary to develop an integrated farming are found as the need to intensify arises. The results contrast with other work on agropastoral systems in West Africa (Schlecht *et al* 1995), Powell and Mohamed-Saleem, 1987, Turner, 1994, Stoorvogel and Smaling, 1990, van der Pol, 1992) where researchers claim that farmers are "mining" their soils. Their work does not consider the ability of farmers to adapt their farming practices to changing environmental conditions, especially declining land availability and rainfall, and increased labour availability. It is in response to such changes that the farming system of the Kano CSZ has intensified and is now able to support a high population density through annual cultivation.

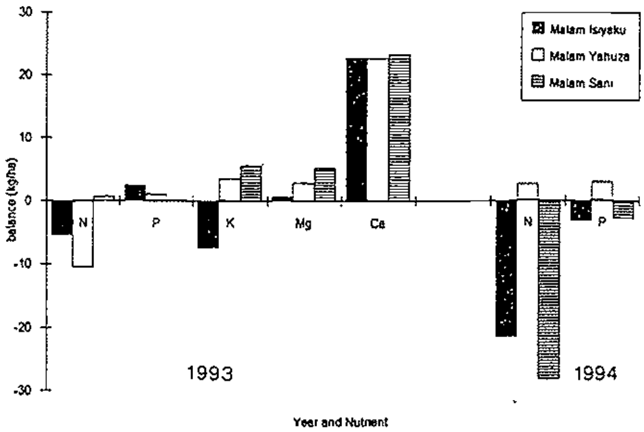


Figure 1. Nutrient balance of landholdings (Kg/ha)

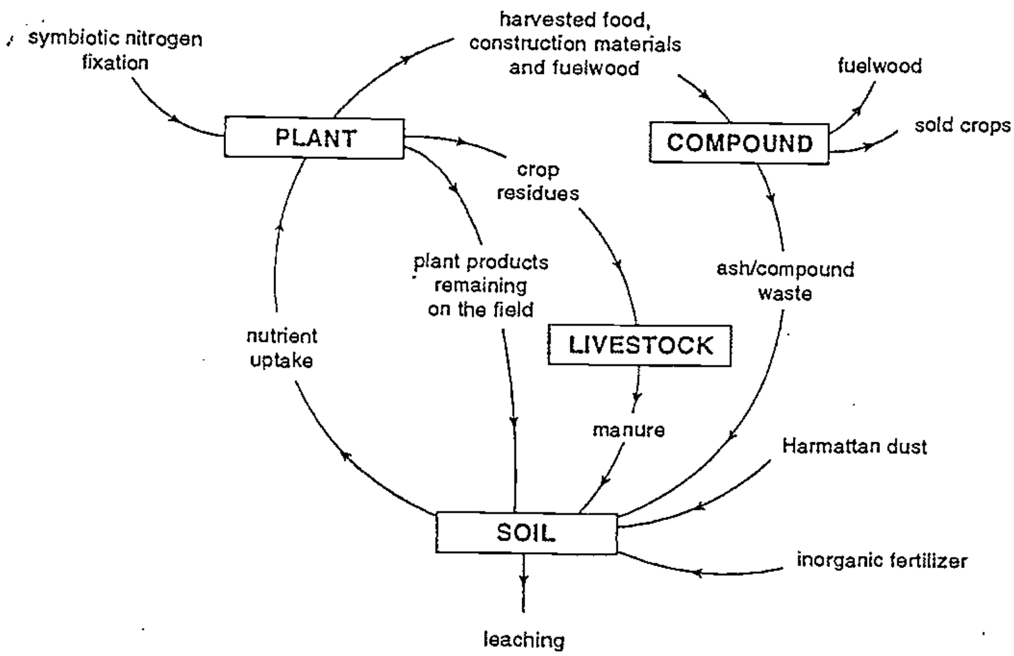


Figure 2. Nutrient cycling in the Kano close-settled zone

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Urban agriculture in Havana, Cuba: soil fertility aspects

P.J.C. Harris
Henry Doubleday Research Association

Introduction

With the collapse of the Soviet Bloc, Cuba's economy and its traditional import and export trade has suffered massive dislocation. Among the many shortages Cuba is now experiencing are inputs of fertilisers and pesticides for agricultural and horticultural production. As a consequence, Cuba is undertaking an unprecedented nationwide experiment to increase the food supply for its population using organic production techniques. The experiment is principally based on small horticultural organic production units (organoponicos) employing raised beds, and on allotment-type plots, mainly located on disused land in urban areas of Havana and other cities and rural areas of Cuba.

Urban agriculture was developed in order to increase the production of fresh vegetables for direct sale to the population and to satisfy the demand for vegetables by growing them within the urban centres rather than in the traditional agricultural zones, thus solving problems of transportation and storage loss. It was hoped that this would contribute to the dietary requirements of the population. Agricultural enterprises were expected to create new areas of work and agricultural production to maintain price stability and lower prices for fresh produce in short supply.

The decision to adopt organic agricultural production was based on both a lack of resources for fertiliser and pesticide inputs and for health, safety and environmental reasons.

Soil fertility management:

- When the organoponicos were established, soil was imported and mixed with composted manure from dairy units, vegetable residues, residues of sugar processing, and sometimes leaf mould from mangrove swamps. This permitted the siting of horticultural production units close to urban populations, often on derelict land.
- The establishment of these organoponicos is expensive and depends heavily of external inputs. In some cases little or no further input of organic matter has taken place since the original construction of the beds and maintaining soil fertility has been difficult, particularly with the intensive vegetable production practised.
- On-farm recycling and composting, and optimum use of available compost and animal manures can slow, but not halt, the decline in soil fertility.
- Soil fertility could also be maintained or enhanced either by increasing inputs and continuing with intensive production or by adopting less intensive production.
- Less intensive production at the farm level could be achieved by utilising more land to grow plants for fertiliser production, for composting, or for animal feed and production, while retaining the same level of production on existing vegetable beds.
- Less intensive production could also be achieved by reducing the frequency of cultivation on the beds, probably by including fertility building plants in a rotation.
- The prospect of reducing the intensity of production in a system designed to provide a valuable addition to food supply at a time of economic crisis, is unattractive, and increasing the organic inputs is the favoured option.

Natural fertilisers: *Rhizobium* inoculation of beans is practised. There was no evidence of the use of rock minerals, lime (other than as a pesticide), calcified seaweed, blood, fish or bone meal, or plants grown specifically for fertiliser. In some areas there is land and water available for biomass production for composting. There is scope for planting compost/fertiliser crops, including fast growing legumes *etc*, and interest in investigating this approach further.

Composting: Composting of garden waste, dried grass and animal manure was carried out at some of the sites visited. The basic techniques for compost preparation were well understood, although the amount of compost produced was almost certainly insufficient to satisfy soil nutrient and organic matter requirements.

Green manures: There was very little deliberate use of green manures, either as cover crops as part of a rotation, or by undersowing. Although green manures are reported to figure as part of the rotation of larger state farms, the intensive vegetable beds of the organoponicos are never sown with green manures because they are more or less continuously cropped.

Crop rotation: The rotation practised is determined by the range of crops which are permitted, market, and the seasonal cropping pattern. There was a clear understanding among extension workers and growers of the need for rotation and the groups of plants which should be rotated.

Cropping pattern: There was only limited evidence of intercropping, for pest control as well as to optimise the use of space. This included cucumber and lettuce, onion and carrot, cucumber and radish, onion and lettuce, tomato and spinach beet.

Recycling of organic materials from local sources:

- Given the intensive nature of crop production practised on the organoponicos and the consequent difficulties in maintaining soil structure and fertility, the use of waste materials as inputs to the farming system presents an attractive alternative to conventional fertilisers.

- The value of waste as fertiliser, soil ameliorant and animal feed is generally recognised. Waste when available is added to the soil during cultivation, composted with plant material, and in some cases obtained to feed pigs, through private arrangements with local canteens.

- With few exceptions the supply available is less than that desired. The main types of waste used are cow and chicken manure from peri-urban livestock units, and waste from sugar processing. These materials usually come well-rotted and do not require further composting.

- Although industrial effluent is treated, raw sewage is generally discharged directly into the sea. There is no history of the use of human wastes and limited interest is using this.

- Domestic waste is another potential source of organic material for the organoponicos. There is no separation of organic from non-organic waste at present, either centrally or at source. Separation of rubbish at home is thought difficult because of the lack of bins or bags.

- Access to the available wastes is a major problem. Some growers have access to transport and are able to solve this problem, most do not. Sometimes there may be a delivery of organic waste from elsewhere but generally not. Transport can be hired but this is very difficult and expensive.

Key constraints:

- Lack of resources for infrastructure and inputs on organoponicos.

- Lack of transport for all activities.

- Lack of resources for information gathering, extension literature, and information dissemination.

- Limited access to international information, databases via electronic communications *etc.*

- Lack of suitable wells, pumps and irrigation systems.

- Below optimum soil moisture retention through limited bulk organic soil conditioners and use of mulching and shelter.

- Difficulty in maintaining and enhancing soil fertility and structure because of:

1. Lack of access to, transport for, and optimum use of, organic waste materials;

2. Below optimum on-farm fertility building and recycling through natural fertiliser and compost plants, green manures *etc*;

3. Below optimum information about, access to, or current use of: Varieties for disease resistance; Crops and varieties for summer cropping; Crop mixtures and spacing; Mulching; Seedling and nursery techniques; Selection and cultivation of plants for natural control; Alternative pest and disease control; Hedges, windbreaks and shade; Hand tools.

Recommendations relating to soil fertility:

Soil fertility survey: A detailed study should be undertaken to monitor the current soil fertility and organic matter content of representative urban agricultural sites, together with their inputs and outputs, to construct nutrient budgets. This would clarify whether current cropping is sustainable, and estimate any inputs needed.

Organic waste inventory: An inventory of available organic wastes and manures, and a calculation of the logistical costs of satisfying demand should be undertaken.

Optimum use of resources: Further work on on-farm recycling and composting, and optimum use of available compost and animal manures should be carried out.

Waste management: Pilot projects should be set up for domestic waste collection and utilisation which identify a number of organoponicos which are located close enough to populations to provide local waste with minimal transport. Consideration should be given to the questions of separation, collection, processing, storing and using the organic wastes.

Adaptation of Cover Crop Legumes to Environment

J. D. H. Keatinge, A. Qi, R. J. Summerfield, T. R. Wheeler and R. H. Ellis

Introduction

Cover crops are legumes, cereals or an appropriate mixture grown specifically to protect soil against erosion, ameliorate soil structure, enhance soil fertility , and suppress pests such as weeds, insects and pathogens. Cover crops are also said to be a temporary or permanent, live, non-woody vegetative soil cover grown within rain-fed annual or perennial cropping systems. Cover crops are further also defined as annual crops sown to create a favourable soil micro-climate, to decrease evaporation and protect soil from erosion, and to produce biomass used for soil fertility management.

Loss of soil organic matter and reduction of inherent soil fertility together with soil erosion are increasingly severe limitations to crop production on steeply sloping hillsides in the tropics and sub-tropics. Pressures in consequence of the direct and indirect effects population growth in the mountainous regions of countries such as Nepal, Uganda and Bolivia pose intense constraints on the cultivation of hillside land. Continued intensification of subsistence cereal crops production without adequate replacement of soil nutrients will result in unsustainability of those hillside farming systems. Furthermore, communities forced to grow annual crops on steep hillslopes are often severely disadvantaged in their ability to provide inputs for soil fertility maintenance. We anticipated that the successful introduction and subsequently greater implementation of cover crop legumes is a viable option likely to improve the long-term sustainability of these hillside cropping systems. These cover crop legumes can be either species used for improved productivity of animal feed with consequent additional animal manure supply or species potentially used as only green manure.

The value of any cover crop legumes in the mosaic of environments and diverse farming systems on the hillsides necessitate the precise knowledge of factors affecting their phenology such as flowering and seed production. Temperature and daylength are the two main environmental variables which influence crop phenology. Thus, experiments with controlled photothermal environments have been carried out to derive phenology/climate models to quantify the effects of temperature and daylength. These phenology/climate models will then be used to examine the potential adaptation to hillside cropping environments.

Materials and Methods

12 selected multi-purpose cover crop legumes were grown from 2 April to 2 October 1996 in 12 controlled photothermal environments made up of all combinations of 3 mean diurnal temperatures at 17°, 22° and 27°C and 4 photoperiods of 11.5, 12.5, 13.5 and 14.5hd $^{-1}$. A general triple-plane rate model developed in a former DFID project (Keatinge *et al.*, 1996) has been used to derive the photothermal coefficients of phenological responses.

Results

Times from sowing to first flowering and those from first flowering to first pod maturity varied appreciably among the photothermal environments within species and *vice versa*. Depending on the cover crop legumes, the number of planes required to adequately quantify the photothermal effects on time to flowering varied from 1 to 3. For example, all the three planes were needed in *Dolichos lablab*.

The time from first flowering to first mature pod was found to be determined mainly by temperature and was well quantified using a linear term of temperature alone.

Applications

The phenology/climate models have been initially used to examine the potential adaptation of those 12 selected cover crop legumes to two target locations—Zapata Rancho and La Tamborada in Bolivia. Zapata Rancho is located at 17°25'S, 66°06'W with an altitude of 3220m above sea level, and La Tamborada at 17°25'S, 66°08'W with an altitude of 2600m above sea level. Some of the useful long-term climatic statistics at each site are as follows:

	Zapata Rancho	La Tamborada
Annual rainfall(mm)	608.9	491.5
Annual mean temperature(°C)	12.3	17.0
Mean start of rainy season	17 November	22 November
Mean end of rainy season	12 April	3 April

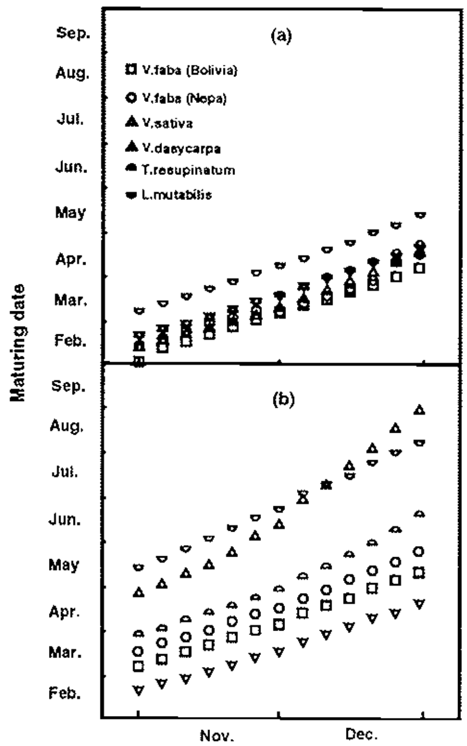

Figure 1

We have simulated the long-time average dates of first pod maturity at 5 days interval between 1 November and 31 December for all the selected cover crop legumes using the daily records of maximum and minimum temperatures between 1976 and 1996 and the daily photoperiod with a solar angle of -6°. We found that all the tropical legumes would mature too late at both locations and not be able to produce any seeds under rain-fed conditions. However, the temperate legumes will be suitable for sowings at the start of the rainy season at both La Tamborada (Figure 1 (a)) and Zapata Rancho (Figure 1 (b)). Preferably,

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Reference

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Integrated Nutrient Management to Sustain Crop Production in the Mid-Hills of Nepal

Pilbeam CJ & Gregory PJ. Department of Soil Science,
The University of Reading, Reading, UK.
Tripathi BP & Acharya GP. Lumle Agricultural Research Centre, Pokhara, Nepal.
Sherchan DP & Gurung GB. Pakhribas Agricultural Centre, Dhankuta, Nepal.
Gaunt J. Rothamsted Experimental Station, Harpenden, UK.

INTRODUCTION

The reduced availability of manures and composts together with the intensification of cropping in the mid-hills of Nepal has contributed to local declines in soil fertility. To compensate for this, the use of fertilizers has been promoted especially in areas of easy accessibility. However, there has been little research attempting to integrate the use of fertilizers with the traditional use of composts and manures to maintain soil fertility.

Figure 1. Women carrying sacks of manure.

AIM

A collaborative project between the Department of Soil Science, The University of Reading, Rothamsted Experimental Station and two agricultural research stations, Lumle and Pakhribas, in Nepal has been funded by the Hillsides Production System of the Department for International Development, UK (Grant Number R6757). The aim of this strategic research project is to provide recommendations for the integrated use of manures and fertilizer to maintain soil fertility in key crop production systems in the mid-hills of Nepal, while minimizing adverse environmental impact. These recommendations will be based on an understanding of nutrient flows (especially N) within a particular crop-soil system. This understanding will be obtained from three sources.

SOURCE 1

^{15}N-labelled urea and manure will be applied to long-term field experiments in Nepal involving the following cropping systems on the different land types:

- maize-millet and potato-maize rotations on bari land at Pakhribas, Dordor and Sindhuwa;
- rice-wheat rotations on khet land at Pakuwa, Chambas and Kholitar, and
- upland rice-blackgram rotations on tar land at Dordor.

Measurements of the nutrient content of the crop and soil samples taken throughout the season, over a number of years will provide data for the development of nutrient budgets for these cropping systems. These results will be compared with the limited data currently available on nutrient fluxes through parts of the crop-soil system.

SOURCE 2

The rates of key processes (*e.g.* mineralization of N from manure), and the impact of environmental variables, such as temperature and soil moisture content, on these rates will be measured in the laboratory at The University of Reading.

Figure 3. Piles of manure on a bari terrace prior to incorporation

SOURCE 3

Data from the above sources will be incorporated into both simple spread-sheet models, and more complex models of N and Soil Organic Matter dynamics (*e.g.* SUNDIAL). These will then be used to examine the possible options for integrated nutrient management practices in the mid-hills of Nepal. The benefits of workable options arising from this analysis will be demonstrated to farmers, extension officers and scientists through field days and workshops.

Dry Season Vegetable Production in the Forest/Agriculture Interface, Ghana.

A wide range of smallscale farmers in the Brong Ahafo Region of Ghana, including both men and women, and those renting land, others with access to tribal, or family land, rely on vegetable production as an important source of income. Vegetables are grown in both the dry and wet seasons. During the dry season effects of soil mining are particularly severe, however this is also the season when best returns can be achieved.

The main problem for rural families with no access to alternative employment is how to raise enough income from farming on which to live and to afford to educate their children.

Vegetable production has been successful as a major source of cash income over the last 6-12 years, however the chemical inputs used are expensive and returns to these inputs are reducing each year. Yields and crop quality are decreasing as the soil's nutrient and organic matter reserves are mined, and resistance to the incidence of pests and diseases decreases.

Some farmers have heard of the use of organic wastes and animal manures to improve soil nutrient status, water-holding capacity and general health of the soil, however little recycling is practised. Land is cleared at the start of the season by burning and animal manure is not commonly collected. Farmers in the area report that this is due to being unsure as to how to process organic wastes and in what quantities to apply them. In the absence of alternative advice, they have adapted commercial and Government guidelines on the use of chemical inputs. Many now face the reality that the sole use of chemical inputs, over the medium and longer term, does not replenish the soils productive capacity. Decreasing yields and quality leading to reduced returns to inputs has led farmers to look for improved and cost effective methods of soil productivity maintenance.

Under the Soil and Water Management component of the Integrated Food Crop Systems project, the Natural Resources Institute is working closely with the Ministry of Agriculture and Food. In a series of on-station and on-farm trails different amounts and mixtures of animal manures, different green manures (indigenous and exotic) and different compost mixtures are being tested for their effect on subsequent vegetable growth. Co-operating institutions and farmers are involved in the design, assessment and testing of on-station technologies and in the adaptation and assessment of promising technologies on-farm. Within the first 6 months of the project 9 farmers have started experimentation with the use of organic soil ameliorants in on-farm trials

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Funding for this component of the Integrated Food Crop Systems Project is from the Forest/Agriculture Interface System of the Department for International Development's Natural Resource Systems Programme.
For further information contact Liz Kiff or David Jackson, Natural Resources Institute, Central Avenue, Chatham Maritime, Chatham, Kent, ME4 4TB.

Sustainable Agriculture in Forest Margins

Barry Pound, Farming Systems Agronomist
Natural Resources Institute (NRI), Chatham Maritime

Poster Abstract

Background
The project "Sustainable Agriculture in Forest Margins" (and its twin "Weed Management for Sustainable Agriculture in Forest Margins") are on-going DFID research projects managed by NRI in collaboration with the Centro de Investigacion Agricola Tropical (CIAT) in Bolivia. The project is located in the tropical lowlands of eastern Bolivia that have been subjected to intensive immigration, with consequent expansion of cropping and livestock production in previously forested areas. Present farming systems, based on slash and burn methods, are mining fertility held in the soil and in vegetation. Farmers have relatively abundant land (30-50 ha.) but other resources (labour, cash) are scarce, leading to extensive farming methods that use natural resources as a source of short-term capital.

The project purpose is to develop and promote improved strategies for integrated crop, livestock and agroforestry systems. This it hopes to achieve through the identification of improved annual and perennial cropping systems, combined with cover crops and agroforestry species for maintaining or enhancing soil fertility, controlling weeds, diversifying farm income and improving bush fallow productivity.

The chart below represents the way the project has developed to date.

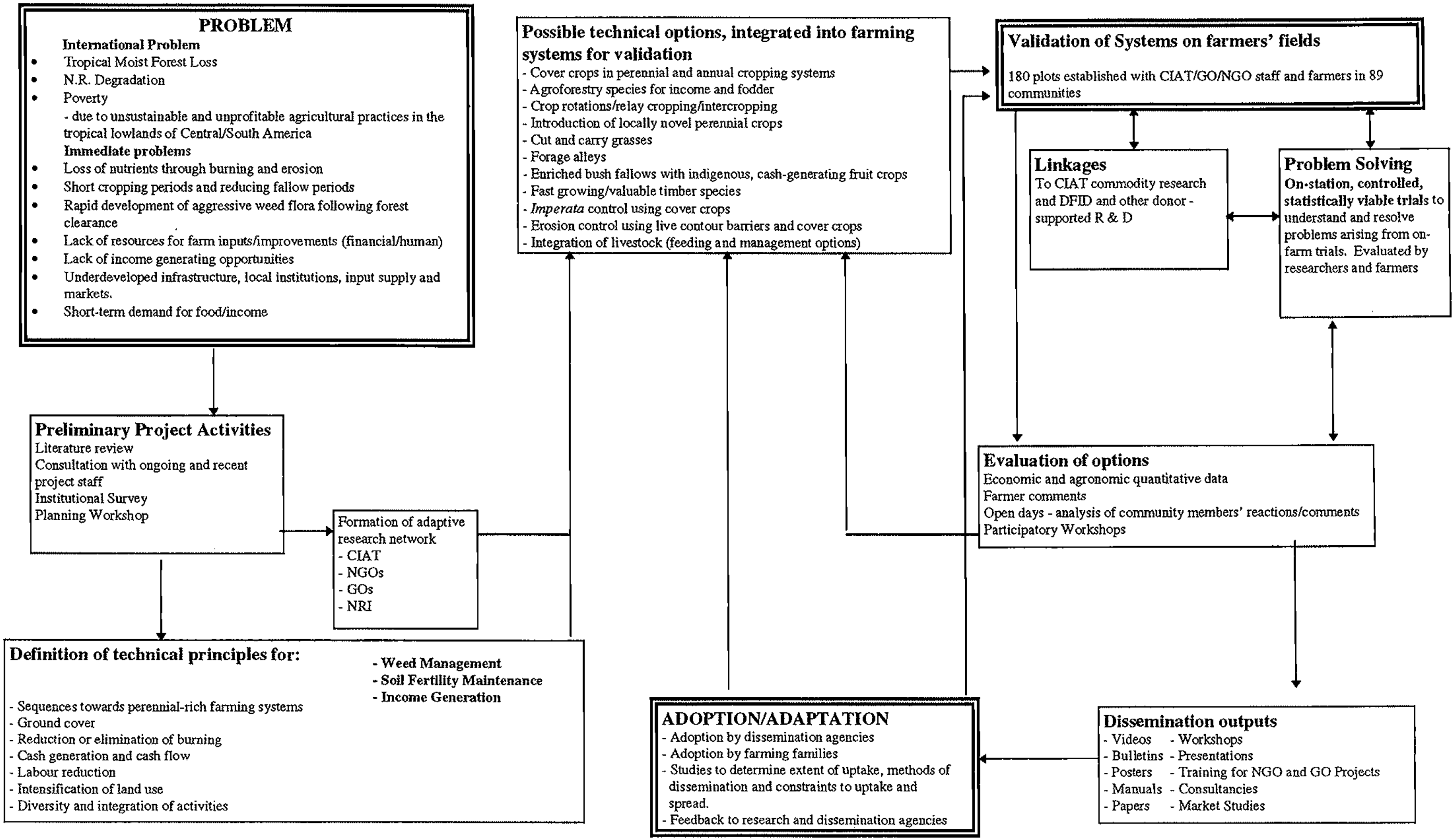
Promising interim outputs are:

Good weed control (and labour reduction) by a range of cover crops e.g.: *Mucuna* spp, *Canavalia ensiformis*, *Calopogonium mucunoides*, *Cajanus cajan*, *Crotalaria* spp.
The introduction of locally novel perennials and semi-perennials (citrus, pineapple, peach palm and others).
Potential use of cover crops (*Mucuna* spp, *Puerarias phaseoloides*) for pasture regeneration.
Use of cut and carry grasses for small-scale dairies.
The potential of relayed or rotations of cover crops with rice to extend the cropping season between fallows.
The enrichment of bush fallows with indigenous fruit and timber species.
The effective use of participatory research methods.

The project has started to produce dissemination materials for use by NGOs, GOs and donor-funded community development and extension programmes in the area to encourage rapid and widespread adoption.

BOLIVIA - FOREST/AGRICULTURE INTERFACE

SUSTAINABLE AGRICULTURE IN FOREST MARGINS[1]/WEED MANAGEMENT FOR SUSTAINABLE AGRICULTURE IN FOREST MARGINS[2]



[1] DFID RNRRS NRSP project managed by NRI (B.Pound) in collaboration with CIAT (Bolivia)

[2] DFID RNRRS CPP project managed by NRI (M. Webb) in collaboration with CIAT (Bolivia)

Ecological and economic impacts of soil management on smallholder farms

K D Shepherd and M J Soule
International Centre for Research in Agroforestry (ICRAF), Nairobi

Poster Abstract

Our goal is to improve farmer welfare and environmental resilience through improved land management with agroforestry. We analysed the ecological and economic viability of existing land management practices on smallholder farms in western Kenya to identify priorities for research and development interventions. Using a systems analysis approach, we constructed an economic-ecological simulation model of the farm system, compiled data on farm characteristics, and simulated over a 20-year time frame: nutrient cycling and availability, plant and livestock production and farm income.

The model was used to assess the sustainability of the existing systems for three farm types. Farmers in low resource endowment farms typically have small land holdings of 0.2 ha, no livestock and low household income of about $500 yr-1. Medium resource endowment farms have 0.8 ha farms with one local cow and a household income of about $1,000 yr-1. Farmers in the high resource endowment category have larger land holdings of 1.6 ha, grade cows (2) and an income of about $3,000 yr-1.

Low and medium resource endowment farms, which comprise about 90% of the farms in the area, have low productivity (< 1 t ha-1 yr-1 maize grain and <250 kg milk farm-1 yr-1) and low profitability (farm return of $<70 yr-1). High resource endowment farms have moderate levels of productivity (3 t ha-1 yr-1 maize grain and 4500 kg milk farm-1 yr-1) and profitability (farm return of $550 yr-1).

The level of household self-sufficiency in maize grain production is very low in low to medium resource endowment categories (10 and 40% respectively), whereas farms with high resource endowment farms are self-sufficient in maize and produce a surplus of milk for sale.

Low and medium resource endowment farms have negative soil nutrient budgets, declining organic matter contents, moderate levels of soil erosion and N leaching, and low levels of nutrient recycling. In contrast, high resource endowment farms have positive nutrient balances, increasing soil organic matter levels, low levels of erosion and N leaching, and high levels of nutrient recycling.

Interventions to decrease poverty must be directed towards farmers in low and medium resource endowment categories. Farm size in these categories (<1 ha) is too small to support commercial (production of a surplus over subsistence needs) staple food production or commercial livestock production systems. Also, these farmers lack the capital resources to adopt sustainable management practices. Therefore, research and development priorities should be shifted towards production systems based on high value products, such as tree fruits. There is also need to increase off-farm income - processing of high value products could help to create off-farm employment. Increased subsistence food production must rely on practices that have low cash and labour inputs, such as improved tree fallows.

Economic and environmental assessment of soil erosion and conservation

M. Stocking and R. Clark
Overseas Development Group, University of East Anglia

Funded by the Department for International Development (formerly ODA) Natural Resources Systems Programme (Hillsides)
Collaborators: Environment & Forest Conservation Division of the Mahaweli Authority of Sri Lanka, Polgolla, Kandy, Sri Lanka.

Project summary

Smallholder hillside agricultural production systems offer some of the greatest potential for increasing agricultural production and developing sustainable land use in many developing countries. However, they are often located in areas that are extremely vulnerable to soil erosion and land degradation. Efforts by donors and governments to address these environmental concerns have achieved only limited success. Better results should be achieved by projects and programmes that incorporate the perspectives of farmers into their design.

The economic appraisal of soil conservation technologies often fails to reflect the situation actually faced by farmers. Furthermore, several different approaches can be used to value the on-site impacts of erosion and conservation (such as replacement cost, loss in productivity), each of which produce different results. This project critically assesses the different approaches to valuation and different methods for the economic analysis of erosion and conservation, based on a case study in Sri Lanka.

The case study examines soil erosion and conservation for smallholder farmers cultivating vegetable crops on steeply sloping hill land in the village of Malulla, Nuwara Eliya District, Sri Lanka. Several schemes promoting soil conservation have operated in the area and a number of different conservation technologies are employed which vary in standards of construction and maintenance. Technologies adopted by the farmers include: trash lines, graded drains, lock and spill drains, stone-faced terraces, strips of *Vetiver* grass and *Gliricidia* hedges.

The approaches to economic valuation examined by the study require biophysical data on the impacts of erosion and conservation. Field data, together with data from secondary sources and physical models, are used to make immediate estimates of erosion rates and their impacts on soil productivity. Simple field measurement techniques are identified and developed, such as estimation of the soil removed from a field based on the depth of residual gravel (or armour layer). Participatory rural appraisal methods are used to collect data from farmers and to identify opportunities and constraints within households that act to increase erosion or to promote soil conservation.

The project aims to increase understanding of the different approaches that can be used to value erosion and conservation. Through the case study it demonstrates how the choice of valuation approach can alter the economic viability of a conservation technology. The findings of the study are used to develop a methodology for economic appraisal of conservation technologies that is more representative of the conditions faced by smallholder farmers.

Appendix 2

Participants at Workshop

PARTICIPANTS

Dr I P Abrol	ICRISAT, Rice Wheat Consortium Co-ordinator, Facilitation Unit, IARI Campus, Pusa, New Delhi 110012, India Tel: 00 91 11 581 9291 Fax: 00 91 11 581 9287 E-Mail: abrol@nda.vsnl.nic.in
Mr Martin Adam	NRI, Central Avenue, Chatham Maritime, Chatham, Kent, UK. ME4 4TB Tel: 01634 880088 Fax: 01634 880066, 880077 E-Mail: martin.adam@nri.org
Prof Brian Alloway	The University of Reading, Department of Soil Science, PO Box 233, Whiteknights Reading Berkshire, UK. RG6 6DW Tel: 0118 931 8911 Fax: 0118 931 6666 E-Mail: B.J.Alloway@reading.ac.uk
Prof J Anderson	The University of Exeter, Prince of Wales Road, Exeter, UK EX4 4PS Tel: 01392 263263 Fax: 01363 866350 E-Mail: j.m.anderson@exeter.ac.uk
Dr John Barrett	DFID, 94 Victoria Street, London, UK. SW1E 5JL Tel: 0171 917 0681 Fax: 0171 917 0249 E-Mail: jc-barrett@dfid.gtnet.gov.uk
Dr Stephen Briggs	Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire, UK. MK45 4HS Tel: 01525 860000 Fax: 01525 862 140 E-Mail: brian.sims@bbsrc.ac.uk
Dr Robert Brook	University of Wales, Bangor, College Road, Bangor, Gwynedd, Wales, UK. LL57 2UW Tel: 01248 351151 Fax: 01248 354997 E-Mail: r.m.brook@bangor.ac.uk

Ms Linda Brown
DFID, Room V304,
94 Victoria Street,
London SW1E 5JL
Tel: 0171 917 0681
Fax: 0171 917 0249

Ms Rebecca Clark
University of East Anglia, Norwich,
UK. NR4 7TJ
Tel: 01603 456161
Fax: 01603 451 999
E-Mail: r.clark@uea.ac.uk

Dr John Coulter
Lower Cowden Farm, Mayfield, East Sussex,
UK. TN20 6HL
Tel: 01435 873143
Fax: 01435 873143

Dr Eric Craswell
IBSRAM, PO Box 90109, Jutujak, Bangkok,
10900, Thailand
Tel: +66 2 941 2500
Fax: +66 2 561 1230
E-Mail: e.craswell@cgnet.com

Dr Jim Ellis-Jones
Silsoe Research Institute, Wrest Park, Silsoe, Bedford,
Bedfordshire, UK. MK45 4HS
Tel: 01525 860000
Fax: 01525 862140
E-Mail: jcm.ellis-jones@bbsrc.ac.uk

Dr Rita Gardner
Royal Geographical Society, 1 Kensington Gore,
London, UK. SW7 2AR
Tel: 0171 591 3000
Fax: 0171 591 3011
E-Mail: R.Gardner@rgs.org

Prof Chris Garforth
Department of Agricultural Extension and Rural Development,
(AERD), The University of Reading, Earley Gate, Reading,
UK. RG6 2AU
Tel: 0118 931 8134
Fax: 0118 926 1244
E-Mail: C.J.Garforth@reading.ac.uk

Dr John Gaunt
IACR Rothamsted, West Common, Harpenden,
Hertfordshire, UK. AL5 2JQ
Tel: 01582 763133
Fax: 01582 760981
E-Mail: john.gaunt@bbsrc.ac.uk

Prof Ken Giller	Wye College, Ashford, Kent UK. TN25 5AH Tel: 01233 812401 Fax: 01233 813140 E-Mail: K.giller@wye.ac.uk
Mr John R Goldsack	NRSP PAC Chairman, Bradford Peverell Farmhouse, Bradford Peverell, Dorset, UK. DT2 9SF Tel: 01305 266543 Fax: 01305 266543
Prof Dennis Greenland	The University of Reading, Department of Soil Science, Whiteknights, PO Box 233, Reading, Berkshire, UK. RG6 6DW Tel: 0118 931 6557 Fax: 0118 931 6660 E-Mail: dgreenland@mcmail.com
Prof Peter Gregory	The University of Reading, Department of Soil Science, Whiteknights, PO Box 233, Reading, Berkshire, UK. RG6 6DW Tel: 0118 931 6442 Fax: 0118 931 6666 E-Mail: P.J.Gregory@reading.ac.uk
Dr Patrick Hamilton	The University of Aberdeen, Department of Geography, Regent Walk, Aberdeen, UK. AB24 3FX Tel: 01224 745107 Fax: 01224 272331
Dr Paul Harding	Lumle Agricultural Research Centre, PO Box 1, Pokhara, Kaski, Nepal Tel: 00 977 61 20 385 Fax: 00 977 61 21 587 E-Mail: p.harding@dfid.gtnet.gov.uk
Dr David Harris	University of Wales, Bangor College Road, Bangor, Gwynned, Wales, UK. LL57 2UW Tel: 01248 351151 Fax: 01248 371533 E-Mail: D.Harris@Bangor.ac.uk
Prof Phil Harris	Henry Doubleday Research Association, Ryton-on-Dunsmore, Near Coventry, West Midlands, UK. CV8 3LG Tel: 01203 303517 Fax: 01203 659229 E-Mail: pharris@hdra.org.uk

Dr Thea Hilhorst
International Institute for Environment and Development (IIED),
4 Hanover Street, Edinburgh, UK. EH2 2EN
Tel: 0131 624 7041
Fax: 0131 624 7050
E-Mail: CTIIED@AOL.COM

Dr Peter Hobbs
CIMMYT, PO Box 5186, Kathmandu, Nepal
Tel: +977 1 417 791
Fax: +977 1 419 352.
E-Mail: Phobbs@cimmyt.mos.com.np

Mr David Jackson
NRI, Chatham Maritime, Chatham,
Kent, UK. ME4 4TB
Tel: 01634 880088
Fax: 01634 880066, 880077
E-Mail: david.jackson@nri.org

Mr Steve Jones
Steve Jones Associates, Rosemary and Lavender Cottage,
Caxton Road, Bourne, Cambridgeshire, UK. CB3 7SX
Tel: 01954 718 026
Fax: 01954 718 027
E-Mail: rural@compuserve.com

Ms Elizabeth Kiff
NRI, Chatham Maritime, Chatham, Kent,
U.K. ME4 4TB
Tel: 01634 880088
Fax: 01634 880066, 880077
E-Mail: elizabeth.kiff@nri.org

Ms Anna Lawrence
The University of Reading, Department of Agriculture,
Earley Gate, Reading, U.K. RG6 2AU
Tel: 0118 931 6514
Fax: 0118 926 1244
E-Mail: a.lawrence@reading.ac.uk

Dr Melissa Leach
Institute of Development Studies
University of Sussex, Falmer,
Brighton, U.K. BN1 9RE
Tel: 01273 606261
Fax: 01273 621202
E-Mail: M.Leach@sussex.ac.uk

Mr Chris Lewcock
NRInternational Limited, Central Avenue, Chatham Maritime,
Chatham, Kent, U.K. ME4 4TB
Tel: 01634 880088
Fax: 01634 883937
E-Mail: chris.lewcock@nri.org

Ms Susan Milner	DFID, 94 Victoria Street. London, U.K. SW1E 5JL Tel: 0171 917 0681 Fax: 0171 917 0679 E-Mail: susan.milner@nri.org
Dr Mike Mortimore	The University of Cambridge, Department of Geography, Downing Place, Cambridge, UK. CB2 3EN Tel: 01935 850 812 Fax: 01935 850 812 E-Mail: mikemortimore@compuserve.com
Dr Stephen Nortcliff	The University of Reading, Department of Soil Science Whiteknights, PO Box 233, Reading, UK. RG6 6DW Tel: 0118 931 6559 Fax: 0118 931 6660 E-Mail. S.Nortcliff@reading.ac.uk
Dr Fred Palmer	The University of Reading, Department of Soil Science, Whiteknights, PO Box 233, Reading, U.K. RG6 6DW Tel: 0118 931 6557 Fax: 0118 931 6660
Dr Colin Pilbeam	The University of Reading, Department of Soil Science, Whiteknights, PO Box 233, Reading, U.K. RG6 6DW Tel: 0118 931 6657 Fax: 0118 931 6660 E-Mail: C.J.Pilbeam@reading.ac.uk
Mr Barry Pound	NRI, Chatham Maritime, Chatham, Kent, U.K. ME4 4TB Tel: 01634 880088 Fax: 01634 880066, 880077 E-Mail: barry.pound@nri.org
Prof David Powlson	IACR Rothamsted, West Common, Harpenden, Herts, U.K. AL5 2JQ Tel: 01582 763133 Fax: 01582 763133 E-Mail: David.Powlson@BBSRC.ac.uk
Dr Aiming Qi	The University of Reading, Department of Agriculture, PO Box 243, Earley Gate, Reading, UK. RG6 2AU Tel: 0118 988 3000 Fax: 0118 935 2421
Dr Charles Quansah	Department of Crop Science, University of Science and Technology, Kumasi, Ghana Tel: +233 51 60332 Fax: +233 51 60137 E-Mail: ustlib@ust.gn.apc.org

Dr Joe Rother	NRI, Chatham Maritime, Chatham, Kent, U.K. ME4 4TB Tel: 01634 883200 Fax: 01634 880066, 880077 E-Mail: joe.rother@nri.org
Dr Ian Scoones	University of Sussex, Institute of Development Studies, Brighton, UK. BN1 9RE Tel: 01273 606261, 678274 Fax: 01273 621202, 691647 E-Mail: i.scoones@sussex.ac.uk
Ms Louise Shaxson	DFID, 94 Victoria Street, London, U.K. SW1E 5JL Tel: 0171 917 0217 Fax: 0171 917 0249 E-Mail:101527.462@compuserve.com, lshaxon@dfid.gtnet.gov.uk
Dr G B Singh	Deputy Director General (SA and AF), Indian Council of Agricultural Research, Krishi Bhavan, Dr Rajendra Prasad Road, New Delhi 110001, India Tel: +91 11 338 2306 Fax: +91 11 338 7293 E-Mail: gbsingh@icar.delhi.nic.in
Dr M V Singh	Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal 462038 India Tel: 00 91 755 553 546, 553 770, 553 787 Fax: 00 91 755 530 946 E-Mail: llss@400.nicgw.nic.in
Dr Eric Smaling	AB-DLO, PO Box 14, 6700 AA Wageningen, The Netherlands Tel: +31 317 475 762 Fax: +31 317 423110 E-Mail: e.m.a.smaling@ab.dlo.nl
Dr William Stephens	Cranfield University, Cranfield, Bedfordshire, UK. MK43 0AL Tel: 01234 750111 Fax: 01234 863300 E-Mail: w.stephens@cranfield.ac.uk
Prof Mike Swift	TSBFUN Complex, Gigiri (Block B), PO Box 30592, Nairobi Tel +254 2 622584/659 Fax: +254 2 622733/521159 E-Mail: TSBFINFO@TSBF.unon.org

Prof Keith Syers	University of Newcastle, Newcastle upon Tyne, UK NE1 7RU Tel: 0191 222 5677 Fax: 0191 222 5677 E-Mail: j.k.syers@ncl.ac.uk
Dr Richard Thomas	CIAT, Cali, Colombia Tel: +57 2 445 0000 Fax: +57 2 445 0073 E-Mail: r.thomas@cgnet.com
Ms Kate Turton	ODI, Portland House, Stag Place, London SW1E 4DP Tel: 0171 393 1600 Fax: 0171 393 1699 E-Mail: agren@odi.org.uk
Dr Stephen Walker	NRInternational Limited, Chatham Maritime, Chatham, Kent ME4 4TB Tel: 01634 883168 Fax: 01634 883937 E-Mail: stephen.walker@nri.org
Dr Elizabeth Warham	DFID, SYMO Office, V226 94 Victoria Street, London SW1E 5JL Tel: 0171 917 0681 Fax: 0171 917 0249 E-Mail: E-Warham@dfid.gtnet.gov.uk
Dr Geoff Warren	The University of Reading, Department of Soil Science, PO Box 233, Whiteknights, Reading , UK RG6 6DW Tel: 0118 931 6557 Fax: 0118 931 6660 E-Mail: G.P.Warren@reading.ac.uk
Dr Martin Wood	The University of Reading, Department of Soil Science, PO Box 233, Whiteknights, Reading, UK RG6 6DW Tel: 0118 931 6557 Fax: 0118 931 6660 E-Mail: M.Wood@reading.ac.uk