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The management of organic matter in tropical soils: what are the priorities?

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Introduction

Soil degradation is one of the most serious environmental problems. Soils represent a resource that is essential to life on this planet (Hillel, 2001). They are the interface between rocks, biota, water and the atmosphere and are therefore a pivotal element of ecosystems. Dryland soils are particularly vulnerable (Katyal and Vlek, 2000) — a problem recognized by the establishment of the Convention to Combat Desertification (www.unccd.org) in 1994. Seventy to 80% of the world's drylands are affected by desertification. The degradation of soils is typically a 'creeping environmental problem' (CEP); i.e., a cumulative environmental change that evolves at an imperceptibly slow pace, which hinders the initiation of counterbalancing measures (Glantz, 1998). Soil losses have been increasing with the growth of the human population. It is particularly troubling that soils today are destroyed at a much faster rate than they can be formed by natural processes.

Soil organic matter (SOM) or humus, and its association with soil minerals is essential to soil function: it forms during the biological decomposition of organic detritus of plants, animals and microbes; keeps plant nutrients and water in the upper soil where roots can access them; and provides tilth — making the soil easier to work. Also, SOM-rich soils generally retain more water than SOM-poor soils. Soils come to life through SOM: highly diverse communities of microorganisms and soil animals (e.g., earthworms, termites, mites, millipedes and others) provide important 'ecosystem services', in particular the recycling of carbon and plant nutrients.

SOM, however, is rapidly lost when organic matter inputs are reduced upon cultivation (Jenkinson and Ayanaba, 1977); losses can be as high as 70% in fragile environments (Jenny and Raychaudhuri, 1960; The Dang and Klinnert, this issue). The loss of SOM and a 'healthy' soil biological activity reduces soil fertility, degrades soil structure and water holding capacity, and utlimately leads to desertification. SOM holds the key to sustainable soil management and, therefore, the prevention or reversal of soil degradation. The estimated total loss of carbon through soil degradation since the advent of agriculture about 10 000 years ago (of 243 Gt; Rozanov et al., 1990) represents 16–20% of the present-day global soil carbon stocks (of 1200–1500 Gt; Haider, 1999).

A limited view of soils as a dead substrate holding nutrients for agricultural production has dominated during the world-wide expansion of intensive agriculture with its heavy reliance on industrial fertilizers. This has placed added demands on the soils to provide the nutrient balance. Conventional land preparation methods (reviewed by Machado et al., this issue) have had a negative impact on soil organisms and the soil structure built and maintained by them. Thus, intensive agriculture has amplified and accelerated the age-old problem of soil degradation (Hillel, 1991). Soil degradation is reflected in declining agricultural productivity and utility (Katyal and Vlek, 2000). Ever growing inputs required to maintain agricultural production are the price for the disregard for the functions of soil organic matter in modern agriculture.

The proper management of soil organic matter is important to food security and the protection of marginal lands (Scherr, 1999). To define the steps needed to understand and manage organic matter in tropical soils is a major challenge for soil science. SOM management practices in temperate and tropical climate zones differ. Much scientific attention has been focused on temperate zones (most recently in Cadisch and Giller, 1995; Carter and Stewart, 1996; Drozd, 1997; Swarup et al., 1998; Davies and Ghabbour, 1998; Lal, 2001) rather than on the tropics, although degradation is most severe in tropical regions (cf., however, IBSRAM, 1990; Elliott et al., 1997; Rees et al., 2001). Existing knowledge about the management of organic matter in the tropics has found astonishingly little practical application — what went wrong?

ZEF organized a workshop (7–10 June 1999) to provide insight into the management of SOM in tropical soils. The participants had been asked to answer why, when and how SOM should be managed in tropical areas, and to review the needs for further research, but also for policy changes. The results represent the state-of-the art of our knowledge on SOM management in the tropics.

Heading the introductory session, Craswell and Lefroy outline roles and functions of organic matter in tropical soils, and Feller dicusses the ecological and agricultural determinants of carbon sequestration in tropical soils. Van Keulen debates the problems and advances of modelling tropical SOM.

Powlson then clarifies the role of soil microorganisms in soil organic matter conservation in the tropics, and Lavelle et al. provide a compelling answer to the question: 'Why feeding the soil macrofauna?' Following this, Palm et al. translate 'theory into practice', almost a foreword to the subsequent papers that are dedicated to management options and regional aspects. Several regional case studies are presented: a review by Katyal et al. of SOM management in India starts the session; the possibilities for SOM management with particular reference to erosion control on hillsides of northern Vietnam are reviewed by The Dang and Klinnert; Tiessen et al. discuss the role of subsistence agriculture in the Brazilian Northeast, and no-till systems in Brazil are reviewed by Machado and Silva. Ganry et al., Bationo and Buerkert, Nandwa, and Roose and Barthes review different aspects of SOM management in cropping systems of Africa. Two papers (Silveira et al., 2001; and Tiessen et al., 2001) exemplify the problems encountered with SOM management and its measurement on the farm, both in Africa and Brazil.

The following analysis of the carbon budget and its management on a watershed level, a case study from Colombia presented by Binder and Patzel, assesses the – surprisingly low – contribution of organic returns from urban areas to OM conservation in the countryside.

The last section starts with a contribution by Ayuk on social, economic and policy dimensions of tropical SOM management. Hossain gives an insight into the activities of an NGO promoting OM management in Bangladesh, and the final chapter is a study of Quansah et al. of the farmers' views and perceptions of OM in Ghana.

At the end, Hillel (2001) discusses historical aspects of soil degradation related to the decline of ancient and modern cultures, and explains why soil management and preservation are so important.

The workshop closed with a plenary discussion in which the participants discussed three central questions:

1. What are the issues of highest priority?
2. How can SOM research and management best be linked to practical application?
3. What are the best entry points to develop a higher public awareness for the need of SOM management and research in the tropics?

The answers were obtained in a moderated process that catalyzed discussions and provided opportunities for all participants to express their views in a differentiated manner (Klebert et al., 1995).

Conclusions

The results of the final workshop discussion about the three questions above are summarized in the following.

What are the key priorities in SOM management and research?

The development of and agreement upon indicators and thresholds for SOM quantity, quality and its degradation are urgently needed. These indicators should be reliable, easy-to-use and uniform (at least within specific purposes or environments). They should ideally be able to provide early warning signals to identify stressed soils. Indicators should allow to assess nutrient- as well as non-nutrient effects. Once established, the indicators should be used as a basis for SOM inventories in critically affected regions or countries (in the time since the workshop, a useful contribution to this topic has been presented by Stocking and Murnaghan (2000)).

Many participants stressed the need for databases and information centers and for the development of strategies and concepts for transferring scientific knowledge to practice. A synthesis of existing data and models is needed, and common databases, decision support systems, and models must be developed to be able to establish, for example, C flows and their management at regional levels (an elegant example of regional C flux budgeting is given in Binder and Patzel, this issue). Local scientific knowledge should be included in these data bases. The Organic Resource Database set up by Wye College/TSBF (Palm et al., this issue; ORD, 2001) could be adopted as a standard. Palm and her co-authors demonstrate convincingly how decision support systems can be made available to both farmers and scientists, and van Keulen (this issue) outlines the prospects and problems of modelling of SOM.

A greater stakeholder involvement is urgently needed. Stakeholders are farmers, decision makers, and every citizen concerned with land use or ecological sustainability. Only participatory research will guarantee that the client's true needs will be considered; e.g., that research on OM is based on farmer demand, that tools (indicators, management options) are usable by the stake holder (cf. World Neighbors, 2000), or that a policy environment sensitive to the need for investments in SOM is created. Eventually, a protocol to guarantee stakeholder involvement could be developed, to be used by scientists as a guideline (cf. the recent paper by Stocking and Murnaghan, 2000).

The monitoring of SOM quantity and quality (ideally including some measures of stability, turnover and carbon sequestration) must be intensified, and this requires the development of suitable indicators.

The often conflicting goals of agricultural production, such as SOM preservation versus the short-term maximization of agricultural production, must be harmonized, or non-competitive forms of OM management should be fostered. Site-specific nutrient management is to be enhanced as a strategy to increase OM production. Additional carbon sources must be incorporated into the farming systems locally, because due to high transport costs OM can not be dislocated over long distances.

An explicit economic valuation of SOM (including non-nutrient values, e.g., ecological sustainability or reduction of poverty) must be established through integrated agrotechnical and economic analyses in order to evaluate trade-offs between different land use systems and competing issues of agricultural production and SOM preservation.

How can SOM research best be linked to practical application?

There is little doubt that the practical use of SOM research will be facilitated in a client-driven process. One suggestion is to let stake holders, not donor agencies, contract the researchers so that they become owners of the scientific results. Alternatively a protocol might be established to ensure stakeholder involvement in the research projects, e.g., by holding meetings to establish roles in the process, or to facilitate perception and assimilation of management alternatives through farmer-participatory and on-farm research. Regional programs should involve researchers and stake-holders from the start, ideally in the form of partnerships and alliances between researchers, farmers, international, government and non-government organizations, communities, the private sector and donor agencies. Scientists should be involved in extension work, e.g., by the generation of information and teaching materials for the public, farmers and politicians.

A network for the management of tropical SOM should be developed by linking to or widening the existing national and international networks and programs (such as IBSRAM, TSBF, GCTE-SOMNET, WWI) and by linking to national agricultural research services. Bringing different disciplines together in working groups, connecting global coordination with local task forces, and linking developed and developing countries can help address specific problems. Such networks can be organized into regional nodes and include research sites dedicated to particular eco-regions. Networks could be dedicated to specific tasks, e.g., participatory organic matter conservation and preservation; the development of indicators; SOM monitoring, the development of methods and tools and the coordination of data bases and models. A network would facilitate workshops and training programs. Existing institutions that are well-established in SOM research should take the lead.

What 'entry points' are able to promote SOM preservation?

Global aspects such as carbon sequestration of soils in the context of climate change may appeal to policy makers particularly in the developed world, but in degradation-affected regions, the clear demonstration of how SOM management and preservation may impact poverty and improve livelihoods of the rural population would represent a strong entry point. A systematic representation of data across climatic gradients (a SOM inventory of critically affected regions or countries, based on existing long-term experiments) should outline regional constraints to SOM management and allow for the definition of regional land use alternatives (e.g., specific techniques to reduce erosion). Benchmark research sites could be established to meet this goal. Process models can be used to synthesize data and to show temporal changes that go unnoticed because their time scale is too long for the human observer.

High visibility indicators of stress should be developed. However, reliable, easy-to-use indicators of SOM change and, perhaps more importantly, indicators accessible to farmers, are largely missing (Quansah et al., this issue, suggest some potentially good indicators for farmers). These indicators must be landscape- or soil-type specific. Thresholds must be identified, and monitoring criteria be set.

Farmer involvement is key because farmers represent a direct interface of human intervention on soils. However, farmers' needs must be pinned against environmental and societal goals. Human capacity for local research must be strengthened and local constraints be assessed. Location-specific, farmer demand-based experiments could be helpful on demonstration sites. Farmers are subject to decisions of policy makers, and therefore, can not be treated in isolation. Management options for OM maintenance or sequestration with low competition with other objectives (e.g., production) should be outlined. Within-farm transfers, budgets and gradients need be elaborated. The multiple benefits of SOM such as the ecological services SOM and soil biota provide, or the often not obvious links to poverty reduction and development must be explained to farmers.

The human, social, and economic costs of neglecting soil conservation are difficult to calculate but are undoubtedly high. SOM is not only a major determinant of rural livelihoods, but its conservation is related to three main areas at the interface between nature and human activities. These are: agricultural productivity, the maintenance of ecological services including biodiversity, and carbon sequestration. Productivity-related issues include nutrient- and non-nutrient effects of SOM. SOM storage and release and the intricate web of short- and long-term processes related to immobilization and mineralization of nutrients are primary determinants of soil fertility.

Outlook

Desertification processes ongoing world-wide, with their components erosion, loss of organic matter, salinization, compaction and anthropogenic pollution, have resulted in far-reaching changes in landscape function. Addressing soil conservation directly is a difficult task. Soil degradation can be slowed and reversed only if sustainable cropping systems are introduced based on the conservation or enhancement of soil organic matter. Such systems could take advantage of diversification in space (intercropping: hedgerows, shelterbelts and agroforestry) and time (crop rotation systems). Making better use of the 'ecosystem services' provided by the agroecosystem, including the preservation and management of soil biota that produce and maintain organic matter (Lavelle et al., this issue) is one important element in the conservation strategies to be adopted. The negative effects of intensive agriculture on the diversity of beneficial soil organisms are not easily documented — however, they eventually will become much more devastating for the maintenance of essential ecosystem functions than the — lamentable — loss of bird or mammal diversity (e.g., Höfer et al., 2000). Soil organisms are today seen as ecosystem engineers, important if not central to ecological function (Jones et al., 1994; Lavelle et al., 1997), and soil fertility maintenance (Stork and Eggleton, 1992). Generally, the diversity of soil organisms is drastically reduced in man-made land use systems, but the role of soil biota is rarely considered or understood in agricultural studies (Hanne, 2001).

Appropriate management of SOM in the tropics still requires considerable research into the regional differences and the variability of SOM quantity, quality and function; the importance of the quality of input material; the role of below-ground versus mulched organic matter (particularly the importance of roots and root exudates); the role of recalcitrant materials (e.g., charcoal) in building a stable SOM fraction in the long-term; and how to balance the need for stable forms against the need for short-term nutrient availability. The question remains how to find alternative sources or how to balance competitive uses for SOM (feed, construction etc.). The definition of reliable and easy-to-assess indicators of SOM should be given high priority as they would allow the design of a appropriate policy approach. Regional organic matter budgets must be established (e.g., Binder and Patzel this issue) to be able to assess SOM availability. Farmers need to balance SOM management against agricultural management that maximizes goals other than SOM (crops, pest control, etc.). Resources should be channeled into research on direct and indirect SOM management techniques (cropping systems;

till versus no-till; hedgerows, contour farming, integration of livestock, etc.). Such management may increase SOM inputs (sources, quantity and quality), conserve SOM, or concentrate it (e.g., the 'zai' system used to restore degraded land in West Africa). Overarching goals identified during the workshop include participatory research for a better engagement with farmers and other stakeholders (to overcome the gap between research and application), long-term assessments through networking, multidisciplinary approaches, and the development of databases for modelling. In the realm of policy, we need to define incentives for direct or indirect soil conservation, invest into the design of sustainable cropping systems, and into the certification of recycled materials such as manure.

Land degradation and the effects of organic matter loss are particularly critical in tropical semiarid regions where the risk of desertification is great, and where precipitation and temperature changes associated with global warming will further undermine ecosystem integrity. If not properly managed all efforts for re-construction of drylands and conservation of organic matter might be doomed in a situation where a rise in average temperature of about 1.4–5.8° is likely (IPCC-WGI, 2001; Mitchell and Hulme, 2000). In the last decade, ecosystem restoration and management (e.g., Samson and Knopf, 1996; Rana, 1998; Peine, 1999) and the restoration of ecosystem 'health' have become objects of scientific study in the temperate ecosystems of the developed world. Functional ecosystems provide benefits which otherwise have to be obtained at a considerable cost. They include protection against wind and water erosion, input of organic residue for the build-up of soil organic matter, retention and filtration of water, and salinity reduction. Designing structurally diverse agro-ecosystems can provide the same 'ecological services' as those provided by natural systems. Establishing forests and agroforestry systems is an important strategy against desertification (UNEP and GLAVGIDROMET, 2000), and preventive efforts are becoming increasingly important in view of the expected rates of global warming. Modelling in other regions has shown that large-scale changes in vegetation cover can interact with climate variability, e.g., in the Sahel (Zeng et al., 1999) or in Amazonia (Shukla et al., 1990). Many deserts are not naturally bare of vegetation, but are man-made, e.g., due the large-scale introduction of cattle about 8000–10 000 years b.p.(Aladin, 1998; Jürgens, 2000). In that context, the possibility to restore vegetation cover using a switch between different ecosystem equilibria that follow the El Niño (ENSO) effect as proposed by Holmgren and Scheffer (2001) needs to be further explored.

Adequate planting systems and cropping techniques are often available 'off the shelf'. Transferring them to farmers often fails if the executing institutions do not engage all stakeholders (farmers, land owners, scientists, civic leaders) from the start. Establishing a comprehensive database on approaches and experiences that work and a network of institutions involved was seen as an important first step by many scientists present at the meeting. To us, the need to open the eyes of the decision makers, particularly those in tropical countries is critical. They must realize that neglecting the conservation of soils will carry exorbitant human, social, and economic costs.

Soils that formed through millennia are the basis of life. They may be irreversibly destroyed in a short time if no immediate action is taken. The destruction will not only reverberate in the livelihood of the rural poor, it may also resound in the cities, and ultimately destabilize whole societies. Soil degradation has wiped out entire civilizations in the past. We do not need to repeat the nefarious experience of our ancestors.

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