Introduction

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No scientific investigation is complete until its results can be expressed quantitatively. Only when this is done can the investigators feel reasonably certain that they have gained the right perspective and that they know how nearly their hypotheses approximate to the truth.

Sir E.J. Russell (1926)

General

If all resources are harnessed, and adequate measures taken to minimize soil degradation, sufficient food to feed the population in 2020 can be produced, and probably sufficient for a few billion more. These were the key conclusions from a Discussion Meeting held at the Royal Society in London in December 1996. The meeting entitled 'Land resources: on the edge of the Malthusian precipice?' attempted to make a rigorous scientific assessment of the evidence regarding the availability of land resources to meet future demands, and to determine what further research is needed to strengthen the scientific base on which such assessments depend (Greenland *et al.*, 1997).

At the meeting global data-sets and models were widely used by specialists with expertise in the area of population growth, crop production, climatology, water, soil and land resources, or the environment. Some of the key points to emerge from the meeting were:

- It is expected that most of the extra food will be produced by those countries with a greater extent and better quality of land resources.
- There are many countries where serious food problems will be experienced in the next two decades and that transfers of food from countries with greater resources to food-deficit countries will be necessary.
- Increased understanding of the basic principles of crop production and sustainable land management is needed for a sustainable basis of production increases in resource-poor countries.
- Research efforts of the developed countries must be not only restored but increased, and collaboration with developing countries enhanced, so that the fall in the rate of increase in cereal yields from a high of almost 3% per annum in 1965 to close to 1.3% per annum in 1997 can be reversed.
- In the developing world, research into soil, water and nutrient management must be intensified.
- Long-term trials are essential if the sustainability and environmental acceptability of various management practices are to be properly assessed (Greenland *et al.*, 1997).

Key topics such as human population growth, soil resources and soil degradation, land-use intensification and integrated nutrient management, agricultural production and sustainable land management were widely discussed during the Royal Society meeting. The development of technically feasible and socio-economically acceptable solutions is among the biggest challenges that agricultural sciences are facing. They form the starting point for this book and the general background against which the information is presented.

This Book and its Rationale

Currently, more than 95% of the human population increase is in the tropics, which puts existing agricultural systems under stress. In order to produce sufficient food and to curb land degradation, permanent and productive cropping systems[1] need to be developed. The sustainability of permanent cropping systems is largely effected by the judicious management of the soil chemical fertility. This has been recognized for many decades, but there is a need for hard data on soil

[1] Permanent cropping systems are systems in which the land is continuously cropped year after year with annual crops (e.g. maize, beans, rice) or perennial crops (e.g. cocoa, rubber). There is usually no fallow or resting period in permanent cropping systems.

changes and nutrient management strategies in order to improve our understanding of agricultural systems and to design sustainable cropping systems in the tropics. Although there is also a need for more sustainable land management practices in agriculture in the temperate regions, there are diametrically opposite problems compared with soils under agriculture in the tropics. Many of the soils under agriculture in the temperate regions are very high in plant nutrients owing to excess use of inorganic fertilizers and animal manure, whereas it is often perceived that soils in the tropics suffer from plant nutrient deficiencies (Hartemink, 2002).

So far the discussion on soil productivity decline, nutrient mining and sustainable land management in the tropical regions has focused on low-external-input agriculture by subsistence farmers (Pieri, 1989; Henao and Baanante, 1999; Scoones and Toulmin, 1999; Smaling *et al.*, 1999). This book has its main focus on agricultural plantations, which have been largely neglected in the discussion on soil fertility decline[2] and sustainable land management. Another major difference with the existing studies is that soil fertility decline is assessed using soil chemical data whereas other studies have used nutrient balances as the main tool to evaluate the sustainability of the systems.

The rationale for the focus on plantation agriculture is that it is an important form of land use in the tropics, and in many countries the area under plantation crops has expanded rapidly in the past decades. For example, in Indonesia the area under oil palm expanded from 133,000 ha in 1970 to almost 1.8 million ha by the mid-1990s (Fairhurst, 1996). In Malaysia the extent of oil palm increased from about 150,000 ha in the early 1970s to over 3 million ha at the end of 1998. Plantation agriculture is contributing to the macroeconomies in many tropical countries and provides much employment. Even in middle-income countries such as Malaysia, total export earnings from oil palm plantations are 6% of the Gross National Product (GNP) (Jalani, 1998). In Ivory Coast a group of plantation crops produce 22% of GNP (Tiffen and Mortimore, 1988). As yields are usually higher on plantations than on smallholder farms, they may contribute proportionally more to GNP than the area they occupy, for example in Kenya tea plantations comprise 35% of the area under tea but they produce more than 60% of the total output (Tiffen and Mortimore, 1988).

[2] Soil fertility decline is defined in this book as: the decline in soil chemical fertility, or a decrease in the levels of soil organic C, pH, CEC and plant nutrients. Biological and physical factors are not considered. Soil fertility decline thus includes nutrient depletion (larger removal than addition of nutrients), nutrient mining (large removal of nutrients and no inputs), acidification (decline in pH and/or an increase in exchangeable Al) and the loss of organic matter – see also page 80.

Plantation crops are sometimes referred to as non-CGIAR (Consultative Group for International Agricultural Research) crops (Smith, 2000). Despite the importance of plantation agriculture, long-term effects of plantation cropping on the soil have received little research attention. No systematic effort has been undertaken to prove that plantation agriculture is a more sustainable form of land use than arable cropping. However, it has long been assumed that a perennial plant cover protects the soil better than an annual crop (Jacks and Whyte, 1939), and it has also been stated that land degradation under perennial crops is usually less than in arable farming under similar conditions (Ruthenberg, 1972).

Set-up of the book

The book focuses on soil fertility decline in the tropics. The information is presented in three parts, which have been partly interwoven: (i) a literature review (Chapters 2 to 4); (ii) review of soil changes under annual and perennial crops including two detailed case studies (Chapters 5 to 10); and (iii) an integrative part, in which the literature and case studies are combined (Chapter 11).

Chapter 2 embraces a global literature review on human population growth, soil resources of the tropics, tropical land use and management, soil degradation, and sustainable land management. A general review of the problems in the use and management of soils in the tropics is given with particular emphasis on soil chemical fertility. Chapter 3 reviews historical and productivity aspects of agricultural plantations in the tropics. Chapter 4 covers theoretical considerations of soil fertility decline and includes sections on data requirements, spatial and temporal variation, soil tests and interpretation of soil fertility decline studies. The information forms the theoretical framework for the subsequent chapters, in which evidence for soil fertility decline is presented.

Chapter 5 focuses on soil fertility decline of annual cropping systems and brings together a wide range of data and studies. Soil changes under plantation crops are critically examined in Chapters 6 to 10 using the published literature on perennial crops, sugarcane plantations and forest plantations. Two detailed case studies are included, based on research conducted at plantations in Tanzania and Papua New Guinea. The data of these studies have been re-evaluated and re-interpretated according to schemes developed in Chapter 4. For both case studies a fair amount of data was available and basic statistics were used. In Chapter 11, the information is synthesized. A summary of the soil changes is presented followed by some of the implications for plantation cropping and a set of conclusions is given in the final chapter.

Thus, this book starts with a global view of the pressing matters in the tropics (wide zoom), then focuses on the soil and the decline in soil fertility under plantation cropping (zoom-in phase), and subsequently the data are aggregated again and the wider implications are reviewed (zoom-out again).

Structuring of chapters

This book deals with evidence of soil fertility decline under different land-use systems in the tropics: annual crops (Chapter 5), perennial crop and forest plantations (Chapters 6 and 7), sugarcane (Chapters 8 and 9) and sisal (Chapter 10). Each chapter is structured in a similar way. After a brief history and introduction, soil erosion is discussed followed by a review of changes in soil chemical properties and calculations on the rates of change. Hereafter semiquantitative studies (nutrient balances), soil process oriented and environmental impact studies are reviewed. Each chapter ends with a discussion and conclusions. Although the primary focus is on changes in soil chemical fertility, brief reviews on soil erosion and soil environmental studies are included in order to embed the soil chemical data in a broader setting, and to supplement the soil chemical data with other important soil data.

Literature and own data

This book is based on data from the literature and on my own research in Tanzania and Papua New Guinea and to a lesser extent on my experiences in Congo and Indonesia. Literature data were used to complement and balance detailed case studies. In the literature review sections, a slight preference has been given to some of my own data as far as they were not presented in the case studies. For example, in the discussion on bulk density in relation to soil nutrient depletion, soil physical data from the sugarcane plantation in Papua New Guinea were used to demonstrate changes under permanent cropping. Likewise, I have used my research data on nutrient content of roots to illustrate variation in nutrient uptake over time, and to compare fertilized and unfertilized plants. There are other sections where my own work was used to exemplify relevant soil properties and processes, and although this might appear as a bias, it has been done in combination with other literature.

An analogy

This book has been structured in a particular way and it can best be explained by an analogy. Suppose a patient named X, suffering from an unknown disease, visits a medical doctor named M. The doctor will firstly ask X what his problem is, followed by some general background information on X. Successively, M will measure or observe the problem. In some cases, M may be able to directly diagnose the problem ('You have a broken leg, sir') but in many cases M may request tests to have his diagnosis verified or to obtain some general impression of the medical status of X. If the disease appears complicated, M may need to do some extra reading and study, provided the patient is not transferred to a more specialist colleague. Once the diagnosis has been ascertained, M will prescribe a treatment to cure X, and will speculate about the future health of his patient.[3]

This book is built along these lines of thought, in which the soils of the tropics under permanent cropping are X and this book can be considered some sort of M. The problem and some background information on the patient are discussed in Chapters 2 to 4, whereas measurements and observations are given in Chapter 5 to 10. The final diagnosis is made in Chapter 11 including a discussion on the future health status in the concluding chapter. This book requires the medical specialist to do a considerable amount of reading, but given the size of the patient and the problem, that may be justified.

What's excluded

This book deals with soils and agriculture in the low-altitude regions of the humid and subhumid tropics. The main focus is on basic or standard soil analytical measurements (pH, organic C, total N, available P, CEC and exchangeable Ca, Mg and K). No information is included on micronutrients, or on soil biological or physical properties. Although a lot of ground is covered, virtually no attention is given to livestock, grazing and pastures. In some plantations, livestock and cropping are intensely mixed (i.e. cows and coconuts) but as animals introduce another complicating factor in the relationship between soils and crops, such studies were excluded. It needs to be mentioned that the literature review is largely based on Anglo-Saxon and Dutch literature and virtually no French, Spanish, German or

[3] Recently I noticed that this analogy was also used by Doran, J.W. and Parkin, T.B. (1996) in their chapter: 'Quantitative indicators of soil quality: a minimum data-set.' In: Doran, J.W. and Jones, A.J. (eds) *Methods for Assessing Soil Quality.* SSSA, Madison, Wisconsin, pp. 25–37. The analogy was used for the discussion of 'ecosystem health' based on other work in the USA. I found that a bit discomforting, but after careful deliberation the analogy was kept as it had facilitated the way in which the book was structured.

Portuguese literature has been used. None the less, it is assumed that the Anglo-Saxon and Dutch literature covers the main trends and developments in the subjects discussed in this book. It should be mentioned that no attention is given to socio-economic aspects of soil fertility decline. Also, the literature data and the results from the soil investigations in Tanzania and Papua New Guinea were not modelled. Although models can be of great help in the understanding of factors driving certain processes and can also show what data are lacking, a disquieting aspect of computer-based modelling is the gap between the model and the real-world events (Phillip, 1991). In soil science, computer modelling has also partly supplanted laboratory experimentation and field observations (Hartemink *et al.*, 2001) and the focus of the book has been placed on bringing together and critically analysing real-world data. Such data are much needed now our understanding of soil processes and the advances in computer modelling have made great progress. Lastly, no geostatistics were used because the data were too few.

Aims and Approach

The main aims are to quantify soil fertility decline under permanent cropping systems in the tropics and to resolve what strategies are needed to assess the rates of change in soil chemical properties. More specifically the book aims to:

- Review the published literature on human population growth, soil resources and soil degradation, food production, land-use change and sustainable land management in the tropics.
- Review data types and boundary conditions for the assessment and measurements of soil fertility decline.
- Review the literature on the history and importance of agriculture and forest plantations in the tropics.
- Analyse and assess the effects of plantation crops on soil chemical properties.
- Re-evaluate the soil chemical data from sisal and sugarcane plantations in Tanzania and Papua New Guinea, and compare the results with those in the published literature.
- Investigate how soil fertility decline differs between different land-use systems and soils.

Three aspects deserve mentioning up front as they have determined why the information is presented as it is. First, the focus of this book is *change*: changes in human population, changes in crop yield and production, and changes in soil chemical properties. Change is defined here as: *to become different, altered or modified*. Studying changes means a comparison of observations made at different periods or different locations. Historical knowledge is an essential element of learning about change.

Therefore, in the book a fair degree of *historical* information is given, which is the second aspect that has influenced the presentation of the information. Wherever possible and relevant, emphasis is placed on historical developments in biophysical knowledge rather than socio-economic aspects of the subjects treated. In addition to the historical aspects of changes, this book aims to be *quantitative* or in other words, it puts a strong emphasis on reports of measurable properties. Although qualitative studies in soil science have improved our understanding and often encouraged quantitative studies, major advances in soil science have come from quantitative studies. Most studies focusing on the subject of soil fertility decline contain few data. In this book a wide collection of data has been brought together and critically analysed. The aim was for completeness, but only factual and quantitative studies have been included.

In summary: this book investigates changes by critically analysing historical and published information in a quantitative manner supplemented with detailed case studies, so as to improve our understanding of the complex relation between permanent cropping and the chemical fertility of soils in the tropics.

References

Fairhurst, T. (1996) Management of nutrients for efficient use in smallholder oil palm plantations. PhD thesis, Department of Biological Sciences, Wye College, University of London.

Greenland, D.J., Gregory, P.J. and Nye, P.H. (1997) Introduction and conclusions. In: Greenland, D.J., Gregory, P.J. and Nye, P.H. (eds) *Land Resources: On the Edge of the Malthusian Precipice?* The Royal Society, London, pp. 861–867.

Hartemink, A.E. (2002) Soil science in tropical and temperate regions – some differences and similarities. *Advances in Agronomy* 77, 269–292.

Hartemink, A.E., McBratney, A.B. and Cattle, J.A. (2001) Developments and trends in soil science: 100 volumes of Geoderma (1967–2001). *Geoderma* 100, 217–268.

Henao, J. and Baanante, C. (1999) *Estimating Rates of Nutrient Depletion in Soils of Agricultural Lands of Africa*. IFDC, Muscle Shoals, Alabama.

Jacks, G.V. and Whyte, R.O. (1939) *The Rape of the Earth – a World Survey of Soil Erosion*. Faber and Faber, London.

Jalani, B.S. (1998) Oil palm research and development in Malaysia: progress and trends. *The Planter (Kuala Lumpur)* 74, 73–92.

Phillip, J. (1991) Soils, natural science, and models. *Soil Science* 151, 91–98.

Pieri, C. (1989) *Fertilité des Terres de Savanes*. Ministère de la Cooperation et CIRAD-IRAT, Paris.

Russell, E.J. (1926) *Plant Nutrition and Crop Production*. University of California Press, Berkeley.

Ruthenberg, H. (1972) *Farming Systems in the Tropics*. Clarendon Press, Oxford.

Scoones, I. and Toulmin, C. (1999) *Policies for Soil Fertility Management in Africa*. IIED, London.

Smaling, E.M.A., Oenema, O. and Fresco, L.O. (eds) (1999) *Nutrient Disequilibria in Agroecosystems: Concepts and Case Studies*. CAB International, Wallingford.

Smith, R.W. (2000) Tree Crops: Essential Components of Sustainable Tropical Agricultural Systems. *TAA Newsletter* March, 17–19.

Tiffen, M. and Mortimore, M. (1988) *The Role of Plantations in Development: a Literature Review.* Overseas Development Institute, London.