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Chapter 13

## **Sustainability of Soil Management Practices – a Global Perspective**

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### **1. INTRODUCTION**

#### **1.1 What is Sustainable Soil Management?**

Sustainable development “meets the needs of the present without compromising the ability of future generations to meet their own needs for land” (W C E D 1987). We can adapt this definition to derive a definition for sustainable soil management: “soil management that meets the needs of the present without compromising the ability of future generations to meet their own needs from that soil”. Thus, soil management is sustainable when it does not alter the capacity of the soil to provide for future needs. In this book, particular emphasis is placed upon the role of soil biology in the maintenance of soil sustainability. Management practices that threaten the soil biological community may also threaten soil sustainability by reducing the capacity of the soil to adapt in the future (Yachi and Loreau 1999).

Soil sustainability can be threatened by a numerous management practices; including over-cultivation, decreased or increased water abstraction, under-fertilisation or over-fertilisation, careless use of biocides, failure to maintain soil organic matter levels and clearing natural vegetation. These may threaten sustainability in a number of ways; through physical and chemical processes (eg. by increasing soil erosion,

salinisation, desertification), or biological processes (eg. by decreasing soil fertility). When soil management is poor, soil sustainability is often threatened by a combination of these factors at the same time.

Because the impacts of poor soil management are so severe in many areas of the world, the adoption of sustainable soil management is of crucial importance for the future of human and natural systems. Practices that improve the sustainable management of soils have already been described in detail in this book (see Chapter 3). In this chapter we consider soil sustainability from a global perspective and examine the current status of sustainable soil management and how it may change in the future.

## **2. THE GLOBAL PERSPECTIVE – SOIL SUSTAINABILITY NOW AND IN THE FUTURE**

### **2.1 Current Global Trends in Soil Sustainability**

Trends in soil sustainability differ from region to region. In some of the more developed areas of the world, huge increases in yield per unit area over the last century (Amthor 1998, Matson *et al.* 1997), coupled with stabilising human population figures, have led to sustainable soil management becoming more prevalent than before. In Europe and much of the United States, unsustainable agricultural practices (such as those leading to the US mid-west “dust bowl” of the 1930s; Cook *et al.* 1999) have given way to more sustainable forms of agriculture, including the conservation reserve program (Reeder *et al.* 1998, Lal *et al.* 1998) and other national equivalents. Improvements in crop varieties and a better knowledge of sustainable management practices mean that the pressure on land for agriculture in some of these areas is diminishing, either making land available for other uses such as woodland (Smith *et al.* 1997), or less intensive production systems (Lampkin 1990). In other areas of the world, such as the tropics, sustainable soil management may be more difficult, and slash-and-burn agriculture is still widely practised (Palm *et al.* 1996). For resource-poor farmers, short-term goals (such as the need to achieve a food crop this year in order to survive), will outweigh consideration of the longer-term impacts of soil management practices. Soil management practices are improving in these regions, but there is still a long way to go before agricultural management systems in these regions can be regarded as sustainable (Palm *et al.* 1996, Sanchez 2000). Poverty in these regions

leads to further land degradation (Barbier 2000) making soil sustainability even more difficult to achieve. Some authors have argued that the world's present development path is not sustainable, in that interactions between climate change, loss of biological diversity, increasing poverty and disease, and growing inequality, combine to increase the vulnerability of humans and nature (McCarthy and Dickson 2000). The development of sustainable soil management practices in the future has to be considered against the political, social and economic back-drop of the future world.

## **2.2 What is Likely to Happen to Soil Sustainability in the Future?**

### **2.2.1 International agreements that may affect soil sustainability in the near future**

A number of international agreements, conventions and instruments are likely to influence the management of soils in the near future. Article 3.4 of the Kyoto Protocol (<http://www.unfccc.int/resource/docs/convkp/kpeng.pdf>) of the United Nations Framework Convention on Climate Change (UNFCCC), for example, explicitly mentions agricultural soils for possible future inclusion as a biospheric sink for carbon (I P C C 2000). The management practices that increase in soil organic carbon (eg. reduced tillage, use of more organic amendments, greater use of mixed farming, inclusion of more wooded areas on farms, biofuel crop growth, protection from desertification etc.; Smith *et al.* 1997, 1998, Smith *et al.* 2000, Lal *et al.* 1998), may also help to improve soil biodiversity (eg. Chan 2001), as well as soil sustainability, in what has been termed a “win-win strategy” (Lal *et al.* 1998). Other conventions, such as the United Nations Convention on Biological Diversity (<http://www.biodiv.org/convention/>), are also likely to yield benefits for soil sustainability through improved agricultural and land management (eg. Liang *et al.* 2001). Other international and regional agreements, such as the United Nations Convention to Combat Desertification (UNCCD), United Nations Forum on Forests, and the Convention on Long-Range Trans-boundary Air Pollution (LRTAP), may also indirectly affect soil sustainability via constraints on land-management. In the section 2.2.2 (this Chapter), we give an example of how one such agreement, the Kyoto Protocol, might influence soil sustainability in the near future.

### 2.2.2 An example - possible impact of the Kyoto Protocol of soil sustainability via an impact on soil organic matter

Soil organic matter plays an important role in maintaining soil sustainability. It can help to maintain soil structure, retain soil moisture, prevent erosion, and can act as a reservoir for nutrients and as a source or sink for carbon (see Chapters 2, 3, 4 and 5). Increasing levels of organic matter in soils is likely to enhance soil biological processes (see Chapters 2 and 3) and soil sustainability (Lal *et al.* 1998). In the Kyoto Protocol, agricultural soils are highlighted for possible future inclusion as a biospheric sink for carbon, which a party could use to help meet its CO<sub>2</sub> emission reduction targets. If agricultural soils were to be used as carbon sinks, there would be incentives to farmers and land managers to increase the soil organic carbon (SOC) content of their soils. In this example, we examine the global potential to increase SOC, and thereby gain some insight into the extent to which soil sustainability might be improved in the future.

There is considerable potential to increase soil carbon stocks due to the abundance of agricultural soils which are depleted in carbon. Cultivation has resulted in a loss of 55 Pg (10<sup>15</sup>g) carbon from soils worldwide (Cole *et al.* 1996). The best agricultural management practices have the potential to restore some of this soil carbon. At the global scale, Cole *et al.* (1996), estimated that 0.4-0.8 Pg carbon could be sequestered in agricultural soils each year, corresponding to an increase of 40-80 Pg carbon over 100 years. These figures are however considered a little high (see below).

In certain areas, some historical carbon loss from agricultural soils may have already been reversed. For example, the introduction of conservation tillage in the USA is estimated to have increased SOC stocks by about 1.4 Pg over the past 30 years (Donigian *et al.* 1994), with the potential to store a further 5 Pg over the next 50 years (Kern and Johnson 1993, Lal *et al.* 1998).

Over the next 50-100 years, if one includes all available management practices, some estimates suggest that there is the potential to sequester 0.075 to 0.208 Pg carbon per year in US arable land (Lal *et al.* 1998, Metting *et al.* 1999), which is equivalent to 7.5-20.8 Pg carbon over 100 years. In the USA, it has been estimated that full adoption of best management practices could restore SOC levels to about 75-90% of their pre-cultivation levels (Donigian *et al.* 1994). Figures from Europe are of a similar order, ie. 0.113 Pg carbon could be offset per year (including carbon offsets from bioenergy crops planted on surplus arable land; Smith

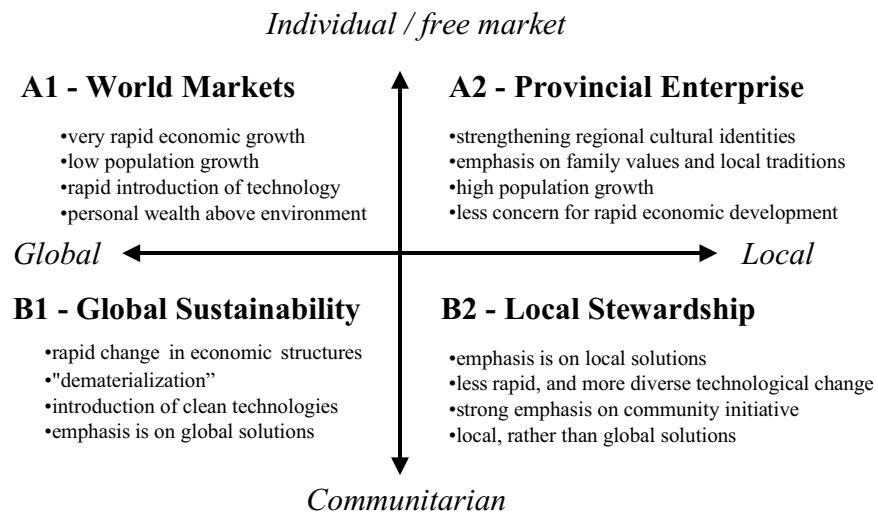
*et al.* 2000). Over 100 years this is equivalent to a carbon offset of 11.3 Pg. In some regions, then, there is the potential to restore much of the historic carbon lost through cultivation, but globally the potential is lower. Much of the potential to reverse SOC loss occurs in temperate regions such as Europe and North America. The figures for USA of Lal *et al.* (1998) and for Europe of Smith *et al.* (2000) suggest that, at best, about 1/3 to 1/2 of the SOC lost through agriculture globally, can be restored over the next 100 years.

Yearly increases in SOC can be sustained for only 50-100 years (Smith *et al.* 1997, Cole *et al.* 1996); as ecosystems reach a new equilibrium position, yearly SOC increases slow and eventually cease. In this context, for activities adopted under Kyoto article 3.4, soil carbon sink saturation will occur within about 50-100 years of adoption. Although not calculated on an area basis, if 1/3 to 1/2 of SOC lost through agriculture can be restored, soil sustainability might increase on a similar proportion of current agricultural land.

Land uses that could enhance carbon sequestration and improve soil sustainability in terrestrial ecosystems include: (i) some agricultural land uses (see above) (ii) biomass crops, grassland, rangeland and forest, (iii) the protection and creation of wetlands, urban forest and grassland, (iv) the manipulation of deserts and degraded lands and (v) the protection of sediments, aquatic systems, tundra and taiga (Metting *et al.* 1999). Over a 50 year time period, the total terrestrial carbon sequestration potential, including all of these activities is estimated to be 5.65-8.71 Pg carbon per year (Metting *et al.* 1999), roughly 10 times the carbon sequestration potential of agricultural land alone. Given the importance of soil organic matter in maintaining soil biological fertility and sustainability, this level of carbon sequestration would almost certainly lead to improved soil sustainability in many regions of the world over the next 50 years. However, the word 'potential' needs to be emphasised when considering carbon sequestration in soil. In order to achieve these increases in soil carbon content, it would be necessary to achieve the maximum uptake of various land management practices which in reality, may be difficult. It was largely for this reason that a cautious approach was taken to the role land carbon sinks may have in mitigating climate change in a recent study by the Royal Society (Royal Society 2001).

### 2.2.3 Soil sustainability over the next 50-100 years

Although the conventions and instruments mentioned in 2.2.1 and 2.2.2 (this Chapter) will influence soil sustainability in the near future, long-term trends will be constrained by social, political and economic growth in different regions of the world. While the political and economic future cannot be forecast, a number of possible futures can be examined. In its Special Report on (greenhouse gas) Emission Scenarios (SRES), the IPCC (2000b) developed a range of “story-lines” on future global development. The SRES story lines have been adopted for use in climate change impact studies (eg. Parry 2000). The interpretation of the SRES story lines as used in Parry (2000) are summarised schematically in Figure 13.1. The x-axis represents the spatial scale of the political units, ranging from local, devolved government to a high level of global co-operation. The y-axis represents the economic framework, ranging from a highly individualistic free-market economy to a collective, more “communitarian” economy. The four quarters of the figure represent different global scenarios. For the purposes of emission scenarios, A1 was further divided into three scenarios depending upon fossil fuel use, but that subdivision is less relevant here.



**Figure 1** Schematic representation of the story lines used in developing the IPCC greenhouse gas emission scenarios

#### **2.2.4 What are the impacts of these possible futures upon soil sustainability?**

*World markets (A1).* Under this scenario the emphasis would be on the pursuit of economic growth rather than sustainable development, and policies would be based on the assumption that natural systems are largely resilient to human stress (Parry 2000). Under the world markets scenario, soil sustainability could suffer due to a lack of concern for developing sustainable land management practices. Furthermore, although rising income levels will make everyone richer, the richest will become relatively richer compared to the poorest (Parry 2000). Poverty is well known to drive deforestation (Weis 2000) and to lead to land degradation (Barbier 2000). Increasing the income of the poorest people in the world would only result in improved soil sustainability if poverty were alleviated by the trickle-down economics engendered in this scenario.

*Global Sustainability (B1).* Under this scenario there would be an increasing tendency to find global solutions to global problems through strong global institutions and the adoption of international regulation (Parry 2000). International trade would be strong, but environmental requirements would have primacy in the case of a conflict. There is also predicted to be significant government commitment to making agriculture more environmentally friendly (OECD 1996). Soil sustainability would undoubtedly be improved under this scenario with global regulation and intervention to improve soil sustainability in the developing world, as well as in the developed world.

*Provincial Enterprise (A2).* Under this scenario policy decisions would be taken at the national and sub-national level, and society would be organised according to short-term consumerist values. Protectionist economic and trade policies would constrain innovation and stifle economic development in poorer countries. A greater economic gulf would develop between the developed northern countries and poorer southern countries. Politicians would regard environmental quality as a low priority compared to protecting the national economy and consumer demand for growth (Parry 2000). Soil sustainability under this scenario would suffer in developed countries, but would suffer even more in less-developed regions, where soils are already more vulnerable.

*Local Stewardship (B2).* Under this scenario environmental problems would be solved locally and according to local conditions. Governance would occur at the local level and would be more eco-centric in nature. The world would become more heterogeneous and relative inequality may

arise due to lack of co-ordinated regional action. The environment would benefit under this scenario, but not as much as under the Global Sustainability (*BI*), since environmental policy would lack spatial co-ordination (Parry 2000). Soil sustainability under this scenario would also improve, provided that resources were available in the poorest areas to implement local sustainable land-management policies.

Among these scenarios, human population growth would be lowest under the Global Markets and Global Sustainability scenarios. These scenarios would therefore create less pressure for new agricultural land than would the Local Stewardship and Provincial Enterprise scenarios, and would thus be less likely to threaten global soil sustainability. Taking human population growth into account, the least favourable future for soil sustainability would be Provincial Enterprise and the most favourable would be Global Sustainability. Whilst Local Stewardship might produce a more environmentally-conscious world, the higher population compared to the Global Markets scenario would trade off eco-centric land-management policies against the need for more land for food production, in turn leading to an increased threat of soil degradation.

Climate change may further increase the threat to soil sustainability in poorer countries because cereal crop yields are predicted to decline in most tropical and sub-tropical regions under future climates (Rosenzweig and Parry 1994, Fischer *et al.* 2001), in countries which have a low capacity to adapt (IPCC 2001). The decrease in organic matter returns to the soil, and the increased need for new land to counteract the effects of lower yields, would enhance negative impacts on soil sustainability in these regions. Even in some temperate regions there is increased risk of crop failure caused by drought, resulting from greater variation in weather from year to year even if the average change in climate is small (Porter and Semenov 1999). The likely overall impacts on soil sustainability of each of the future world story-lines is summarised in Figure 2.

As it is not possible to predict exactly what will happen to soil sustainability in the future, here we use accepted, realistic story-lines, which are based on credible socio-economic reasoning and modelling, to assess the impacts of a range of possible futures. Some possible futures are perhaps more likely than others, and recent political / economic trends have been towards globalisation and the pursuit of increased free trade (McCarthy and Dickson 2000). However, a number of international conventions and instruments are currently in place that are likely to improve soil sustainability in the near future. The future, at least regionally, is likely to contain components of all scenarios, but based upon



**Figure 2** Summary of likely impacts on soil sustainability of the story-lines used in developing the IPCC emission scenarios.

recent trends, the future will probably most closely resemble a combination of the Global Market and Global Sustainability scenarios. In order to cope with the uncertainty inherent when planning for the future, soil management strategies should be developed which are beneficial now, and which are predicted to also be beneficial in the future.

### 3. DEVELOPING A 'NO REGRETS' STRATEGY FOR SUSTAINABLE SOIL MANAGEMENT

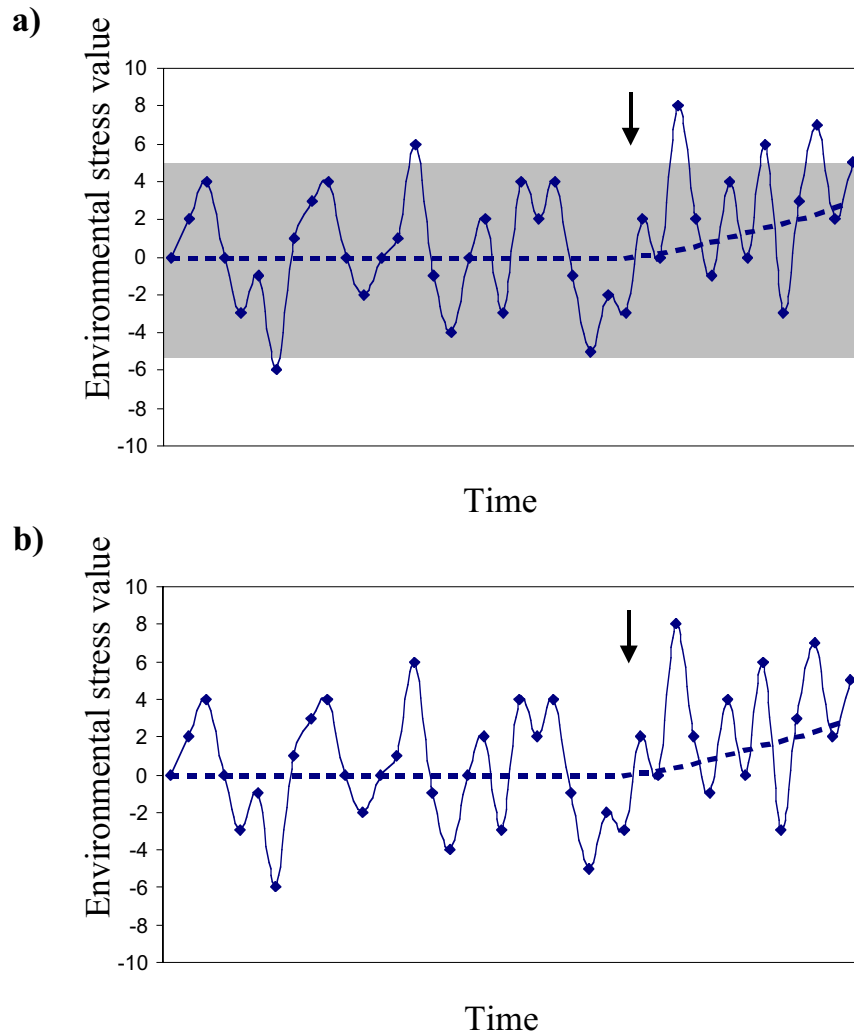
A move towards globally sustainable soil management needs to be coupled with solutions to the other related environmental problems and socio-economic / political issues such as poverty, food security and over-population. Global solutions to soil sustainability will be best achieved as part of larger, comprehensive, sustainable development strategies. However, there are a number of best-management practices that could be adopted now to improve soil sustainability in the future, irrespective of the political and economic landscape of the future. These practices include the

cessation of clearing natural vegetation, maintenance of soil organic matter via careful tillage, plant residue management, use of organic amendments, fertilisation and careful irrigation, the careful choice of crops and rotations and the careful use of biocides and soil amendments. These practices are similar to those described in Chapter 3 in which a move towards “microbial farming” is advocated.

The strategy, whereby management practices known to benefit the soil now are implemented, with the expectation that it will improve the resilience of these soils to future challenges, is known as a 'no regrets' strategy. A schematic representation of how a 'no regrets' policy might increase the resilience of the soil is shown in Figure 3.

The main plot of each part of Figure 3 (adapted from a plot used to demonstrate ecosystem vulnerability in Smit *et al.* 2000) shows the variation in the value of an environmental stress. While the stress falls within the coping zone (shaded), the soil / ecosystem is resilient to the environmental stress. Problems occur when the value falls outside this zone. In Figure 3-a, the system management remains the same giving the same coping range throughout the period, whereas in Figure 3-b, the soil management is changed at time-zero to improve the resilience of the system.

As seen in Figure 3-a, the stress on the soil increases after the environmental change (marked by the arrow) and moves outside the coping range three times in the last quarter of the time period (having strayed outside of the coping range twice in the first 3/4 of the period). However, when sustainable soil management is implemented at time zero (Figure 3-b), the coping range of the system increases such that the environmental stress falls within the expanding coping range at all times after the environmental change, and is only once outside the range before the environmental change. Figure 3 demonstrates schematically that a 'no regrets' policy implemented now, will increase the resilience of the soil to environmental stresses in the present (before an environmental change) as well as in the future.



**Figure 3** Environmental stress, coping ranges and improved soil management adapted from Smit *et al.* (2000). The main plot of each part shows the variation in an environmental stress. The broken line shows the mean value of that soil parameter over time. The arrow shows the onset of an environmental change. The shaded area shows the coping range (Smit *et al.* 2000). In a), the system management remains the same, giving the same coping range throughout the period. In b), the soil management is changed at time zero to improve the resilience of the system. See text for further explanation.

#### 4. CONCLUDING REMARKS

In the near future, a number of current international agreements and instruments such as the Kyoto Protocol, may indirectly improve soil sustainability by providing incentives to better manage soil organic matter. It is possible that 1/3 to 1/2 of the soil carbon lost globally through agriculture might be restored over the next 100 years if the Kyoto Protocol is fully implemented. If such an investment in improved soil management were made, soil sustainability would almost certainly improve in many regions of the world in the near future.

Soil sustainability in the more distant future will depend upon the world's future social, economic and political development. One scenario (Global Sustainability) would clearly benefit soil sustainability, one (Provincial Enterprise) would clearly damage it, and the other two (Global Markets and Local stewardship) would provide mixed incentives / disincentives for sustainable soil management.

At regional scale, the education of farmers, land-managers and regional planners would also help to enhance soil sustainability, since the implementation of known technology is currently hampered by education (Sanchez 2000).

At the global scale, soil sustainability needs to be tackled in hand with other related problems. The IPCC (2001) noted that global, regional and local environmental issues such as climate change, loss of biodiversity, desertification, stratospheric ozone depletion, regional acid deposition and local air quality are inextricably linked. The lack of soil sustainability should certainly be added to that list. The IPCC (2001) further noted that recognising the linkages among local, regional and global environmental issues, and their relationship to meeting human needs, provides an opportunity to address global environmental issues at the local, national and regional level in an integrated manner that is cost-effective and meets sustainable development objectives. The importance of integrated approaches to sustainable environmental management is becoming ever clearer.

In addition to attempting to solve a raft of environmental problems together, social and economic problems also need to be addressed in the same package. All of the scientific and technical measures outlined in this book have the potential to improve soil sustainability, but the extent to which soil management becomes sustainable will be determined by how widely these measures are implemented. Soil sustainability is ultimately a human problem and it is impossible to separate soil sustainability from the

political landscape of the future. Threats to soil sustainability (and a range of other problems) would be reduced by control of the human population size as this would ease the pressure on land for food production. Poverty remains the main driver for soil degradation in the poorest parts of the world, where the soil is most vulnerable (Barbier 2000). At the global scale, relief of poverty in these regions would probably do more to improve soil sustainability than any of the scientific or technical measures described. The development of sustainable soil management practices clearly requires a multidisciplinary approach and an awareness by all involved of the multiple goals to be achieved. It can be seen as a part of a wider international initiative termed “sustainability science”. This is an attempt to bring together the often conflicting efforts to meet fundamental human needs while preserving the life-support systems of planet Earth (Kates *et al.* 2001; <http://sustsci.harvard.edu/keydocs.htm#sustsci>; <http://sustainabilityscience.org>).

It is clear that the political and economic landscape of the future will determine the feasibility of many strategies to promote sustainable soil management, but there are a number of best management practices available now that could be implemented to improve soil sustainability now, and in the future (a no regrets policy). Since these practices are consistent with, and may even be encouraged by, many current international agreements and conventions, their rapid adoption should be encouraged as widely as possible.

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