CHAPTER 18

Carbon Sequestration and Land Degradation

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Abstract. Storing carbon (C) in soil as organic matter is not only a viable strategy to sequester CO_2 from the atmosphere, but is vital for improving the quality of soil. This presentation describes (1) C sequestration concepts and rationale, (2) relevant management approaches to avoid land degradation and foster C sequestration, and (3) a summary of research quantifying soil C sequestration. The three primary greenhouse gases (CO_2, CH_4, and N_2O) derived from agriculture have increased dramatically during the past century. Conservation management practices can be employed to sequester C in soil, counter land degradation, and contribute to economic livelihoods on farms. Trees can accumulate C in perennial biomass of above-ground and below-ground growth, as well as in the deposition of soil organic matter. Minimal disturbance of the soil surface with conservation tillage is critical in avoiding soil organic C loss from erosion and microbial decomposition. Animal manures contain 40-60% C, and therefore, application to land promotes soil organic C sequestration and provides readily-available, recycled nutrients to crops. Green manures can be used to build soil fertility, often with leguminous plant species having symbiotic root associations with nitrogen-fixing bacteria. Grasslands have great potential to sequester soil organic C when managed properly, but can also be degraded due to overgrazing, careless management, and drought leading to accelerated soil erosion and undesirable species composition. Opportunities exist to capture and retain greater quantity of C from crop and grazing systems when the two systems are integrated. Fertilization is needed to achieve production goals, but when applied excessively it can lead to environmental pollution, especially when considering the energy and C cost of manufacture and transport. Agricultural conservation management strategies to sequester CO_2 from the atmosphere into soil organic matter will also likely restore degraded land and/or avoid further land degradation.

18.1 Introduction

Land degradation is an insidious process that threatens the sustainability of agriculture, not only in the arid and semi-arid regions, but also in the sub-humid and humid regions, as a result of the loss of agro-ecosystem capacity to meet its full potential. Resulting from complex, and little understood, interactions among periodic weather stresses, extreme climatic events, and management decisions, land degradation is a serious global concern in a world searching for sustainable development to meet the needs of a rapidly increasing human population, to reverse the negative impacts of our choices on the environment in which we live, and to fairly distribute the world's resources in a socially justifiable manner.

Atmospheric concentration of radiatively active trace gases [also called greenhouse gases (GHGs)] has been increasing dramatically during the past several centuries (IPCC 2001). Several of the important GHGs in the atmosphere are derived, at least partially, from agricultural activities. Three of the most important GHGs related to agricultural activities are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). On a global scale, the relative contribution of each of these GHGs to global warming potential is depicted in Figure 18.1. Carbon dioxide accounts for almost 75% of the global warming potential of GHGs. The source of this CO_2 is dominantly from fossil fuel combustion. Since 1750, the concentration of CO_2 has increased 31%, the concentration of CH_4 has increased 151%, and the concentration of N_2O has increased 17% (Fig. 18.2). In the USA, the contribution of agriculture to GHG emission has been estimated to be only 7% of the country's total GHG emission (USDA 2004).

Global concern for the rising atmospheric concentration of GHGs is also increasing, because of the important implications of these gases on global warming. Potentially dramatic consequences of even relatively minor climate change could cause devastating weather-related occurrences, such as increased frequency and duration of droughts, more widespread and severe flooding events, greater frequency and intensity of tornadoes and cyclones, and melting of polar ice caps that could threaten abundant human civilizations along coastal continental areas. Understanding the linkages between agricultural land-use activities and GHG dynamics should help society to strengthen its resolve to avoid these potentially devastating impacts and design effective mitigation strategies to bolster ecosystem functioning and overcome human-induced land degradation.

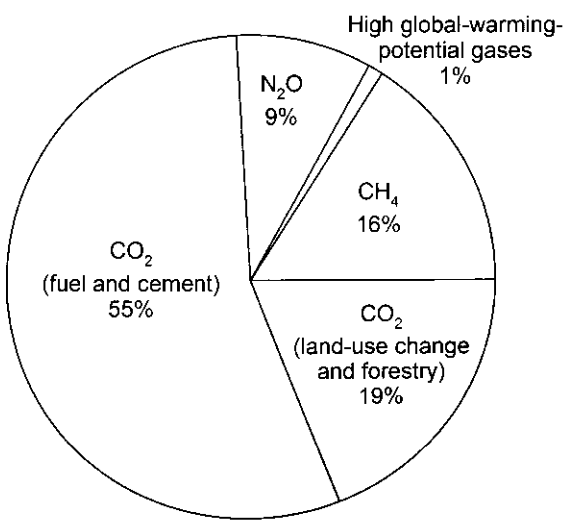

Fig. 18.1. Relative distribution of greenhouse gas emission by gas type on a global basis in 2000 (EPA 2006)

Rising concentration of atmospheric CO_2 has been largely attributed to expanding use of fossil fuels as an energy source. Reducing net GHG emission is possible by:

- Reducing fossil fuel combustion and becoming more energy efficient
- Relying more on low-C energy sources, such as
  - Capturing solar energy
  - Generating wind power
  - Harvesting biofuels
- Sequestering C

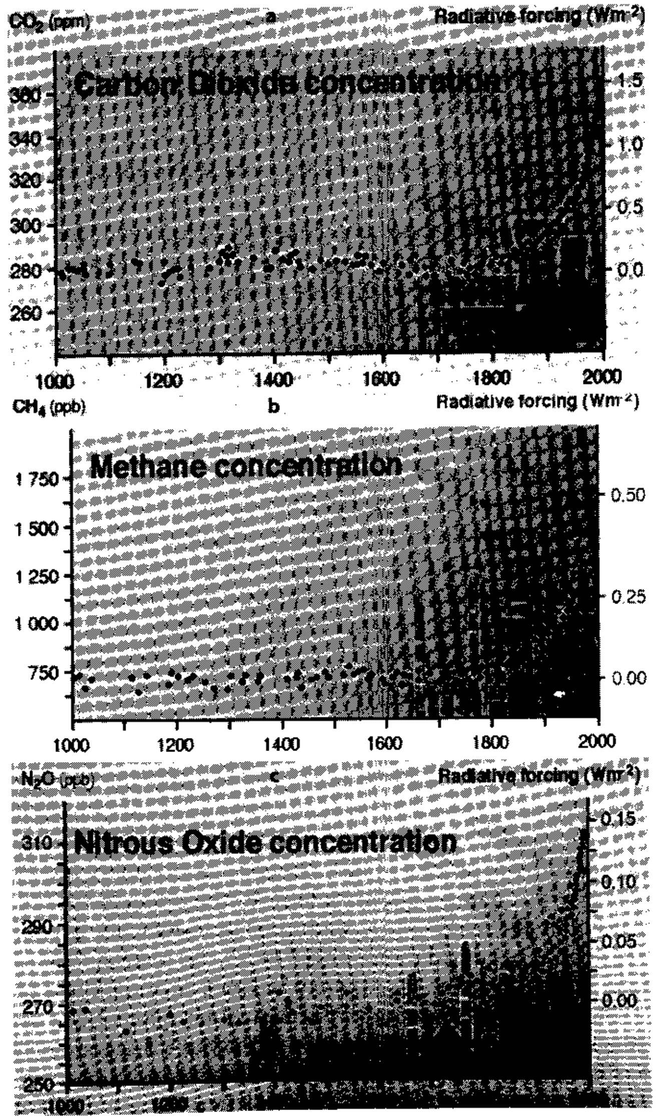

Fig. 18.2. Historical record of CO_2, CH_4, and N_2O in the atmosphere (IPCC 2001)

This paper focuses on the last option of sequestering C to reduce GHG emission. Carbon sequestration can be defined as the long-term storage of C so that the accumulation of CO_2 in the atmosphere can be reduced or slowed. Carbon sequestration can occur globally in one of several compartments:

- Terrestrial biosphere
- Underground in geologic formations
- Oceans

This paper focuses on the terrestrial biosphere, which is directly manipulated by agriculture through changes in vegetation and soil disturbance.

Carbon sequestration in the terrestrial biosphere can be accomplished by:

- Increasing the net fixation of atmospheric CO_2 by terrestrial vegetation with emphasis on enhancing physiology and rate of photosynthesis of vascular plants.
- Retaining C in plant materials and enhancing the transformation of C to soil organic matter.
- Reducing the emission of CO_2 from soils caused by heterotrophic oxidation of soil organic C.
- Increasing the capacity of deserts and degraded lands to sequester C.

Storing C in soil as organic matter is not only a viable strategy to sequester C from the atmosphere, but is also essential in improving the quality of soil. Soil organic matter plays a vital role in:

- Soil fertility, by slowly supplying nitrogen and many other essential elements and molecules to plants through mineralization/immobilization turnover.
- Water cycling, by contributing to soil aggregation and water-holding capacity.
- Soil biodiversity, by providing the C and energy sources needed for soil biological community development.
- Environmental detoxification, by supplying chemical bonds, physical support, and biological activity.
- Biogeochemical cycling, by storing and delivering many globally important elements interacting through the atmosphere, hydrosphere, lithosphere, and biosphere.

18.2 Management Approaches

The terrestrial C cycle can be simply divided into the two primary processes of photosynthetic uptake of CO_2 from the atmosphere (i.e., C input) and respiration of CO_2 from living organisms back to the atmosphere (i.e., C output). On a global scale under steady-state conditions, rates of C input and output have often been considered balanced (Schlesinger 1997). Terrestrial C sequestration efforts, therefore, must recognize the inherent balance between these processes.

Maximizing C input to the terrestrial biosphere from the atmosphere is possible in agricultural systems through a variety of management options, including:

- Plant selection, whereby large differences in photosynthetic capacity occur among species, cultivars, and varieties. Perennial plant species often have ad-

vantages over annual crops at capturing C, because of a longer growing season and more extensive root distribution (Liebig et al. 2005). However, selection of appropriate annual crops in rotation sequence can maximize growth potential under certain environments. A continuing effort has focused on cultivating high-biomass producing energy crops to maximize photosynthetic capture of CO_2 (Baral and Guha 2004).
- Tillage management, whereby the type and frequency of tillage is used to promote the most prolific plant production possible. Tillage is often used to improve the physical condition of soil so that crops can achieve maximum growth potential, but it is also a tool that disturbs soil and promotes oxidation of soil organic matter (Franzluebbers 2004).
- Fertilization management, whereby the source, rate, timing, and placement of fertilizer is used to optimize plant production potential. Sufficiently balanced and adequate nutrient supply are essential management considerations to maximize genetic potential of plants (Lal and Bruce 1999), but the high energy cost of mining and manufacturing inorganic sources of nutrients must be recognized as a source of GHG emission (Schlesinger 2000).
- Integrated management, whereby pests can be adequately controlled and environmental and socio-economic consequences of agricultural activities can be balanced with agronomic production considerations (Makumba et al. 2007).

Minimizing C loss from soil to the atmosphere has also been a major focus of agricultural research on C sequestration. Management options to minimize C loss from soil include:
- Reducing soil disturbance by less intensive tillage and erosion control (Lal et al. 1998).
- More fully utilizing available soil water, which not only promotes optimum plant growth, but also reduces the oxidative capacity of soil microorganisms to decompose soil organic matter and crop residues (Lal 2004).
- Maintaining surface residue cover to increase plant water use and production. Surface residue cover also fosters greater fungal abundance in the soil microbial community, which promotes greater stabilization of soil aggregates and resistance of soil organic C to decomposition (Nichols and Wright 2004).

In agriculture, there are many management practices that can be employed to sequester C and counter land degradation. The following sections describe some key management practices to combat land degradation. How these management practices might also contribute to soil C sequestration will be highlighted.

18.2.1 Tree Plantings

Trees can accumulate C in perennial biomass of above-ground and below-ground growth, as well as in the deposition of soil organic matter. The intentional mixing of trees or other woody perennials with agricultural crops, pastures, and/or livestock is defined as agroforestry. Agroforestry exploits the ecological and economic interactions of the different components to attain greater sustainability (Nair 1993). This section focuses on agroforestry-related changes in C accumulation rather than on natural or planted forests.

Issues of importance in agroforestry systems are:

- Climate
- Selecting adapted species
- Soil conditions
- Plant density
- Intended use
- Spatial arrangement of trees and other land uses.

The types of agroforestry practices include complex agroforestry systems, boundary plantings, hedgerow intercropping, and improved fallow (Albrecht and Kandji 2003). Carbon sequestration potential of tropical agroforestry systems has been estimated.

From plantation survey data in Australia (400-600 mm zone), mean C accumulation rate of 3.8 Mg ha^{-1} yr^{-1} occurred in the woody biomass from a variety of tree species (Fig. 18.3). In the central Philippines, C sequestration in the above-ground biomass of *Leucaena leucocephala* during 6 years of growth was estimated at 10.7 Mg C ha^{-1} yr^{-1} (Lasco and Suson 1999).

Carbon accumulation in the soil is the major sink for hedgerow intercropping systems used to produce biomass for improving soil fertility. In Nigeria, *L. leucocephala* and *Gliricidia sepium* intercropping systems sequestered 0.20 Mg C ha^{-1} yr^{-1} in the topsoil compared with sole cropping (Kang et al 1999). From two exper-

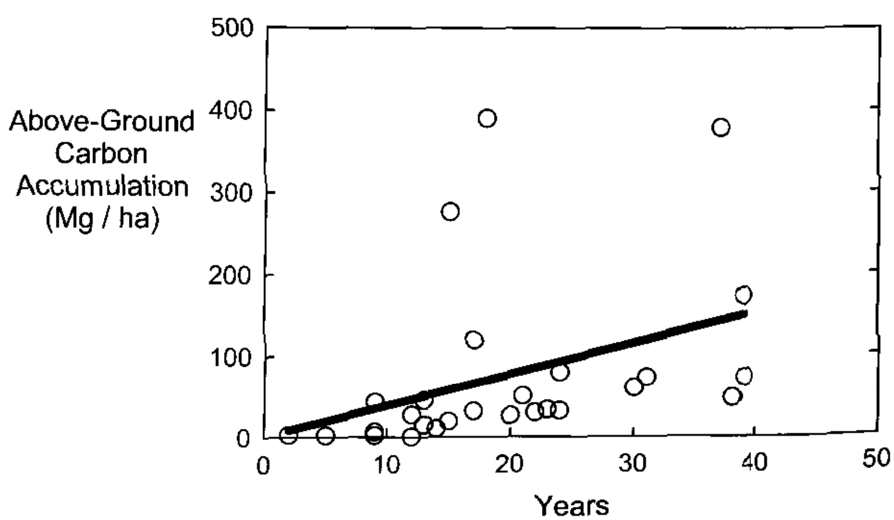

Fig. 18.3. Survey of above-ground C accumulation from a diversity of trees in Victoria, Australia (400-700 mm rainfall) as affected by stand age (Hassall and Associates Pty Ltd 1998)

iments in Malawi (6 to 9-year studies), a *G. sepium* intercropping system sequestered soil organic C at a rate of 1.2 Mg ha^{-1} yr^{-1} in the surface soil (0-20 cm), but at a rate of 6.2 to 11.7 Mg ha^{-1} yr^{-1} when calculated to a depth of 0-200 cm (Makumba et al. 2007). Deep rooting of the trees was considered a key feature of this difference in estimates. Using Century and RothC models in Sudan and Nigeria, soil organic C accumulation with tree plantings was estimated at 0.10 ± 0.05 Mg ha^{-1} yr^{-1} (Farage et al. 2007).

18.2.2 Conservation-Tillage Cropping

Minimal disturbance of the soil surface is critical in avoiding soil organic matter loss from erosion and microbial decomposition. Successful conservation-tillage cropping systems have been developed and evaluated throughout the world. As part of a system for conservation agriculture, conservation-tillage cropping can improve plant production, reduce environmental pollution, and store a greater quantity of soil organic C (http://www.fao.org/ag/ca/index.html).

Climatic conditions can influence the amount of soil organic C expected to be sequestered with adoption of conservation tillage. With more extreme dry and/or wet conditions, soil organic C sequestration tended to be highest in milder and warm-wet climatic regions of North America (Fig. 18.4). Mean soil organic C sequestration in North America is estimated at 0.33 Mg C ha^{-1} yr^{-1}. In the warm-moist climatic region of the southeastern USA, adding a cover crop to a conservation-tillage system can nearly double the rate of soil organic C sequestration due to addi-

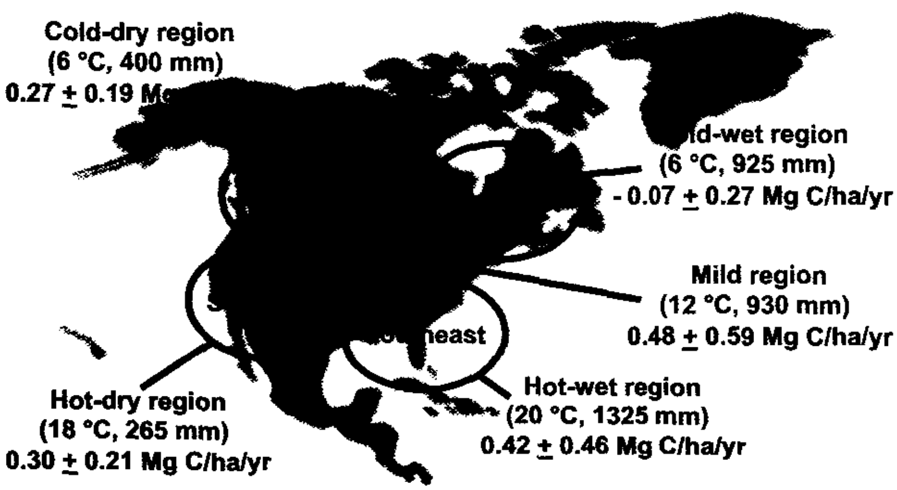

Fig. 18.4. Summary of mean ± standard deviation of soil organic C seques-tration by no tillage in different regions of North America (Franzluebbers and Follett 2005)

Table 18.1. Predicted change in soil erosion and organic C sequestration by EPIC-Century modeling during a 25-year period in Mali (Doraiswamy et al. 2007). Traditional cropping and mean crop yield from 1985-2000 included maize (1.5 Mg ha^{-1}), cotton (1.2 Mg ha^{-1}), and millet and sorghum (1.0 Mg ha^{-1})

Management	Erosion (Mg ha^{-1} yr^{-1})	Change in organic C (Mg C ha^{-1} yr^{-1})
Conventional tillage (CT)	16.5	−0.023
CT with increased fertilizer	15.0	−0.006
Ridge tillage (RT)	6.6	0.001
RT with increased fertilizer	5.9	0.027
RT with fertilizer and residues	3.5	0.086

Fertilizer inputs averaged 24 kg N ha^{-1} and 7 kg P ha^{-1} with the low level and 39 kg N ha^{-1} and 9 kg P ha^{-1} with increased fertilizer level

tional plant biomass input and better crop growth due to surface residues (Franzluebbers 2005).

Maintaining adequate surface residue cover with conservation-tillage cropping systems has also been shown to be very important for efficiently utilizing rainfall and producing adequate crop yield. From the 12th year of an irrigated wheat–maize rotation in the volcanic highlands of central Mexico, the rate of water infiltration was 18 cm h^{-1} when crop residue was removed and 90 cm h^{-1} when crop residue was retained on the soil surface with no tillage management (Govaerts et al. 2007). The change in water delivery to the soil resulted in rather dramatic changes in crop yield during the last 7 years of the study, in which maize and wheat yields were 40% greater when crop residue was retained as compared to removal of crop residues.

Using a remote sensing–crop modeling approach in Mali, Doraiswamy et al. (2007) observed that modification of traditional cropping systems to better control erosion with ridge tillage could shift agricultural production in the region from a net emitter of CO_2 to a net sink for CO_2. Combining ridge tillage with other improvements in crop management could reduce soil erosion to 20-40% of that predicted in traditional cropping systems with conventional tillage (Table 18.1).

18.2.3 Animal Manure Application

Since animal manure contains 40-60% C, its application to land should promote soil organic C sequestration. In a review of studies conducted in the southeastern USA, poultry litter application to crop and pasture lands led to significant change in soil organic C only when evaluations were conducted for more than 2 years (Table 18.2). Conversion of C in poultry litter to soil organic C was 17 ± 15% among these studies. Although soil organic C has been shown to increase with animal ma-

Table 18.2. Summary of how poultry litter application to crop and grazing land affected soil organic C in 8 published studies in the southeastern USA (Franzluebbers 2005)

Response	Soil organic C ($Mg\ ha^{-1}$)	
	Without manure	With manure
2-year studies (n=6)	19.8 ± 8.9	19.6 ± 8.4
11 ± 8-year studies (n=8)	30.6 ± 11.4	36.8 ± 10.6
SOC sequestration for all ($Mg\ ha^{-1}\ yr^{-1}$)	0.26 ± 2.15	
SOC sequestration for >2-year studies	0.72 ± 0.67	

nure application, very few whole-system data have been collected. Manure application may simply transfer C from one land to another, while investing energy in transport and handling operations. A full C accounting approach is needed to adequately assess manure application as a viable C sequestration strategy.

Other long-term studies on farmyard (FYM) application to soil have clearly shown its benefit to soil fertility, yield enhancement, and soil organic C storage. In an 18-year field experiment in Kenya (23 °C, 970 mm), soil organic C increased by 0.17 ± 0.07 *Mg C ha^{-1} yr^{-1} with FYM (10 Mg ha^{-1} yr^{-1}) compared to without* FYM (Kapkiyai et al. 1999). Of the C applied in FYM, 9 ± 3% was retained in soil as organic C. Crop yield with FYM (5.3 Mg ha^{-1}) was 61% greater with FYM than without FYM.

In a 45-year field experiment in Nigeria (28 °C, 1070 mm), soil organic C increased by 0.21 ± 0.01 Mg C ha^{-1} yr^{-1} with FYM (5 Mg ha^{-1} yr^{-1}) compared to without FYM (Agbenin and Goladi 1997). In this naturally P-deficient soil, total soil P increased by 12 ± 12 kg ha^{-1} yr^{-1} with FYM.

In a 30-year field experiment at Ranchi, India (23 °C, 1450 mm), soil organic C was *greater with FYM (3.9 g kg^{-1}) than without FYM (3.3 g kg^{-1}) (Manna et al.* 2007). Total soil N was also 17% greater with FYM than without FYM application. However, soybean and wheat yields were generally not affected by FYM application.

In a 30-year field experiment at Hawalbagh, India (1035 mm), soil organic C increased by 0.56 ± 0.02 Mg C ha^{-1} yr^{-1} with FYM (10 Mg ha^{-1} yr^{-1}) compared to without FYM (Kundu et al. 2007). Above-ground crop biomass production with FYM (6.4 Mg ha^{-1}) was 2.4 times greater than without FYM application.

In a 22-year field experiment in Italy (14 °C, 760 mm), soil organic C increased by *0.20 Mg C ha^{-1} yr^{-1} with FYM (7.5 Mg ha^{-1} yr^{-1}) compared to without FYM (Govi* et al. 1992). Soil humification index increased to 60% with FYM compared to 51% without FYM.

In a 20-year study of pearl millet–wheat cropping in India (26 °C, 440 mm), soil organic C increased with increasing FYM application rate (Fig. 18.5). However as a percentage of C applied in FYM, increasing FYM application rate led to less efficient retention of C in soil (Gupta et al. 1992).

Reviewing the climatic influence of animal manure application on soil organic C storage, temperature regime appears to have a greater impact than precipitation

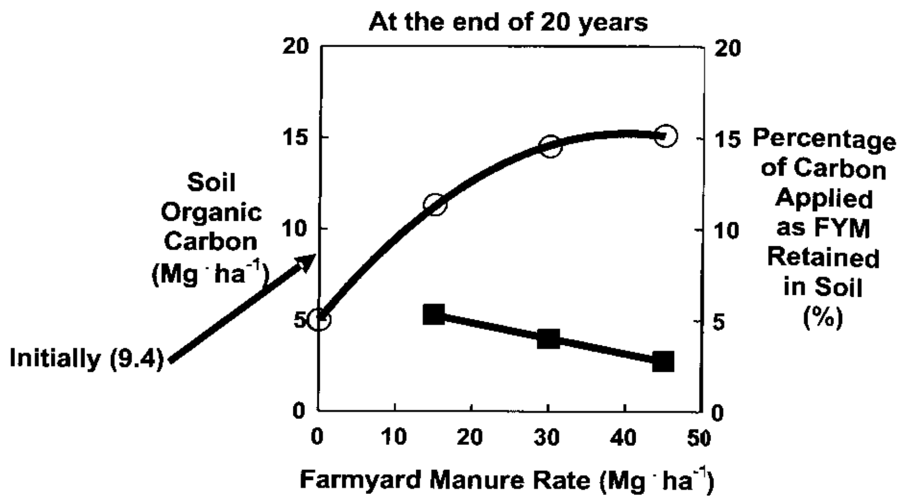

Fig. 18.5. Soil organic C as a function of farmyard manure application rate during 20 years in India (Gupta et al. 1992)

regime. Retention of C in soil was 23 ± 15% of C applied from animal manure in temperate or frigid regions, but was only 7 ± 5% in thermic regions. Moist regions retained 8 ± 4% of C applied with animal manure, while dry regions retained 11 ± 14%. These data are consistent with environmental controls on soil microbial activity and suggest that future research will require increasing acknowledgement of the linkage between climate and potential C sequestration.

18.2.4 Green-Manure Cropping Systems

Green manures are used to build soil fertility, often with plant species having the capacity to fix nitrogen from the atmosphere through root associations with nitrogen fixing bacteria. The C contained in green manure biomass following its termination can be subsequently stored in soil organic matter.

On an abandoned brick-making site in southeastern China (16.5 °C, 1600 mm), planting of ryegrass as an understory crop under China fir for 7 years resulted in soil organic C sequestration of 0.36 ± 0.40 Mg C ha^{-1} yr^{-1} (Zhang and Fang 2006). With soybean as a green manure for 8 years in Columbia (27 °C, 2240 mm), maize yield with green manure (4.2 Mg ha^{-1}) was 20% greater than without green manure (Basamba et al. 2006). Soil organic C did not change during the 8 years of green manuring, probably because of rapid decomposition caused by abundant precipitation, warm temperature, and nutritious residue quality.

At the end of 12 years of *Sesbania* green manuring in India (24 °C, 715 mm), soil organic C sequestration was 0.09 ± 0.03 Mg C ha^{-1} yr^{-1} (Singh et al. 2007). At the end of 13 years of wheat/soybean–maize cropping with and without vetch as a green-manure cover crop in southern Brazil (21 °C, 1740 mm), soil organic C sequestration was −0.30 ± 0.15 Mg C ha^{-1} yr^{-1} under conventional tillage and 0.66 ± 0.26 Mg C ha^{-1} yr^{-1} under zero tillage (Sisti et al. 2004). These data suggest that climatic conditions, green manure nutrient quality, and placement in the soil are all important considerations in affecting soil organic C change with green manuring.

18.2.5 Improved Grassland Management

Degradation of permanent grasslands can occur from accelerated soil erosion, compaction, drought, and salinization. Strategies to sequester soil organic C in grasslands must, by necessity, improve the quality of grasslands. Strategies for restoration should include:

- Enhancing soil cover
- Improving soil structure to minimize water runoff and soil erosion

Achieving a balance between agricultural harvest and environmental protection is needed (i.e., stocking density should be optimized). On an oak-grassland in central Texas USA (18 °C, 440 mm), water infiltration was highly related to percent ground cover. However, cattle stocking density played an even larger role in controlling water infiltration with time (Fig. 18.6).

Establishment of bermudagrass pasture following long-term cropping in Georgia USA (16 °C, 1250 mm) resulted in significant soil organic C accumulation during the first 8 years of management (Fig. 18.7). How forage was managed had a large impact on the rate of soil organic C accumulation during the first 5 years, e.g. soil organic C sequestration rate was 0.30 Mg C ha^{-1} yr^{-1} when forage was removed as hay, 0.65 Mg C ha^{-1} yr^{-1} when forage remained unharvested, and 1.40 Mg C ha^{-1} yr^{-1} when forage was grazed moderately to moderately heavy by cattle during the summer (Franzluebbers et al. 2001).

18.2.6 Cropland-Grazingland Rotation

Opportunities exist to capture a greater quantity of C from crop and grazing systems when the two systems are integrated, because:

- Ligno-cellulosic plant materials can be utilized by ruminant animals
- Manure is deposited directly on the land
- Weeds can be managed with management rather than chemicals

Especially when combined with conservation-tillage cropping, significant potential exists to avoid loss of soil organic C that can accumulate during a perennial pasture phase (Fig. 18.8). In Uruguay, soil erosion averaged 19 Mg ha^{-1} under conventional-tillage continuous cropping, 7 Mg ha^{-1} under conventional-tillage crop–pasture rotation, 3 Mg ha^{-1} under no-tillage continuous cropping, and <2 Mg ha^{-1} under under no-tillage crop–pasture rotation (Garcia-Prechac et al. 2004). Soil or-

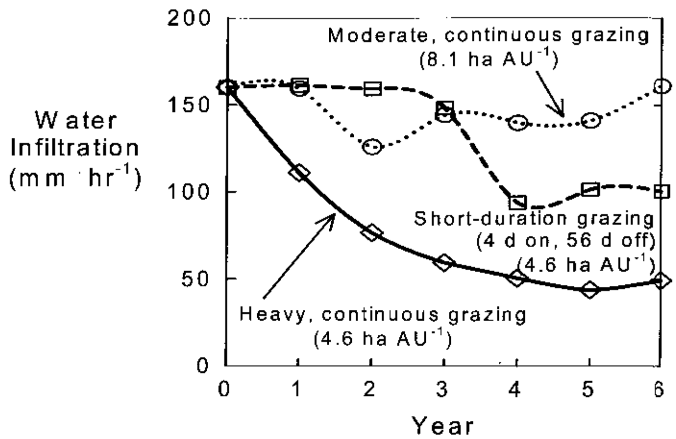

Fig. 18.6. Water infiltration as affected by long-term grazing management in an oak-grassland from Texas (Thurow et al. 1988)

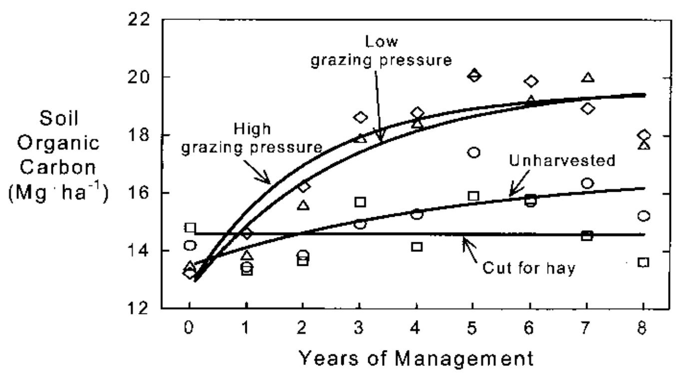

Fig. 18.7. Soil organic C as affected by 8 years of bermudagrass manage-ment in Georgia USA (Franzluebbers et al. 2001)

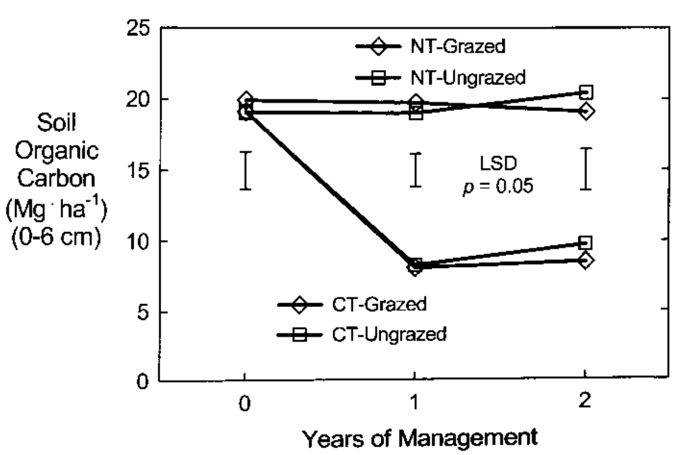

Fig. 18.8. Organic C in the surface 6 cm of soil during the first 2 years of cropping following long-term perennial pasture in Georgia (Franzluebbers unpublished data)

ganic C with crop–pasture rotation was also greater than with continuous cropping in both tillage systems. In the long-term, crop yield was enhanced with crop–pasture rotation than with continuous cropping, especially with no tillage (Garcia-Prechac et al. 2004).

In Argentina, rotations with ≤7 years of conventional-tillage cropping alternated with ≥3 years of perennial pasture were able to maintain soil organic C and other important soil properties within acceptable limits to avoid degradation (Studdert et al. 1997). Diaz-Zorita et al. (2002) found that cattle grazing in crop–pasture rotations compacted surface soil only under conventional tillage, but not under no tillage. The ability of soil to resist compaction under no tillage was attributed to greater structural stability.

In warm-moist climatic regions of the world, sufficient opportunities exist to integrate crops and livestock to achieve greater agricultural sustainability through enhanced nutrient cycling, better pest control, and diversification of agricultural enterprises (Katsvairo et al. 2006, Franzluebbers 2007).

18.2.7 Optimal Fertilization

Fertilization of crops is often needed to overcome deficiencies in nutrients supplied by soils, especially in soils exhausted by years of (a) soil erosion, (b) intensive disturbance with tillage, and (c) continuous harvest of products that remove large quantities of nutrients. On the other hand, excessive fertilization can occur when maximum agronomic prescriptions exist without regard for economic and environmental consequences. Today, the C cost of fertilization has become increasingly scrutinized (Schlesinger 1999; Izaurralde et al. 2000).

In a review of data available from the warm-moist climatic region of the southeastern USA, there was a positive response of soil organic C with the application of N fertilizer (Fig. 18.9). The mean N fertilizer rate to achieve maximum soil organ-

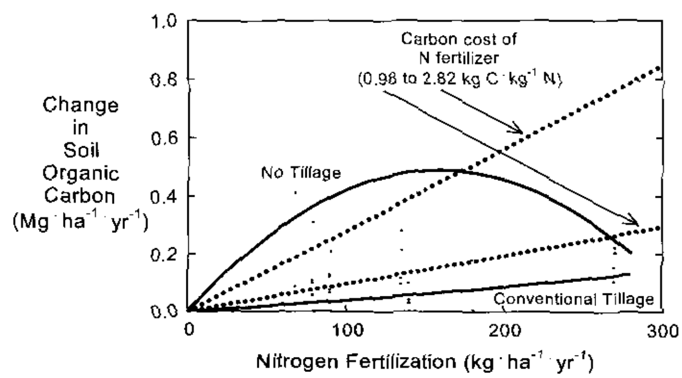

Fig. 18.9. Mean change in soil organic C as affected by N fertilizer rate in the southeastern USA (Franzluebbers 2005). *Dotted lines represent* the lower and upper limits of C cost of N fertilizer manufacture, distribution, and application

ic C sequestration was 171 kg N ha^{-1} yr^{-1}, within the range of values often reported to maximize plant yield. However, when considering the C cost of N fertilizer (i.e. C costs of manufacture, distribution, and application), the optimum N fertilizer rate was 107-120 kg N ha^{-1} yr^{-1} based on C costs of 0.98 to 1.23 kg C kg^{-1} N fertilizer (Izaurralde et al. 1998, West and Marland 2002). Also accounting for the global warming potential of assumed N_2O emission associated with N fertilizer application (1.586 kg C kg^{-1} N fertilizer; IPCC 1997), optimum N fertilization to maximize C offset would then be reduced to 24-37 kg N ha^{-1} yr^{-1} to achieve soil organic C sequestration of 0.07-0.11 Mg C ha^{-1} yr^{-1} (Franzluebbers 2005).

18.3 Summary and Conclusions

- Greenhouse gas concentrations in the atmosphere are increasing and the threat of global change requires our attention.
- A diversity of agricultural management practices can be employed to sequester a greater quantity of C in plants and soils. However, further research efforts are needed to:
  - Synthesize currently available data
  - Fill the gaps in our knowledge with additional, targeted research efforts
- Strategies to sequester soil C will also likely restore degraded land and avoid further degradation.

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