In : Senanayake. R. 1993 Soil Ecology, Agriculture and the Greenhouse Effect. Australian Jounnal of Soil and water Conservation 6 (1) : 27-30.

ASPECTS OF THE SOIL ECOSYSTEM IN AUSTRALIA : IMPLICATIONS FOR AGRICULTURE AND THE GLOBAL GREENHOUSE EFFECT

Ranil Senanayake

Summary: The soil ecosystem is comprised of abiotic and biotic fractions whose rate of erosion determines soil stability. The biotic fraction of soil can be managed to provide greater stability and carbon sequestering potential.

The soil ecosystem has been described as a principal component of all agroecosystems, the stability of which is essential to the development of sustainable agriculture (Senanayake 1990, 1991). The move to develop management strategies that achieve sustainable land use requires a good working knowledge of this ecosystem. Many functional components of this ecosystem have been researched in Australia (ie. CSIRO 1983), providing a good base for soil ecosystem management research.

As the current level of management skills has not generally led to sustainable methods of land use,there is a need to develop a higher degree of skill in soil management. The official tally in 1978 (CSCS 1979), suggested that about 51 per cent of agricultural land in Australia was being subjected to some degree of degradation. Today, many new sources of land degradation have been identified and the percentage of land affected may be much higher. This state of the land has been one of the driving forces that established the current effort in Landcare (Roberts 1990). However, agriculture is not the only reason to develop better skills in soil management. Studies on the nature of soil as an ecosystem demonstrate that it may play a significant role in greater global cycles. For instance, in terms of the atmospheric cycle of carbon dioxide, the soil acts as a dynamic buffer.

The soil ecosystem is comprised of two distinct fractions called the 'organic fraction' and 'inorganic fraction' (Figure 1). There is a slow flow between them in the form of mineralisation and decomposition,. These fractions act as reservoirs that can be identified by their history. The organic fraction is largely the breakdown products of photosynthetic compounds and their derivatives. The inorganic fraction is largely the breakdown products of rocks. Most soils are comprised of a mix of these two fractions in various proportions.

The organic fraction of soil has been calculated to contain between 1200 - 1800 Gigatonnes (GT) of carbon (Kohlmaier et al 1983). Globally, this reservoir maintains a flux with an atmospheric reservoir of 725 GT carbon as carbon dioxide (Pearman 1989). Most of this organic fraction is comprised of matter which originated in the process of photosynthesis with a propensity to lose energy over time. One model proposed to describe this flux is a steady state model (Houghton *et al.* 1985), where the net primary production (NPP) from the world's terrestrial ecosystems is about 45 - 62 GT and the loss of carbon dioxide to the atmosphere by decomposition will equal the input of plant debris to the soil. This suggests that an amount of organic carbon equivalent to that generated by NPP is decomposed each year. However, studies on the amount of carbon dioxide released from soils suggest a higher figure, about 75 GT per year (Schlesinger 1977). The implication of these figures is that not all soils are currently in a steady state for soil organic matter, While accumulation of carbon occurs in certain soils (Armentano *et al.* 1984, Lemon 1977), the major trends in land use such as logging and cultivation lead to an increase in decomposition because of increased soil temperature, aeration and moisture (Witkamp 1971, Marks and Bormann 1972).

Although Pearman (1987), suggests that soil organic matter is being maintained in a dynamic equilibrium and that the soil ecosystem is very effective at conserving fixed carbon, present trends in agriculture and land use, especially techniques that reduce the organic matter content of soil, may destabilise this equilibrium. The impact of modern agriculture on the organic matter content of soil has been demonstrated to be severe in many instances and has begun to affect many regions of the world (Lal 1987). When displaced from its original matrix and exposed to changes in climate, soil organic matter will release carbon dioxide and volatilise in a relatively short time. The mechanism of repeated drying and wetting, has been demonstrated to increase carbon dioxide production from 16 to 121 percent (Sorensen 1974), Similar trends have been observed by chemical inputs such as increased salt in the soil environment (Theng *et al.* 1968) or biological such as the catabolic stimulation of native soil organic matter by exogenous organic matter (Broadbent and Nakashima 1974). An end result of this process of soil degradation is an increase in the volume of carbon dioxide entering the atmospheric pool.

Another fact to be considered when addressing the cycling of organic matter in soil, is that soil organic matter does not degrade evenly. It is comprised of many different classes of compounds, with different rates of cycling within it. This organic matter can be subdivided based on different variables. Van Rees et. al. (1985) suggests three fractions based upon size and time of residence. In this scheme, one fraction is very short lived (1-2 years) and comprises about 1-2 per cent of total organic matter, another fraction has a moderate age (3-100 years) and comprises about 10-20 per cent of the total organic matter, and the last fraction is very old (100-4000 years) and comprises about 78-89 per cent of total organic matter. This relationship is illustrated in Figure.2. This model suggests three distinct cycles operating in a temporal sense as well as a bio-chemical sense.

The distribution of the various fractions in the soil profile suggest a process of biochemical distillation that leads to the formation of complex humic compounds. Photosynthetic products accumulate on the surface of the soil where they enter the respiration process and pass through various organic systems until the humic compounds are formed. These large complex molecules are distributed through the soil and often serve to delineate the profile termed the 'solum' or the region of the soil profile that contains a visible concentration of organic matter. While many of the humic compounds have ages measured in thousands of years, the 'younger' molecules are concentrated at the surface of the soil and decrease exponentially with depth (O'Brien and Stout 1978), suggesting that the surface of soil is the site of primary synthesis. Thus management of the surface layer will have potential to affect the rate of organic matter cycling.

As the process of biochemical distillation of photosynthetic products can keep atmospheric carbon dioxide tied to or sequestered by the biological system for periods exceeding 4000 years (Beckermann and Hubble 1974). While about 16 percent of the long lived fraction identified as 'old carbon' can have lifetimes from 5700 - 15,000 years (O'Brien and Stout opp cit)The role of soil in sequestering, or tying up, atmospheric carbon dioxide has to be recognised. An evaluation of the sequestering potential of various soil ecosystems may identify terrestrial ecosystems other than forests that have the potential to be used in the management of atmospheric carbon dioxide.

The rate of sequestering will depend on the quality of the photosynthetic material and the condition of the soil ecosystem.. Some compounds such as glucose are more readily metabolized than lignin. In reality, a gradient of substrates from 'readily metabolized', to 'resistant' exists in the organic matter pool. The products of readily metabolized organic compounds are predominantly carbon dioxide and soil microbial biomass (Tate 1989) . This fraction releases about 80 - 90 percent as carbon dioxide within 12 weeks (Kassim at al. 1981) while 3 - 8 percent is incorporated into microbial biomass.. Similar studies on the 'resistant' fraction demonstrated a carbon dioxide output of only 5 - 13 percent and microbial biomass increase from 0 - 0.7 percent within one year (Stott et al 1983). However these rates vary considerably with plant species (Shanks and Olson 1961),.suggesting a range of sequestering values for different vegetation formations in similar environments. The increment of photosynthetic material into the pool of long lived compounds can be estimated by examining the pool of humic compounds and the nature of the ecosystem that it resides in.

At the level of practical management this pool is easily detected by the dark colour that it imparts to most soils. It helps delineate the A horizon of soil, also known as the organic layer or solum soil Studies on agricultural techniques suggest a strong correlation between management and solum depth or quality. For instance the

differential effect of various cultivation techniques on the status of the solum as measured by its carbon, nitrogen and phosphorous content ,is now becoming evident (Russell and Williams 1986). Most of the studies to date identify solum state in terms of organic carbon or nitrogen. Other indicators such as microbial population ecology have been suggested (Senanayake 1990). Still others, like the ratio of short to long lived compounds in sequestered carbon pools, etc. can be described and developed.

These studies suggest that certain types of land management provide a better carbon sequestering potential, biodiversity conservation value and other characters that accompany an increase in solum status. However,these trends in solum status may differ depending on the end use of the ecosystem in question. For instance, an increase in organic matter or a build-up of earthworms as dominant soil macroorganisms are seen to be indicators of good management in terms of agriculture, but the environmental conditions that favour such a process are also inimical to much of the native biota (Matthews, 1976, Douglas, 1987). Therefore, management goals need to be clearly stated in terms of the end use of each ecosystem. If agricultural production is the goal, modification or change of the natural ecosystem to achieve high productivity is the management response. If conservation of natural ecosystems is the goal, management to avoid such change will becomes the management response. An understanding of the differential nature of these ecosystems is central to the development of sustainable land use. A consideration that must be attended to when designing for carbon sequestering by the ecosystem.

Australia provides an example of this process. Most of the crop or pasture plants used in Australian agriculture have been developed under European or Mediterranean conditions. Here, a friable soil high in organic matter has been seen as the ideal. In fact this aspect of soil has been seen as an ideal through the eight thousand or so years of man's agricultural history (Allison 1973). However, the clearing and preparation of forest land for agriculture initiates a process of organic matter loss that removes over half of its original content (Houghton *et al.* 1983). For example in Australia, it has been shown that brigalow (Acacia harpolhylla) scrub had a substantially higher organic carbon content than adjacent grassland communities on similar soils (Isbell 1966)). The clearing of this scrub resulted in a loss of organic matter from 14 - 41 percent below the virgin level (Graham 1976). However, impoverished soil can often regain organic matter depending on management practices. For instance, Jackman (1960) reported an increase in soil carbon from 4.6 to 20.0 per cent in 22 years following pasture in Taupo plumic soils of Ne Zealand. This represents an accumulation rate of approximately 1100 kg carbon/ha/yr. In a similar study Barrow (1969) reported a gain of 440 kg/ha/yr during a period of 30-40 years in Western Australia. In long term experiments at Rothamstead, soil that received no farmyard manure has maintained a constant amount of organic matter of about 25 t/ha , while soil that was given annual dressings of farmyard manure increased organic carbon from 25 t/ha in 1852 to 50 t/ha in 1871 (Attiwill and Leeper 1987). Once land has been cleared and demarcated for agriculture, management to build up the organic matter content becomes an important goal.

Conclusions.

The condition of the soil ecosystem, while being crucial to sustaining agricultural productivity, is also important in terms of providing a long term sink for atmospheric carbon. This ecosystem has the potential to sequester carbon for very long time periods. As the current global response to control carbon dioxide emissions is the proposal of a carbon tax.(Krause et. al. 1989) the logical corollary, that of extending a carbon credit that draws on the tax has also been extended (Anon 1991a). Examples of scientifically directed action to provide sequestering have also been developed (Faure et. al. 1990). The current estimates of the revenue generated by a carbon tax suggests a figure of US dollars 130 billion for America alone (Brown 1991). This figure was obtained from estimates made by US congress at a tax rate of $100 per ton (Anon 1990). However, in 1991 the OECD has proposed a rate of $200 per ton (Anon 1991b) This economic scenario suggests that soil management has tremendous potential for development. The performance of Australian pasture which acts as a sink for atmospheric carbon at a rate of 3.7 million t/yr (Russell 1986), is an indication of the need for economic re-evaluation of rural product.

Acknowledgements:
I wish to express my thanks to Prof Martin Willams of the Dep of Geography and Environmental Science of Monash University and Prof. L.A.Douglas of the Dep of Agriculture and Forestry of Melbourne University for their helpful comments and advice in the preparation of this paper.

References.

Allison, F.E. 1973 *Soil Organic Matter and its Role in Crop Production.* Elsevier Scientific Publishing Co.; New York.

Anon 1991a. The Melbourne Greenhouse Action Declaration. Greenhouse Action Australia. Newsletter No.3 .1 - 11.. Melbourne.

Anon 1991b Sootbusters - European Plans to Tax the Burning of Carbon.. The Economist 321(7728) 19 - 20.

Anon 1990 Carbon Charges as a Response to Global Warming, the Effect of Taxing Fossil Fuels. US Congressional Budget Office, US Govt Printing Office, Washington, D.C.

Barrow, N.J. 1969 The accumulation of soil organic matter under pasture and its effect on soil properties. *Australian Journal of Experimental Agriculture & Animal Husbandry*, **9,** 9-16.

Beckman, G.G. & Hubble, G.D. 1974 The significance of radiocarbon measurements of humus from krasnozems (Ferrasols) in subtropical Australia. *Transcripts of the 10th International Congress on Soil Science*, **6**, 362-371.

Broadbent,F.E.and T, Nakashima 1974 Mineralization of carbon and nitrogen in soil amended with carbon-13 and nitrogen-15 labelled plant material.Soil Sci.Soc.Am.J. 38:313-315.

Brown, Lester (ed) 1991 State of the World 1991. Allen and Unwin. N.Y.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) 1983 *Soils: An Australian Viewpoint*. CSIRO; Melbourne/Academic Press; London.

Commonwealth & State Government Collaborative Study (CSCS) 1978 *A Basis for Soil Conservation Policy in Australia*. Australian Government Publishing Service; Canberra.

Douglas, L.A. 1987 Effects of cultivation and pesticide use in soil biology. In *Tillage, New Directions in Australian Agriculture* (P.S. Cornish & J.E. Pratley, eds). Inkata Press; Melbourne.

Fauer H., L.Faure-Denard and R.W.Fairbridge 1990 Possible effects of man on the carbon cycle in the past and in the future In Greenhouse Effect, Sea Level and Drought. 459-462. Kluwer Academic Publishers, Netherlands

Graham, T.W.G. 1976 Soil Nitrogen status in relation to land development and pasture productivity in the brigalow region of central Queensland. Unpubl. M. Agric. Sci. Thesis. Univ of Queensland. St Lucia.

Houghton, R.A., W.H.Schlesinger, S.Brown and J.F.Richards 1985 Carbon Dioxide Between the Atmosphere and Terrestrial Ecosystems. In Atmospheric Carbon Dioxide and the Global carbon Cycle (ed) J.R.Trabalka.115 - 140 Oak Ridge Nat.Lab. Tenn.

Isbell, R.F. 1966 Soils of the East Bald Hill area, Colinsville district, North Queensland. CSIRO Aust. Div Soils. Soils Land Use Serv. no.48.

Jackman,I. 1960 Organic Matter Stability and Nutrient Availability in Taupo Plumice. N.Z. Journ. Ag. Res. 3: 6-23.

Kassim, G., J.P.Martin and K.Haider. 1981 Incorporation of a wide variety of organic substrate carbons into biomass as estimated by the fumigation procedure. Soil Sci. Soc. Am. J. 45 : 1106 - 1112.

Kohlmaier, G.H., H. Brohl;, U.Fischbach, G.Kratz and E. O. Shire.1983 Role of the biosphere in the carbon cycle and biota models In Carbon dioxide, current views and developments in energy/climate research. eds W.Bach, A,J.Crane, A.L. Berger and A.Longhetto, D.Reidel Co. Dordecht.

Krause, F., W.Bach and J.Koomy 1989 Energy Policy in The Greenhouse Vol I.International Project for Sustainable Energy Parths (IPSEP) El Cerrito, Calif.

Lal R, 1987 Managing the Soils of Sub - Saharan Africa. Science. 236; 1069 - 1076.

Lemon, E.R. 1977 The Lands Response To More Carbon Dioxide In The fate of Fossil Fuel CO2 in The Oceans. (eds) N.R.Andersen and A.Malahoff. 97 - 130. Plenum Press. N.Y.

Matthews, E.G. (1976) *Insect Ecology.* University of Queensland Press; Brisbane.

Marks,P.L. and F.H.Bormann 1972 Revegetation Following Forest Cutting. Mechanisms for Return to Steady State Nutrient Cycling. Science 176 : 914 - 915.

O'Brien, B.J. & Stout, J.D. 1978 Movement and turnover of soil organic matter as indicated by carbon isotope measurements. *Soil Biology and Biochemistry*, **10,** 309-317.

Pearman G. 1989 The greenhouse effect. Global and Australian perspectives. Proc Conf. Energy and Greenhouse Effect. Aust. Inst. Ensery. Melbourne.

Roberts, B. 1990 The Birth of Land Care. Univ of Southern Queensland Press, Toowoomba.

Russell, J.S. & Williams, C.H. (1982) Biogeochemical interactions of carbon, nitrogen, sulphur and phosphorus in Australian agroecosystems. In *The Cycling of Carbon, Sulphur and Phosphorus in Terrestrial and Aquatic Ecosystems*, (I.E. Galbally & J.R. Freney, eds), pp. 61-75. Australian Academy of Science; Canberra.

Russell,J.S. 1986 Improved Pastures In Australian Soils, The Human Impact (eds) J.S.Russell and R.F.Isbell.374-396 Univ.Qld Press.St Lucia.

Schlesinger, W.H. 1977 Carbon Balance in Terrestrial Detritus. Ann.Rev.of Ecology and Systematics. 8 : 51 - 81.

Senanayake, R.1990 In Defence of Living Soil. Australian Journ. Soil and Water Conserv.3 (3) : 6 - 7.

Senanayake, R 1991 Sustainable Agriculture, Definitions and Parameters of Measurement. Journ. Sust. Ag. 1(4) : 7 - 28.

Sorensen, L.H. 1964 Rate of decomposition of organic matter in soil as influenced by repeated air drying- rewetting and repeated additions of organic matter. Soil Biol. Biochem. : 287-292.

Stott, D.E., J.P.Martin, D.D.Focht, and K.Haider 1983. Biodegradation,Stabilization in humus and incorporation into soil biomass of 2,4-D and catchol carbons. Soil Sci. Soc. Am. J. 47:66 - 70.

Tate, R.L. III. 1989 Soil Organic Matter. John Wiley & Sons. N.Y.

van Rees, H., Cummings, D. & van de Graaf,R. (1985) *Soil Structure in Relation to Water Erosion: A Review*. Land Protection Service Technical Publication No. 1. Department of Conservation, Forests and Lands; Victoria.

Witkamp, M. 1971. Soils As Components Of Ecosystems. Ann. Rev. of Ecology and Systematics 2 : 85 - 110.

Senior Research Scientist
Dept of Geography and Environmental Science
Monash University
Clayton
Victoria
Australia.

Figure 1. Fractions of the soil ecosystem.

Figure 2. Relationship between soil fractions with different residence times.