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Preface to workshop ‘Management of carbon in tropical soils under global change: science, practice and policy’

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1. Background

It was first decided to organize a workshop on ‘Modelling of Soil Dynamic Practices’ in 1990 at the XIV International Soil Science Society (ISSS) Congress in Kyoto after the Committee on International Programs [1] (CIP) of ISSS-sponsored Symposium ‘V 8—Global Soil Changes and their Dynamics in a Changing Environment’. This topic seemed redundant when we learned that our Canadian colleagues intended to focus on similar matters during their ‘Lethbridge Symposium’ planned for 1992 (Wood and Dumanski, 1994). By letter exchange and intense discussion with those CIP members meeting in conjunction with the symposium on soil resilience and sustainable landuse September 1992 in Budapest, we opted for a meeting on carbon in tropical soils. We thought that a focus on the African savanna might be even more urgently required than emphasis on rice soils and wetlands, with the International Rice Research Institute (IRRI) there a potential host, and where high caliber expertise was available. Thus, we accepted Dr. Pedro Sanchez’s invitation to have our workshop at the International Center of Research in Agroforestry (ICRAF) in Nairobi, Kenya. Meanwhile the financial problem was settled by a donor group of German GTZ, National Aeronautics and Space Administration (NASA),

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[1] Drs. I.P. Abrol, India; A. Aguilar, Mexico (ex off.); R. Arnold, USA; W.E. Blum, Austria (ex off.); A.M. Algala, Egypt; D.G. Greenland, UK; K. Kyuma, Japan; B.G. Rosanov, Russia; P.A. Sanchez, USA (Kenya); H.W. Scharpenseel, Germany (Chairperson); W.G. Sombroek, The Netherlands (FAO, Italy); J.W.B. Steward, Canada; P.B. Tinker, UK; G. Varallyay, Hungary; G. Vachaud, France; D.H. Yaalon, Israel.

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United Nations Environmental Program (UNEP), United States Environmental Protection Agency (US-EPA), and the United States Department of Agriculture–Natural Resources Conservation Service (USDA–NRCS). As the then chairman of the Standing Committee CIP of ISSS I should thank, besides the donors, in particular Dr. Pedro Sanchez, the Director General of ICRAF, our host and Dr. Mike Swift, Director of the Nairobi-based Tropical Soil Biology and Fertility Program (TSBF), who accepted the strenuous task of being the workshop conveners. Hereby I tacitly include their able cooperators. Our scientific co-sponsors, in addition to ISSS, ICRAF and the UNEP were TSBF and the International Geosphere Biosphere Program–Global Change in Terrestrial Ecosystems (IGBP–GCTE) through liaison of Mike Swift and Bernard Tinker.

2. The carbon cycle

Growing interest in studying the organic carbon cycle in which CO_2 contributes ca. 50% and CH_4 ca. 18% of the anthropogenic greenhouse forcing and with annual 0.5% rises of CO_2 and 1.1% increase of CH_4, was triggered by the classic works of Arrhenius (1896) at the end of the past century and the vision by Callendar (1938) of the anthropogenic CO_2 impact on the temperature regime. During the 1980s and especially since the first Scientific Advisory Committee (SAC) conference on the IGBP, in Stockholm (1988), where most of the planned core projects were initiated, global circulation models and many local and regional studies emerged with emphasis on the greenhouse (radiative) forcing trace gases CO_2, CH_4, N_2O, tropospheric ozone, and CFCs. Information about interactions, such as between CO and CH_4, oxidation by OH radicals, or their oxidation in the presence (> 10 ppT) or absence (< 10 ppT) of NO with regard to tropospheric O_3 production or consumption (Crutzen, 1970), became available as did effects of CFCs and N_2O on the stratospheric ozone layer (Molina and Rowland, 1974; Crutzen and Gidel, 1983). As a result, it seemed clear to expect by CO_2 doubling (CH_4, N_2O, O_3 and CFCs were accounted for with their CO_2-equivalents) a temperature rise of ca. 4°C and at least 1 m eustatic sea level rise.

An intermediate decision was coming up due to deficient quantitative assessment of the positive and negative climate forcing impacts by water vapor, aerosol, SO_4-droplets and the stratospheric ozone–halogen system. A more critical analysis of all contributing climate forcing factors leads to a total positive greenhouse forcing of 3 W m^{-2} ($CO_2 + CH_4 + N_2O +$ tropospheric $O_3 +$ FCC), and a total negative greenhouse forcing of 1 W m^{-2} (stratospheric O_3-halogen system plus aerosol + SO_4-droplets). A difference of positive radiative forcing amounting to 2 W m^{-2} remains. The development by Hart (1978) of the atmospheric curves for CO_2, CH_4, N_2, O_2 over the entire Hadean, Archaean, Proterozoic and Phanerozoic Periods, and the comparison by Whittaker and Likens (1973) of C compartments in woods and grassland, along with many 'state-of-the-art' reviews, tend to stress the risky reality of a forthcoming climate change. Young (1989) gives an estimate of the aboveground dry matter-NPP of the various tropical climate zones (Table 1).

Esser (1990) emphasized the gains in higher biomass production by CO_2 fertilization that happens synchronously with worldwide rising production of mineral fertilizer, especially during the past 50 years. These gains (ca. 1.5 Pg C y^{-1}) exceed the release of C by wood clearing processes. Tans et al. (1990) proposed the use of the missing carbon fraction (MCF) of 1.5 to 2.0 Pg C y^{-1} to explain an increased biomass production in the northern latitudes. However, Broecker and Tsung-Hung (1992) proposed the transport of the MCF by the North Atlantic conveyer circulation towards the tropics. If one believes the MCF, higher biomass production may also be predicted in lower latitudes (Scharpenseel and Pfeiffer, 1995).

Idso (1990) and others questioned the menace of temperature rise by trace gas related greenhouse forcing, arguing that the CO_2 greenhouse effect may be greatly overestimated. Budiko et al. (1985) felt that a slow climate change towards the conditions existing in the Pliocene, with its vast greening, would be beneficial. Although the leading international trend of opinion is supportive of the vision of a climate change scenario [the Intergovernmental Panel on Climate Change, Climate Change report 1995 (IPCC, 1996) claims a discernable human influence on climate], buffering capacity, short-term temperature rises and falls (also observed in the Holocene), superimposing influences by varying of solar radiation (Haigh, 1996) and lack of parallelism between CO_2 and temperature revealed by measurements in sediments over 900 million years ago, (Berner et al., 1995) cause some people to rethink all alternatives.

A multi-authored article in *Science* (Cess et al., 1993) discussed the variations among fifteen models of three-dimensional general global circulation. They felt that the climate feedback mechanisms for restoring the global mean radiation balance, in response to the radiative perturbation by the CO_2 increase, had generally been neglected. One is reminded of 'self regulation of Gaia' hypothesis of Lovelock (1991). In another approach, Flam (1993) discussed the

Table 1
Natural dry matter production in climate zones

Aboveground dry matter NPP according to climate zones	
Humid tropics, short dry season	20.0 kg ha^{-1} yr^{-1}
Subhumid tropics, moist	10.0 kg ha^{-1} yr^{-1}
Subhumid tropics, dry	5.0 kg ha^{-1} yr^{-1}
Semiarid zone	2.5 kg ha^{-1} yr^{-1}

Agroforestry for Soil Conservation, Science and Practice of Agroforestry No. 4. ICRAF, Nairobi/Kenya and CABI, Wallingford, UK (Young, 1989).

overwhelming importance of the sun's brightness, for Earth's future climate, possibly being dominant compared to trace gas impacts. Lindzen (1993) reminds us of the difference between greenhouse and climate forcing, and emphasizes the overwhelming importance of water vapor as a thermostat of the world's climate.

Schneider (1994), in a discussion concerning detection of climate change signals (fingerprints), distinguishes a combined set of three climate forcing factors: (1) regionally heterogeneous anthropogenic and natural landuse changes and associated aerosols, (2) global scale influences from solar variability and (3) transient increases in human produced greenhouse gases.

3. Carbon compartments

Let us return to the immediate task addressed by the papers in this special issue. All possible missing links, such as the poor estimates of C sources and sinks in the soil of our tropical and subtropical ecosystems, have to be explored and elucidated to get a reliable base of data for realistic models. It is essentially an open-end operation.

As a skeleton of carbon pools and compartments, sources and sinks, which form the background of carbon management in tropical soils under global change, I offer some key information (Table 2). It should also remind you of the Rio Conference's 'Second Paradigm' landuse proposal to emphasize recycling, and relax wherever possible the use of agrochemistry. Some key facts:

(1) Fossil C, the largest pool in the organic carbon cycle, comprises about 10,000–13,000 Pg C. According to the International Energy Agency in Paris, ca. 1000 Pg of C are economically available; 250 Pg C being already consumed, ca. 750 Pg are left (Grassl and Klingholz, 1990). Since about 50% of the C will go to the atmosphere pool of 730 Pg C, a further rise of the CO_2-concentration of about 50% must be expected, with no change in current use. The IGBP 1994 report estimated a minable remainder of 1027 Pg C (ca. 100 Pg Oil-C, ca. 100 Pg gas-C, ca. 827 Pg coal-C), which could produce an atmospheric input of ca. 500 Pg of C resulting in a CO_2 rise of about two thirds.

(2) When climate experts speculate about conditions after doubling, even tripling of atmospheric CO_2 in the course of the next century, they focus on CO_2, which produces only 50% of the trace gas forcing. The CO_2 equivalents of the other greenhouse active trace gases are responsible for the other 50%. When talking about the need of reducing CO_2 emission, the inclusion of the CO_2-equivalents of completely different compounds is misleading.

The organic C in soil organic matter (SOM) is the second largest compartment in the organic C cycle. After rather ambiguous estimates of the C pool size between 1000 and 3000 Pg of C (Batjes, 1992), a systematic scrutiny of the

Table 2
Carbon pools, areas, sizes, and annual inputs

C pool, C compartment	Area (10^6 ha)	Stocks (Pg)	C input (Pg yr^{-1})
Ice-free continental surface	12,800		
Woodland (SOM-C + Biomass-C)	> 4,000		
Grassland	> 3,000		
Cropland	1,400		
Wetland (low C residence time to puddling depth, fast C turnover in riceland)	1,020 [c]		
Riceland (51.6% irrig.; 27.2% rainf.; 13.8% upland; 8.0% deep water) [d]	143 [d]		
Caliches, calcretes (up to 50% of C biologic origin)	ca. 1,000	ca. 1,000	ca.01 [e]
C outside epipedon			
Argillic horizons	2,360	ca. 27 [f]	
Spodic horizons	480	ca. 5 [f]	
Paleosols	1,770	9–10 [f]	
Anthropodenic C release		ca. 7.0 y^{-1}	
Biogenic		ca. 1.5 y^{-1}	
Biomass net photosynthesis			60 Pg
Biomass gain by CO_2 fertilization at contemporary rise in production of mineral fertilizer			ca. 1.5–2.0 [g]
Missing carbon fraction (biomass in N latitudes)			ca. 1.5–2.0 [h]
Fluvial transport of C due to erosion			ca. 0.8
(by human initiative)			ca. 0.6

[a] Eswaran et al., 1993.
[b] Dixon et al., 1994.
[c] Twilley et al., 1993.
[d] Neue et al., 1991.
[e] Schlesinger, 1985.
[f] Scharpenseel, 1993.
[g] Esser, 1990.
[h] Tans et al., 1990.
[i] Wollast and McKenzie, 1989.

different soil orders led Eswaran et al. (1993) to settle for 1550 Pg SOM-C in the 12.8 billion hectares of ice-free continental soils.

The dominant subtropical caliche soil layers in a belt of 300 to 550 mm rainfall comprise about 1 billion hectares with approximately 1000 Pg of secondary carbonate-C, of which up to a maximum of 50%, revealed by ^{13}C measurements (Freytag, 1985) are of respirative biological origin. An additional

C sequestration in calcrete soils is only possible to the extent of further Ca or Mg release from silicate weathering. A mere change from primary lithogenic carbonate to secondary pedogenic calcrete carbonate via an intermediate bicarbonate phase does not produce additional C sequestration. The annual C input in calcrete/caliche layers is estimated by Schlesinger (1985) as being of the order of ca. 10 Tg C. The NPP is highest in the tropical climate zones (Young, 1989; Table 1). The largest SOM-plus living biomass C pool is the forest ecosystems with 1146 Pg C (Dixon et al., 1994), with 37% in lower, 14% in middle, and 49% in higher latitudes. Their models predict forest ecosystems to be both C sources as well as C sinks in the future.

Whittaker and Likens (1973) indicated that the SOM-pool in old temperate grassland can exceed the living biomass-C of tropical rain forests. By ^{14}C dating, it has been shown that the C residence time in the SOM of grassland commonly exceeds that of C in woodland, where both exist in similar edaphic environments (Scharpenseel, 1993). The wetlands of the world (ca. 10^9 ha) comprise the largest organic C pool of 640 Pg C (Twilley et al., 1993), with about 130 million hectares of wet riceland containing about 12 Pg of C (Neue et al., 1991).

The 1.4 billion hectares of cropland have about 130 to 140 Pg SOM-C. Due to the continued removal of the crops under subsistence farming, much of the land is lower in N than grassland or forest soils. The total N in the 12.8 billion hectares of ice-free continental surface soils amounts to about 95 Pg N (Eswaran et al., 1993). Soil related biotic systems emit annually ca. 7 Tg N_2O (Bouwman, 1992), of which ca. 3 Tg come from N fertilizer, which contributes to greenhouse forcing and stratospheric ozone layer destruction (Crutzen and Gidel, 1983).

SOM is essential for adequate yields in subsistence farming. It requires about 60 kg N ha^{-1} y^{-1} from SOM decay, lightnings and legumes, to produce yields of 850 to 1000 kg grain ha^{-1}. In wetland rice culture, yields tend to increase with SOM increases up to 4–4.5% (Neue et al., 1991). In steppe and savanna areas the SOM–yield relationships require further investigations.

Modern research on C cycling in soils to identify and quantify the functional SOM-C compartments is successful as an intellectual modelling approach. However, it requires adequate methodologies to verify the pool sizes of the identified functional SOM-C compartments (Parton et al., 1987).

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