Influence du semis direct avec couverture végétale sur la séquestration du carbone et l´érosion au Brésil

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Résumé – Les sols constituent le plus gros réservoir superficiel de C (hors les roches carbonatées), environ 1500 Gt C, ce qui équivaut à presque trois fois la quantité stockée dans la biomasse terrestre, et deux fois celle de l'atmosphère. Toute modification de l´usage des terres et, même pour les systèmes agricoles à l'équilibre, toute modification de l'itinéraire technique, peut induire des variations du stockage du carbone dans les sols. Les pratiques de labour favorisent souvent une aération du sol, qui est propice à l'activité microbienne et conduisent à une dégradation de la structure. Il en résulte sur le moyen et long terme une minéralisation accrue de la matière organique du sol. Du fait de l´absence (ou limitation) des travaux du sol (No-tillage, NT) et d´un maintien d´une couverture végétale permanente (DMC), les systèmes de semis direct favoriseraient la séquestration du carbone et limiteraient l´érosion.

Au Brésil, l'apparition du semi-direct dans la Région Sud, au Paraná date du début des années 1970. Un des objectifs majeurs de l'époque était la lutte contre l'érosion, puis les recherches se sont développées vers la gestion des résidus de récolte et leur effet sur la fertilité, que ce soit pour la gestion du phosphore, le contrôle de l'acidité ou la localisation des engrais. Cette pratique, qui a pris une grande extension et continue de s'accroître dans le centre et le nord du pays, occupe actuellement entre environ 18 millions d'hectares avec une très grande diversité de milieux, d'agrosystèmes et d'itinéraires techniques.

Au Brésil, la plus part des auteurs donnent des vitesses de stockage du carbone dans des sols sous semis-direct allant de 0,4 à1,7 t C ha^{-1} yr^{-1} pour la couche 0-40 cm, avec les taux les plus élevés pour la région centrale du Cerrado. Mais certaines précautions sont nécessaires lors de la comparaison, en terme de séquestration du carbone, des systèmes de semis direct avec les systèmes labourés. Les comparaisons ne doivent pas se limiter au seul stockage de carbone dans le sol, mais doivent prendre compte les changements dans les émissions de méthane et d´oxyde nitreux qui sont des gaz à effet de serres importants.

L´adoption des techniques de semis-direct s´accompagne d´une diminution des pertes en sol par érosion de l´ordre de 90% et du ruissellement superficiel de l´ordre de 70%. Ce qui évite ainsi la perte de nutriments qui sont souvent en quantité limite dans les sols du Brésil. Le succès des techniques de semis-direct au Brésil est dû historiquement au contrôle de la fertilité des sols qui est assuré surtout par la préservation de la ressource sol. Plus récemment, ce succès est amplifié par la préservation de la ressource carbone.

Mots-clés : Semis-direct, Mulch, Stocks, Flux, Gaz à effet de serre, Erosion, Brésil

Influence of notillage on carbon sequestration and erosion in Brazil

Abstract – The soils represent a large carbon (C) pool, approximately 1500 Gt C, which is equivalent to almost three times the quantity stored in the terrestrial biomass, and twice that in atmosphere. Any modification of the land-use and, even for the agricultural systems at steady state, any modification of the management, can induce variations of the soil C stocks. Tillage practices often induce soil aerobic conditions, which is favorable to microbial activity and lead to a degradation of the structure. As a result, on the long term, mineralization of the soil organic matter increases. The adoption of no-tillage (NT) systems and the maintenance of a permanent vegetable cover (DMC), may increase C level in the top soil.

In Brazil, NT practices, and mostly DMC, was introduced ca. 30 years gao in the southern area, in Paraná. One of the major objectives of that time was the fight against erosion, and then researches developed towards the management of the crop waste products and their effect on the fertility, either for the management of phosphorus, either for the soil acidity control, or the localization of manures. This practice, which took a great extension and is still increasing in the center and the north of the country, currently occupies ca. 18 million hectares with a very great diversity of environmental conditions, agrosystem and management.

In Brazil, most of the authors gave rates of carbon storage in the soil varying from 0.4 up to 1.7 t C ha^{-1} for the 0-40 cm soil, with the highest rates in the Cerrado region. But, caution must be taken when analyzing DMC systems in term of C sequestration. Comparisons should not be limited to the sole C storage in soil, and should account changes in methane and nitrous oxide fluxes because there are greenhouse gases contributing to the global warming.

Key words : No-tillage, Mulch, Stocks, Fluxes, Greenhouse Gas, Erosion, Brazil.

1. INTRODUCTION

No-tillage (NT) is presumably the oldest crop production used by humans. In some parts of the tropics, NT is still a part of slash-and-burn agriculture. After clearing an area of forest by controlled burning, seed is directly placed into the soil. However, as humans developed a more systematic agriculture, cultivation of the soil became an accepted practice for preparation of a more suitable environment for plant growth. Pictures in ancient Egyptian tombs portray a farmer tilling his field using a plow and oxen prior to planting of the seed. Indeed, tillage as symbolized by the moldboard plow became almost synonymous with agriculture (Dick et al., 1997). No-tillage can be defined as a crop production system where soil is left undisturbed from harvest to planting except for nutrient injection. In other words, NT is an ecological approach to soil surface management and seedbed preparation.

In Brazil, NT was developed in response to soil erosion and continuously declining of land productivity and under "conventional" systems based on soil tillage (CT) in the Southern part. The underlying land management principles that led to the development of NT systems were to protect the soil surface from sealing by rainfall, to achieve and maintain an open internal soil structure, and to develop the means for safe disposal of any surface runoff that would nevertheless still occur. Consequently, the NT technical strategy was based on three essential farm practices, namely: (i) not tilling the soil; (ii) maintaining soil cover at all times; and (iii) using suitable crop rotations. This particular NT system, also sometime reported as zero-tillage systems, is direct seeding mulch based cropping systems (DMC).

Farming methods that use mechanical tillage, such as the moldboard plough for seedbed preparation or disking for weed control, can promote soil carbon (C) loss by several mechanisms: they disrupt soil aggregates, which protect soil organic matter from decomposition (Karlen and Cambardella, 1996; Six et al., 1999), they stimulate short-term microbial activity through enhanced aeration, resulting in increased levels of net CO_2 release and other gases released to the atmosphere (Bayer et al., 2000a,b; Kladivko, 2001), and they mix fresh residues into the soil where conditions for decomposition are often more favorable than on the surface (Karlen and Cambardella, 1996; Plataforma Plantio Direto, 2003). Furthermore, CT can leave soils more prone to erosion, resulting in further loss of soil C (Lal, 2002). DMC practices however cause less soil disturbance and result often in significant accumulation of soil C (Sá et al., 2001, Schuman et al., 2002) and consequent reduction of gas emissions, especially CO_2, to the atmosphere (lal, 1998; Paustian et al., 2000) compared to CT. Furthermore, the possibility of an earlier seeding date with direct seeding enables very often in Brazilian conditions a second crop cycle with a commercial or only a cover crop. Total biomass returned annually to the system becomes then consequently superior. Nevertheless, there is considerable evidence that the main effect is in the topsoil layers with little overall effect on C storage in deeper layer (Six et al., 2002)

The objective of this paper is to provide a synthesis on Influence of DMC on C sequestration and erosion in Brazil

2. HISTORY OF NO-TILLAGE EXPANSION IN BRAZIL

The history of DMC started in the South of Brazil. The first scientific NT experiment was conducted in 1969 by the Federal University of Rio Grande do Sul in the southern part of Brazil in an 1-ha area, but was interrupted by the accidental destruction of the NT seeding machine just after the first seeding (Borges Filho, 2001). Other study started at the very beginning of the 70's in the Parana state near Londrina and Ponta Grossa (Borges Filho, 2001 ; Sá, 2001; Six et al., 2002). The success of the NT systems mainly in controlling soil erosion and in reducing costs attracted some farmers of the Parana State. Moreover, the 70's corresponded also to the release of modern herbicides, beginning with glyphosate purpose-built herbicides. During the crop year 1974/75 the DMC systems was adopted in about 235 properties, representing ca. 16500 ha of cultures in the Parana State. Untill the end of the 70's the diffusion of the DMC systems was slow and limited to the Parana and Rio Grande do Sul states mainly due to the lack of studies and technical assistance. At the beginning of the 80's, some producers organized themselves in associations to promote DMC systems, the most famous being the "Clube da Minhoca" (literally "Earthworm Club") and the "Clubes Amigos da Terra" (Soil Friends Clubs) (Borges Filho, 2001).

In the Cerrado regions (Central area of Brazil covered by Savanna vegetation) the DMC was imported from the South of the country, at the beginning of the 80's, but some adaptation to the systems had to be done. The winter of the Cerrado region is dryer and hotter than the South region and the summer is hot and humid inducing a faster degradation of the crop residues. One of the first tests of DMC was realized in 1981 at Rio Verde in the Goiás State by Eurides Penha who seeded 200 ha of soybean on soybean residues from the previous crop. The year after, another farmer tried out DMC systems with soybean and maize in Santa Helena de Goiás a neighboring city (Borges Filho, 2001). At the beginning the expansion was slow, accelerated at the end of the 80's. During the crop year 1991/92 area under DMC in the Cerrado was ca. 180000 ha representing 13.3 % of the total Brazilian land under DMC. Then DMC expansion was faster in the Cerrado than in the rest of Brazil (Figure 1).

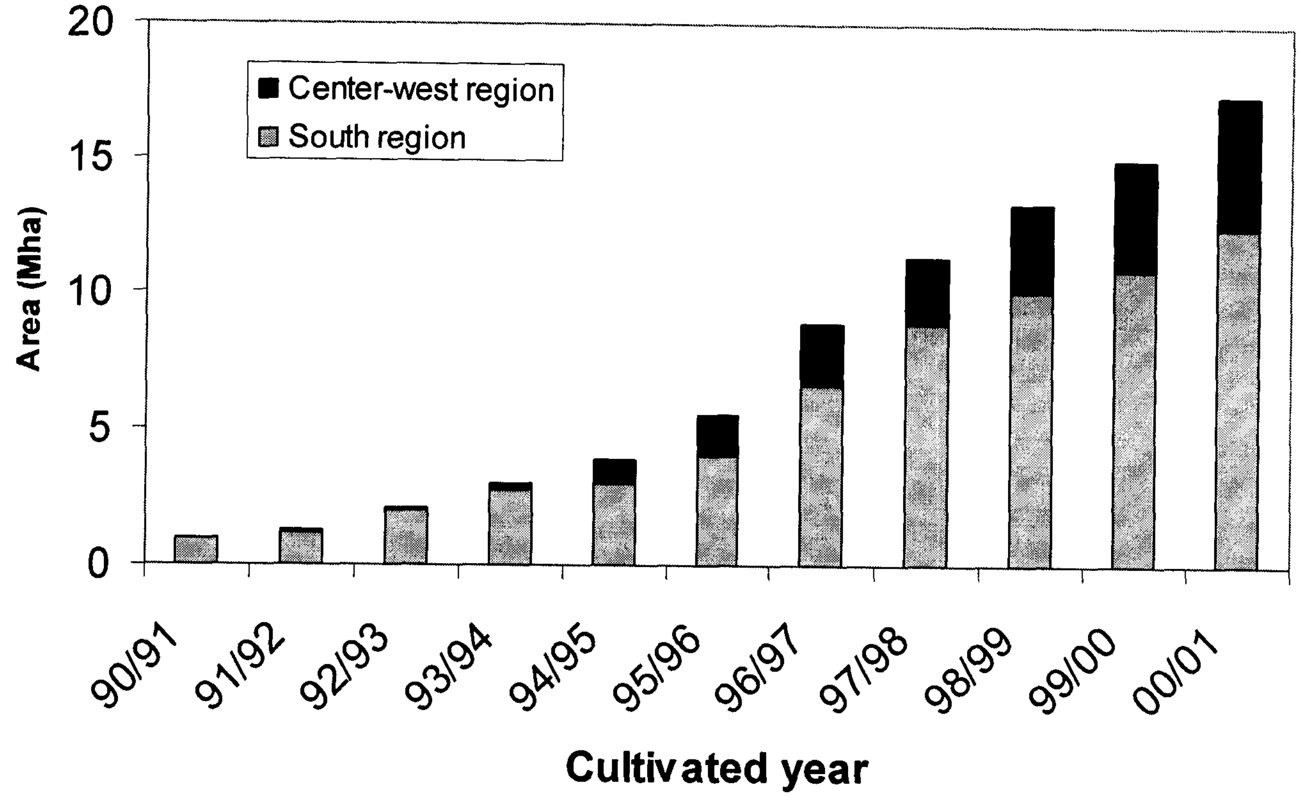

Figure 1. Cultivated area under DMC systems in Brazil. Adapted from Febrapdp (2002).
Figure 1. Superficie cultivée en semis-direct avec maintien d'un couverture végétal (DMC) au Brésil. Donnés adapté de Febrapdp (2002).

Globally, at present, approximately 63 million ha are under NT systems over the world, with USA having the largest area at about 21.1 million ha (Derpsch, 2001). The ca. 18 million ha covered by DMC practice (Febrapdp, 2002) make Brazil the second largest adopter in the world. This expansion is taking place not only as result of the conversion from CT in the southern region (72%) but also after clearing natural savannah in centre-west area (28%). More recently, due to the high profits, ranchers in the Amazon region are converting old pastures to soybean/millet under DMC. During the crop year 2000/01 the DMC systems dominated in the South region (Parana – 5 Mha, Rio Grande do Sul – 3,6 Mha and Santa Catarina – 1 Mha) and Cerrado region 4.9 Mha, and had certain expression in the Mato Grosso do Sul (1.7 Mh) and São Paulo State (1 Mha).

3. CARBON SEQUESTRATION

For the purpose of this review the term C sequestration is used according to the definition discussed by Bernoux et al. (2004) and reported here: "Soil C sequestration", for a specific agro-ecosystem, in comparison with a reference one, should be considered as the result, for a given period of time and portion of space, of the net balance of all GHG, expressed in C-CO2 equivalent or CO2 equivalent, computing all emissions sources at the soil-plant-atmosphere interface, but also all the indirect fluxes (gasoline, enteric emissions,...). Applied to DMC system compared to CT systems it means that not only C storage should be taken into account, but also the GHG fluxes such as N_2O and CH_4 at the field and farm levels.

3.1. Carbon storage

Lindstrom et al. (1998) reported that globally, conservation or reduced tillage can store 0.1–1.3 t C ha^{-1} yr^{-1} and could feasibly be adopted on up to 60 percent of arable lands. These estimates depend on continued use of conservation tillage. Use of intensive tillage or moldboard plowing can negate or offset any gains made in C sequestration.

Changes in soil C stocks under NT have been estimated in earlier studies for temperate and tropical regions. Cambardella and Elliott (1992) showed an increase of 6.7 t C ha^{-1} in the top 20 cm in a wheat-fall rotation system after 20 years of NT in comparison to CT. Reicosky et al. (1995) reviewed various publications and found that organic matter increased under conservation management systems with rates ranging from 0 to 1.15 t C ha^{-1} yr^{-1}, with highest accumulation rates generally occurring in temperate conditions. Lal et al. (1998) calculated a C sequestration rate of 0.1 to 0.5 t C ha^{-1} yr^{-1} in temperate regions. For the tropical west of Nigeria, Lal (1997) observed a 1.33 t C ha^{-1} increment during 8 years under NT as compared to the CT of maize, which represents an accumulation rate of 0.17 t C ha^{-1} yr^{-1}. More recently, A recent review by Six et al. (2002) reported that in both tropical and temperate soils, a general increase in C levels ($\approx 325 \pm 113$ kg C ha^{-1} yr^{-1}) was observed under NT systems compared with CT.

In the tropics, specifically in Brazil, the rate of C accumulation has been mostly estimated in the two main regions under DMC systems (south and centre-west regions). In the southern region Sá (2001) and Sá et al. (2001) estimated a greater sequestration rates of 0.8 t C ha^{-1} yr^{-1} in the 0-20 cm layer and 0.9 t C ha^{-1} yr^{-1} in the 0-40 cm soil depth after 22 years under DMC compared to the same period under CT. The authors mentioned that the accumulated C was generally greater in the coarse (> 20 μm) than in the fine (< 20 μm) particle-size-fraction indicating that most of this additional C is weakly stable. Bayer et al. (2000a,b) found a C accumulation rate of 1.6 t ha^{-1} yr^{-1} for a 9 year DMC system compared with 0.10 t ha^{-1} yr^{-1} for the conventional system in the first 30 cm layer of an Acrisol in the southern part of Brazil. Corazza et al. (1999) reported an additional accumulation of approximately 0.75 t C ha^{-1} yr^{-1} in the 0-40 cm soil layer due to NT in the Cerrado region located in the centre-west. Estimates by Amado et al. (1998, 1999) indicated an accumulation rate of 2.2 t ha^{-1} yr^{-1} of soil organic C in the first 10 cm layer. Other studies considering no-till system carried out in the centre-west part of Brazil (castro Filho et al., 1998, 2002; Lima et al., 1994; Peixoto et al., 1999; Resck et al., 2000; Riezebos et al., 1998) reported soil C sequestration rates due to NT varying from 0 up to 1.2 t C ha^{-1} yr^{-1} for the 0-10 cm layer.

Table 1 reported more detailed accumulation rates organized by region derived from published and unpublished material (Master and doctorate thesis and report). In the Cerrado region C storage rates vary from 0.4 up to 1.7 t C ha^{-1} for the 0-40 cm soil layer, which is the same amplitude of variation found for the South region (-0.5 to 0.9 t C ha^{-1}). Considering the surface soil layer, i.e. the first 20 cm depth, mean rates of C storage were similar among "Cerrado" (0.65 t C ha^{-1}), "South" (0.68 t C ha^{-1}), and "Other" (0.60 t C ha^{-1}) regions. As can be seen in Table 1, variation presented in the South region (-0.07 to 1.6 t C ha^{-1}) for the 0-20 cm layer is much broader than the other regions. The calculated value of 0.68 t C ha^{-1} was obtained averaging 15 observations (Table 1) in which the standard deviation (0.54 t C ha^{-1}) has the same magnitude as the estimated mean value. However, it is important to mention that those are mean values, aggregating different soil and crop types, used here only to illustrate data on Table 1; and therefore, must be used with caution.

Table 1. C storage rates (accumulation rate when a CT system is converted to a DMC systems) in DMC systems in Brazil
Tableau 1. Taux d'accumulation de carbone dans le sol (quand un système avec labour (CT) est converti en semis-direct (DMC) pour des systèmes en semis-direct au Brésil.

Place	State[a]	Succession or dominant plant	Reported soil classification	Clay (%)	Layer (cm)	Time (yr)	Rate (tC/ha)	Ref.
Cerrados region								
Planatina	DF	S/W	Latossol (Oxisol)	40-50	0-20	15	0.5	Corazza et al., 1999
Sinop	MT	R - S/So - R/So - S/M- S/E	Latossol (Oxisol)	50-65	0-40	5	1.7	Perrin, 2003
Goiânia	GO	R/S	Dark red Latossol		0-10	5	0.7	Metay, unpublished
Rio Verde	GO	M or S/Fallow S/M or So or Mi	Red Latossol	45-65	0-20	12	0.8	Scopel et al., 2003
Not specified	?	M or S	Dark Red Latossol (Oxisol)	>30	0-40	16	0.4	Resck et al., 2000
South region								
Londrina	PR	W/S	Oxisol		0-10	22	0.31	Machado & Silva, 2001
					0-20	22	0.25	
					0-40	22	-0.17	
Londrina	PR	S/W – S/L –M/O	Red Latossol		0-20	7	0.5-0.9	Zotarelli et al., 2003
Londrina	PR	S/W/S or M/W/M or S/W/M	Oxisol (Typic Haplorthox)		0-10	14	0.4^d	Castro Filho et al., 1998
					0-20		0.2^d	
Londrina	PR	S/W/S or M/W/M or S/W/M	Oxisol (Typic Haplorthox)		0-40	21	0^c	Castro Filho et tal., 2002
Ponta Grossa	PR	(S or M)/(O or W)	Oxisol (Typic hapludox)	40-45	0-40	22	0.9	Sá et al., 2001
Tibagi	PR	(S or M)/(O or W)	Oxisol (Typic hapludox)	40-45	0-40	10	-0.5	Sá et al., 2001
Tibagi	PR	M/W – S/O – S/O	Red Latossol (Oxisol)	40-45	0-10	22	1.0^d	Venzke Filho et al., 2002

Tibagi	PR	M/W-S/O-S/O	Red Latossol (Oxisol)	42	0-20	10	1.6	Siqueira Neto, 2003
Toledo	PR	S/O	Haplic Ferrasol		0-10	3	-0.68[d]	Riezebos et al., 1998
		S/O			0-10	10	0.37[d]	
Passo Fundo	RS	W/S	Oxisol		0-10	11	0.59	Machado & Silva, 2001
					0-20	11	-0.07	
					0-40	11	0.29	
Passo Fundo	RS	W/S	Red Latossol (Typic hapludox)	63	0-30	13	0[c]	Sisti et al., 2004
		W/S-V/M			0-30	13	0.4	
		W/S-O/S-V/M			0-30	13	0.7	
Passo Fundo	RS	W/S	Red Latossol (Typic hapludox)	63	0-10	11	0.3	Sisti et al., 2004
					0-20	11	0[c]	
					0-30	11	0[c]	
Passo Fundo	RS	W/S – W/M	Red Latossol (Typic hapludox)	63	0-10	11	0.4	Sisti et al., 2004
					0-20	11	0.2	
					0-30	11	0[c]	
Santa Maria	RS	M and Mu/M	Ultisol	15	0-20	4	1.3	Amado et al., 2001
Eldorado do Sul	RS	M/G			0-17.5	5	1.4[d]	Testa e tal., 1992
		M/La			0-17.5	5	0.6[d]	
		O/M			0-17.5	5	0.2[d]	
Eldorado do Sul	RS	O+V/M+C	Acrisol (Typic Paleudult)	22	0-17.5	9	0.84	Bayer et al., 2002
Eldorado do Sul	RS	O/M	Acrisol (Typic Paleudult)	22	0-30	9	0.51	Bayer et al., 2000b
		O+V/M+C			0-30	9	0.71	

Eldorado do Sul	RS	O+V/M+C	Acrisol (Typic Paleudult)	22	0-17,5	12	1.26	Bayer et al., 2000a
Lages	SC	M or S / W or O	Cambissol		0-20	8	1.0	Bayer & Bertol, 1999
Other regions								
Campinas	SP	S or C / M	Rhodic Ferralsol (Typic Haplorthox)	60	0-20 0-20	3 8	0.8[de] 0.4[de]	De Maria et al., 1999
Sete Lagoas	MG	M/B	Dark red Latossol (Typic Haplustox)		0-15 0-45	10	0[c] 0[c]	Roscoe & Buurman, 2003

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[a] PR =Parana, RS =Rio Grande do Sul, DF = Distrito Federal, SC = Santa Catarina, SP = São Paulo, MT = Mato Grosso, GO = Goiás, MG = Minas Gerais; [b] Dominant succession: W = Wheat (*triticum aestivum*), S = Soybean (*Glycine max*), So = Sorghum (*Sorghum vulgaris*), R = Rice (*Oriza sativa*), E = *Eleusine coracana*, O = Oat (*Avena sativa*), V = Vetch (*Vicia sativa*), M = Maize (*Zea mays*), B = Beans (*Phaseolus vulgaris*), Mu = Mucuna (*Stizolobium cinereum*), C = cowpea (*Vigna unguiculata*), L=Lupine bean (*Lupinus angustifollios*), La = Lablabe (*Dolicbos lablab*), G = Guandu (*Cajanus cajan*); [c] 0 means that the difference was not significant; [d] calculated using an arbitrary soil bulk density of 1.2 g cm^{-3}; [e] value reported for OM, C= OM / 1.724.

Studies performed in Brazil reported that OC contents under DMC and conventional system can be practically the same as those found under native vegetation. For instance, Sisti et al. (2004) reported that the soil under native vegetation (neighbouring the experimental area) had a high C and N concentration (37 g C and 3.1 g N kg per soil) in the first 5 cm depth. C and N concentration declined to approximately half of these values at 10-15 cm layer. As was to be expected, the C concentration of the surface 5 cm of soil was considerably higher in all three rotations managed with DMC than with conventional system, although this was still not as high as under the native forest. Machado and Silva (2001) in an Oxisol of the south region of Brazil, after 11 years of soybean-wheat cultivation under DMC and CT systems, compared to an adjacent non-cultivated area, showed a decrease of 23.4% and 47.8%, respectively, in the OC content for the first 5 cm soil depth. However, the authors pointed out that considering the 0-40 cm layer, the content of OC under both tillage systems was practically the same as in the forest soil.

Another important point when comparing Soil C stocks in DMC and conventional systems is to avoid comparing very superficial layer such as 0-5 cm and 0-10 cm. Because in conventional systems involving tillage it occurs a homogenisation in the first 20 cm, and thus superficial layer cannot be compared directly without a bias.

3.2. GHG emissions (DMC versus CT)

Increasingly, attention has been focused on the relationship between atmospheric carbon dioxide concentration and C concentrations in the soil. Carbon dioxide is the primary greenhouse gas that contributes to climate change by accumulating in the atmosphere and trapping the sun's heat. Farming practices, such as tillage intensity and rotation, may alter C sequestration in soil and this help alleviate the trend towards increasing concentrations of carbon dioxide in the atmosphere. But other GHG fluxes such as N_2O and CH_4 at the field and farm levels may be altered by DMC. Six et al. (1999) reported that, on average, in temperate soils under NT compared CT, CH_4 uptake ($\approx 0.42 \pm 0.10$ kg C-CH_4 ha^{-1} yr^{-1}) increased and N_2O emissions increased ($\approx 2.91 \pm 0.78$ kg N-N_2O ha^{-1} yr^{-1}). These increased N_2O emissions lead to a negative Global Warming Potential (GWP) of the system when expressed on a C-CO_2 equivalent basis: GWPs are measurements of the relative radiative effect of a given substance (CO_2 here) compared to another and integrated over a determined time period. This means that one kg of CH_4 is as effective, in terms of radiative forcing, as 23 kg of CO_2. On a C or N mass base, 1 kg of C-CH_4 is equivalent to 8.36 kg of C-CO_2, and 1kg of N-N_2O to 126.86 kg C-CO_2. The authors studied other changes induced by NT and concluded that "from an agronomic standpoint NT is beneficial, but from a global change standpoint more research is needed to investigate the interactive effects of tillage, fertilizer application methodology and crop rotation as they affect C-sequestration, CH4-uptake and N_2O-fluxes, especially in tropical soils, where data on this matter is still lacking". This is particularly true for the N_2O fluxes when legume crops are used as cover-crops or green N fertilizer, because some studies tend to show that N_2O emissions may be enhanced as a result (Flessa et al., 2002; Giller et al., 2002).

Few results have been published about N_2O emissions in tropical regions. Pinto et al. (Pinto et al., 2002) showed low NO and N_2O emissions, low nitrification rates and the majority of inorganic N in the form of NH_4^+ all indicate conservative N cycle in the Cerrado. Passianoto et al. (2003) suggested that NT regimes will result in lower CO_2 emissions than degraded pastures, but higher N_2O and NO emissions than degraded pastures in Amazônia and that the addition of N fertilizer stimulated N_2O and NO emissions.

In a recent study (Metay et al., 2004) compared the production and emission of N_2O from two treatments: CT (offset) and DMC (no-tillage and direct sowing in the cover plants after weed-killer application). The main crop was rice (*Oriza sativa*) and the cover whether a fodder grass (*Brachiaria*) whether a legume (*Crotalaria*). The experiment was established at "Embrapa Arroz e Feijão" field experiment station, in Santo Antonio de Goiás (Goiás State, Brazil) in 2002-2003. Climatic data, C sequestration, temperature, mineral nitrogen, soil moisture have been monitored for more than one year as potential determinants of the GHG emissions. For measuring GHG fluxes, twelve chambers were used for each treatment. Fluxes were measured twice a week. Chambers were closed for 2 hours. The chamber atmosphere was sampled 5 times during this period in 13 ml vacuum container tubes that we had previously purged. N_2O fluxes were calculated by linear interpolation.

N_2O concentrations in the soil atmosphere were determined using permanent gas samplers inserted into the soil at various depths (10, 20 and 30 cm). The results demonstrated that N_2O emissions were very low (< 1 g ha^{-1} day^{-1}, limit that is considered as a real flux) for both systems. Peaks of N_2O were observed after fertilization. For N_2O is produced mainly by denitrification process, low NO_3^- in soils and water filled pore space (WFPS) lower than 60% most of the time may explain this situation. Possible explanations for the low WFPS under these crops include evaporation under high temperature (25°C on average). But measurements of gas concentrations in soil showed that the production of N_2O is quite important (concentrations from 1 to 30 times the atmospheric concentration). This leads to think that N_2O is produced but can not diffuse to the soil surface because the denitrification is complete and produces N_2 or because it is nitrified before diffusing. Data on microporosity in the upper layer will be studied further so as to better understand the diffusion and compaction conditions in these soils (Yamulki et al., 2002). These results were relevant concerning the sampling period, occurring immediately after fertilizing (November, December and January). We may notice a higher variability on fluxes after fertilization which agrees with the general pattern that fertilization increases the emissions of N_2O for a higher organic N is available (Weitz et al., 2001). Further measures on potential denitrification will be led so as to better understand the capacity of this soil to produce and emit N_2O.

Regarding the CH_4 fluxes, Six et al. (2004) recognized that few studies reported CH_4 flux differences between DMC and NT systems, and that all found a significant enhancement of CH_4 uptake (averaging 0.6 kg ha-1 yr-1) with DMC adoption. Our preliminary results obtained in the Cerrado region near Rio Verde confirm that observation. CH_4 fluxes where analyzed in November 2003 and January 2004 in 3 DMC systems aged respectively 9, 11 and 13 years, and compared to a CT situation. First results showed CH_4 sinks in all situations, but higher in the DMC systems. CH_4 sinks in the CT was 3.8 and 4.8 g C-CH_4 ha^{-1} day^{-1} respectively in November and January, whereas they varied between 8 and 16 g C-CH_4 ha^{-1} day^{-1} in November and 7.3 and 14.3 g C-CH_4 ha^{-1} day^{-1} in the DMC situations. But these data really need to be completed with measurement all along the crops cycles, before drawing a general conclusion.

3.3. Farm level.

Several studies led in Brazil showed that NT systems when compared to CT provided an economy of Fuel. For example Landers (2001) reported the evolution of the fuel consumption by a farmer cooperative in Planaltina (Goías State) over ca. 2270 ha during a six-year period of conversion from 100% CT for the agricultural year 92/93 to 100% NT for the agricultural year 97/98. The total used tractors time was 10630 hours in 92/93 and 5135 hours in 97/98, showing a decrease in fuel consumption of about 50%. Landers (2001) noted that it was also possible to reduce the number of machinery operators to almost half, while the others were gainfully employed in new farm enterprises.

Regarding the pesticides uses and the fugitive emissions associated mainly during their production no consistent compilation still have been published authorizing to compare CT and DMC in term of GHG emission associated with the pesticides uses for each system.

4. EROSION

Erosion is the removal of a mass of soil from one part of the earth and its relocation to other parts of the earth. Water erosion is that portion of erosion caused by water (Laflen & Roose, 1998). Soil degradation due to water erosion is one of the major threats to sustainable agricultural land use and lead to serious and costly degradation of water and air quality. Pimentel et al. (1995) estimated world wide costs of soil erosion to be about US$ 400 billion per year. According to Laflen and Roose (1998) there is no region of the globe where soil degradation due to water erosion is not a threat to the long-term sustainability of mankind.

Change in land use can alter the soil organic C, which usually decreases as the climax vegetation is removed for conversion to an agricultural land use (Houghton, 2003). Also, the rate of soil organic C depletion is vastly accentuated with onset of soil degradation by any of the major degradative processes, eg. physical, chemical or biological (Lal, 1998). For instance, the soil organic C content is dramatically lowered by accelerated soil erosion on-site. However, soil organic S content of the depositional site may increase. The net result of erosion and deposition on a watershed scale depends on the balance of net losses and gains in soil organic C for all landscape units (Lal, 1997).

Soil erosion is responsible for on-site depletion of soil organic C content due to transport of dissolved and particulate organic C in runoff and eroded sediment. The total amount of soil displaced annually by water erosion from world soils is estimated at 190 Pg, of which 19 Pg is transported by world rivers to the oceans. Assuming a mean C content of 3%, total C displaced from world soils by water erosion amount 5.7 Pg yr^{-1}. Assuming that one-fifth of the C displaced by erosion is easily decomposed and mineralized; it will lead to C efflux of 1.14 Pg yr^{-1} into the atmosphere (Lal, 1995).

For the tropics, Lal (1995) estimated that the total transport or movement of C displaced with soil erosion is 1.59 Pg yr^{-1}. According to the author, this estimate may range from a low of 0.80 Pg yr^{-1} to a high of 2.40 Pg yr^{-1}. However, only a fraction of soil moved from its original place is transported out of the watershed. The delivery ratio for tropical watershed may also be as low as 10%. This implies that as much as 0.16 Pg C yr^{-1} may be transported out of tropical watersheds with a range of 0.08 to 0.24 Pg C yr^{-1}.

In Brazil, almost every estate has registered problems related to soil erosion. At the present, Brazil loses about 500 million tons of soil due to erosion, which is correspondent to removing 15 cm of the topsoil in the Southeastern and Center-western regions of the country (Thomazine et al., 2003). According to De Maria (2004), NT reduces about 90% of the soil loss and 70% of the runoff. For instance, in Sao Paulo State (Southeastern of Brazil) there are 2.4 millions ha under crop cultivation. If the entire cultivated area were under CT, about 24 million tons of soil per year would be lost by erosion and more than 4 billion m^3 of water by runoff. On the other hand, adopting NT practices, soil losses would have been 5 million tons per year and water due to runoff would be approximately 2 billion m^3. Erosion process cause also nutrient losses. Considering again the scenarios mentioned before, NT cultivation would cause a loss of 12 ton yr^{-1} of phosphorus, 120 ton yr^{-1} of potassium and 850 t yr^{-1} of calcium plus magnesium, amounts that are much smaller than those usually lost in CT (250, 4000, and 12000 ton yr^{-1}, respectively).

In order to reduce soil erosion rates, some Brazilian farmers have adopted appropriate farming systems, such as use of cover crops, mixed crop rotations, and conservation tillage. Conservation tillage systems have been developed as alternatives to conventional moldboard plowing to reduce not only water but also wind erosion and to maintain and/or increase soil organic C levels (Six et al., 2002). These practices manage litter and crop residues with minimum and NT. Keeping a mulch of crop residues protects the soil surface against raindrop impact, decreases evaporation, increases water storage, reduces production costs, and slows soil organic C decomposition (Rosell et al., 1997).

Moreover, conservation tillage reduces emissions and sequesters more C. A reduction emission is due to low fuel consumption, less herbicide use, and low machinery use. In general, cultivation and plow-based tillage systems decrease soil organic C content. However, adoption of conservation tillage improves soil organic C, enhances soil aggregation, improves soil biodiversity, and increases C sequestration in soils (Lal et al., 1997)

It has been reported (Bajracharya et al., 1998; Lal, 1995, 1997) that while deposition of eroded soil does not necessarily lead to the direct sequestration of C, it is likely to increase the overall sequestration of soil organic C by leading to an accumulation of organic material which has a greater potential to be converted to the stable soil organic C form. Depositional and non eroded areas increase potential soil organic C sequestration possibly by providing favorable conditions for aggregation. C sequestration in soil seems to occur within the aggregate stability. Those authors concluded that erosion is likely to lead to a gradual depletion of soil organic C by exposing the stable C pool in micro aggregates of not only the surface layer but subsoil as well, to degradative processes by disrupting macro aggregates and removal of successive layers of soil.

5. SUMMARY AND CONCLUSION

Caution must be taken when analyzing DMC systems in term of C sequestration. Comparisons should not be limited to the sole C storage in soil. Fluxes of methane and nitrous oxide may shift or change the final balance computed in C-CO_2 equivalent based on GWP of each gas. Most preliminary results tend to indicate that DMC adoption in Brazil is a promising mitigating strategy. The success of DMC systems among farmers is not to be proved in Brazil and is not really depending of C sequestration benefit. Thus DMC systems represent in Brazil really a high potential to mitigate GHG that is not depending of an eventual C market or political incentives.

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