

# REVISED CARBON SEQUESTRATION RATES IN TROPICAL AND SUBTROPICAL SOILS UNDER NO-TILLAGE IN BRAZIL<sup>1</sup>

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## INTRODUCTION

Brazil has the second world largest cropland under no-tillage reaching 23 millions ha in 2007/08. The no-till reach approximately 50% of total cropland and it is the largest experience with no-till in tropical and subtropical environment. The larger adoption of no-tillage replacing conventional tillage is a recent process; it has been increased sharply since the 90's. Therefore, at the present time it is estimated that most of Brazilian no-tillage is reaching 20 years of adoption in areas that previously had a historic of 20 to 30 years of conventional tillage. During the conventional tillage adoption the rates of soil erosion were over 20 Mg ha<sup>-1</sup> y<sup>-1</sup> and the decline observed in soil organic matter content in croplands is at least partially credited to this severe soil erosion. The decline of original soil organic matter in agriculture soils ranging from 25 to 50% in accord to wheatear, soil texture/mineralogy and soil management conditions. The improvement in tillage system was faster than the improvement in the cropping system therefore the traditional cropping systems (cash crops with low crop rotation) are still the most applied by commercial farmers. Soybean, the main cash crop, area in Brazil reach 21 millions ha in 2008. In large areas farmers growth soybean in summer monocropping with low rotation with maize (3 to 5 years of soybean to 1 year of maize) reducing the potential of carbon sequestration rate. Maize area is 14 millions ha. No-tillage area is located mainly in Oxisol and Alfisol soils under tropical and subtropical climates. The kaolinitc is dominant clay mineralogy in both Alfisol and Oxisol, although iron and aluminum oxides were higher in the second group of soils.

In subtropical climate black oat is the main cover crop used and the soil cover ranging from 42 to 57%, while in tropical climate pearl millet is the main cover crop and the soil cover ranging from 15 to 35% (Bastos Filho et al., 2007). The results with carbon balance in monocropping soybean show a neutral effect in carbon in the soil-plant-atmosphere system under no-tillage (Escobar, 2007). In this case, the winter cover crops are the main option in South Brazil while the late summer/fall cover crops are the main option in Central Brazil to improve the carbon input trough improvement in soybean system.

In Southern Brazil the wet subtropical has regular rainfall distribution through the year (all months had precipitation > evapotranspiration) which allows the double cropping system and

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a branch of options of summer and winter cover crops to improve cropping system. In Cerrado (Central Brazil) it is common have irregular rainfall distribution with two distinct seasons: a dry (evapotranspiration>precipitation) and wet season (precipitation>evapotranspiration). The duration of dry season is variable but in general it would be last three to six months. Therefore, the options to improve cropping system are narrower in Central than in Southern Brazil. Heavy rains with high erosivity index are common in both regions. In addition, in Southern Brazil the temperature had three to four months with lower temperature (fall/winter) with seldom freezing weather followed by warmer months, while the temperature in Central Brazil is higher and it had isotherm pattern. As a consequence, the residue decomposition is much faster in Central than in Southern Brazil. Although, the elevation of the site could change these patterns, in general the climate is more carbon conservative in Southern than in Central Brazil.

Considering the large variation of climate, soils, and cropping systems existing in Brazil a general average carbon sequestration rates had a high uncertain. In order to review the previous estimation of carbon sequestration rates in agriculture soils a set of 11 long term experiments, sampled by the authors and collaborators, have been used to investigate tillage and cropping systems (Table 1). In this set, eight experiments were located in Southern Brazil under subtropical and three under tropical climate (Cerrado – tropical savanna); eight experiments were under Oxisols and three were under Alfisols. In the set of the experiments investigated the tillage effect in carbon sequestration was estimated basis on the change in carbon stock over the years comparing no-tillage and conventional tillage (Equation 1) and the cropping system effect was estimated basis on the change in carbon stock over the years comparing improved and traditional cropping system (Equation 2). The experiments have been carried out in a range of 7 to 19 years. The soil depths investigated were 0-20 and 0-30 cm.

**Tillage effect**

$$C \text{ sequestration rate} = \frac{C \text{ stock in no-tillage soil} - C \text{ stock in conventional tillage soil}}{\text{Years under no-tillage}} \quad (1)$$

**Crop rotation effect in no-tillage**

$$C \text{ sequestration rate} = \frac{C \text{ stock in improved crop rotation} - C \text{ stock in traditional crop rotation}}{\text{Years under traditional crop rotation}} \quad (2)$$

In most of experiments investigated there was carbon sequestration under no-tillage compared to conventional tillage, although the rates were a little lower than previous estimation (Bayer et al., 2006). In Southern Brazil the rate of carbon sequestration in no-till compared to conventional tillage was approximately the double of observed in Central Brazil (Table 1). This result is attributing to higher temperature and precipitation especially during the late spring, summer and early fall in Central Brazil compared to Southern Brazil. The combination of high temperature and high precipitation during some months in Central Brazil accelerate the residue decomposition and soil carbon turnover. During the dry season the soil carbon turnover is reduced due to water limitation to microbial biomass activity. Mieleniczuk et al. (2003) estimated the rate of SOM mineralization under conventional tillage regimes in Southern Brazil to be on average 5–6% per year compared to an average of about 3% per year in no-till soils.

In traditional cropping system with low input of biomass ( $< 5 \text{ Mg ha}^{-1} \text{ y}^{-1}$  of above ground dry mass) the no-till in tropical Brazil had neutral carbon sequestration ( $0.03 \pm 0.07 \text{ Mg ha}^{-1}$ ) and in the Southern Brazil had a slight carbon sequestration ( $0.12 \pm 0.06 \text{ Mg ha}^{-1}$ ) (Table 2). In contrast, under intensive cropping systems with high input of biomass ( $> 9$  of above ground dry mass) the carbon sequestration rate of no-till was sharply increased and it was similar between Southern ( $0.36 \text{ Mg ha}^{-1} \text{ y}^{-1}$ ) and Middle-West Brazilian regions ( $0.42 \text{ Mg ha}^{-1} \text{ y}^{-1}$ ). These results suggest that in order to achieve a similar potential of carbon sequestration of temperate USA in tropical and subtropical Brazilian environment the soil input of residues should be increased in relation to the North America country. Therefore, in Tropical environment it is necessary improve the cropping system mainly by using cover crops and crop rotation and avoid remove the crop residues to animal feeding, energy source or other proposes.

In Table 1 considering the Southern region the improvement in cropping system under no-tillage show 71% higher potential of carbon sequestration than the improvement in tillage system alone. These results stress the potential of C sequestration in tropical and subtropical soils of Brazil mainly if no-tillage is associated with improve in cropping system (cover crops-based crop rotations) allowing high biomass input. Mielniczuk et al. (2003) estimated that in subtropical the requirement of biomass input in order to maintain the soil carbon stock under no-till should be 8 to  $10 \text{ Mg ha}^{-1} \text{ y}^{-1}$ . Derpsch (2001) and Steiner et al. (2001) argue that the integration of cover crops into no till cropping systems is probably the single most fundamental explanation to the success of such systems in Brazil and other South America countries. The role of nitrogen input in increasing the potential of carbon sequestration in tropical soils has been investigated recently (Bayer et al., 2006). The legumes cover crops would play an important as a source of nitrogen with positive reflexes in carbon sequestration (Amado et al., 2006).

The analyze of soil organic C and physical fractions of soil organic matter in the most soils evaluated demonstrate that there is no evidence of C saturation in any soil depth of no-tillage soil, suggesting the high potential of this variable-charge soils to sequester C in long term. The iron and aluminum oxides are important to stabilize the carbon in tropical soils, while the aggregation has a complementary role in carbon protection. Also, the layer of 0.05 m of mulch maintained in soil surface, common in Brazilian no-tillage, defined by farmers as “plantio direto na palha” is important to protect the aggregates from the disruption caused by the tropical raindrop impact. Six et al. (2000) suggest that the carbon occluded into microaggregate is stabilized with high time of soil residence. Therefore, this carbon could be sequestred. The concept of permanent soil cover as proposed by FAO increase the residence of the free particulate organic matter inside the macroaggregate. The higher stability of macroaggregates from Oxisol compared to Mollisol markedly in soils rich in aluminum and iron oxides is important mechanism of carbon protection.

## CONCLUSION

The less carbon conservative in tropical compared to temperate climate associate to higher temperature and moisture could be compensate by the higher potential of soil carbon input by biomass in wet tropical/subtropical environment. Therefore, the improvement in cropping system is an efficient tool to improve carbon accumulation resulting in similar potential strategy for C sequestration in both temperate and tropical environments.

**Table 1. Recent carbon sequestration rates estimated in no-tillage soils from South (subtropical) and Middle-West regions (tropical) of Brazil (after Bayer et al., 2006).**

Localization	Soil type	Clay	Coordinates	Dominant Mineralogy	Annual Precipitation	Annual Temperature	Elevation	Depth	Crop system	Soil C stocks		Years	C sequestration rate
		g kg <sup>-1</sup>			mm	°C	m	cm		Conventional	No-tillage		Mg C ha <sup>-1</sup> y <sup>-1</sup>
<b>SUBTROPICAL REGION</b>													
Tillage effect													
EEA/UFRGS (1) Eldorado do Sul, RS	Typic Paleudult	220	30°50'S 51°38'W	Kt	1440	19.4	96	0-20	O/M O+V/M+C	27.76 32.79	31.08 37.27	18	0.18 0.25
EEA/UFRGS (2) Eldorado do Sul, RS	Typic Paleudult	186	30°50'S 51°38'W	Kt	1440	19.4	96	0-20	O+V/M	31.07	32.81	8	0.22
COTRISA Santo Angelo, RS	Clay Hapludox	711	28°18'S 54°15'W	Kt, Iron oxides	1760	23.5	289	0-20	W/S	40.23	40.36	25	0.00
FUNDACEP Cruz Alta, RS	Clay Hapludox	570	28°38'S 53°30'W	Kt, Iron oxides	1727	19.2	435	0-30	W/S O/S/W/S O/S/O/V/ M/Ro/W/ S	64.75 65.84 66.22	65.22 70.00 73.20	19	0.08 0.20 0.44
Campos Novos, SC	Clay Hapludox	760	27°24'S 51°13'W	Kt, Iron oxides	1964	16.5	960	0-20	Intensive crop rotation	46.3	49.1	7	0.40
Average													0.17

Crop rotation effect													
EEA/UFRGS Porto Alegre, RS	Typic Paleud ult	220	30 <sup>0</sup> 50'S 51 <sup>0</sup> 38' W	Kt	1440	19.4	96	0-20	F/M	-	28.74	19	-
									O/M		30.52		0.09
									O+V/M		32.39		0.19
									O+V/M+		35.61		0.36
									C		38.60		0.56
EEA/UFSM Santa Maria, RS	Typic Paleud ult	150	29 <sup>0</sup> 45'S 53 <sup>0</sup> 42' W	Kt	1769	19.3	96	0-30	F/M	-	30.9	18	-
									R/M		32.5		0.09
									Mu+M		34.0		0.17
									Jb+M		34.3		0.19
Fundacao ABC Castro, PR	Clay Haplu dox	400	24 <sup>0</sup> 40' S 49 <sup>0</sup> 41' W	Kt, Iron oxides	1560	17.6	800		W/S	-	45.25	17	-
									O/M/W/S		48.51		0.19
									V/M/W/S		48.15		0.17
									V/M/O/S/		47.23		0.12
									W/S		48.62		0.20
									R/M/R/M		50.76		0.32
ARNS FARM Cruz Alta, RS	Clay Haplu dox	550	28 <sup>0</sup> 36' S 53 <sup>0</sup> 42' W	Kt , Iron oxides	1727	19.2	435	0-30	Ro/M/Ro/	-	69.20	10	-
									W/S		70.43		0.12
									O/M/B/W/		71.34		0.21
									S		75.37		0.62
									V/M/Ro/		74.49		0.53
									W/S		76.92		0.72
									V/M/Ct/W				
									/S				
V/Ro/W/S													
V/M/Ct/W													
/S													
Average 0.29													
<b>TROPICAL REGION</b>													

Tillage effect													
EMBRAPA Dourados, MS	Clay Haplu dox	596	22 <sup>0</sup> 13' S 54 <sup>0</sup> 17' W	Iron oxides	1400	24.0	430	0-20	W/S	40.91	40.30	16	-0.04
SLC Costa Rica, MS	Clay Haplu dox	500	18 <sup>0</sup> 32' S 53 <sup>0</sup> 07' W	Iron oxides	1500	23.0	641	0-20	M/S/M/S /Co/S	53.02	56.65	11	0.33
SLC Luisiania, GO	Clay Haplu dox	800	16 <sup>0</sup> 15' S 47 <sup>0</sup> 57' W	Iron oxides	1350	18.0	930	0-20	S/S/M/S/ S/M	56.65	55.93	13	-0.06
Average													0.08

O= black oat; M=maize, V=vetch, C=cowpea, W=wheat, S=soybean, Ro=radish oil, F=fallow, P=pigeon pea, R=rye, Mu=mucuna, Jb= jack bean, B=black beans, Ct=crotalaria, Co=cotton, Al= alfafa; kt=kaolinite

**Table 2. Revised C sequestration rates in tropical and subtropical soils from Brazil.**

Region	Bayer et al. (2006) Mg C ha <sup>-1</sup> yr <sup>-1</sup>		Revised estimative Mg C ha <sup>-1</sup> yr <sup>-1</sup>
Subtropical – BR	0.48	Traditional crop rotations <sup>2</sup>	0.12±0.06
		Intensive crop rotations <sup>3</sup>	0.36±0.09
Tropical – BR	0.35	Traditional crop rotations <sup>2</sup>	0.03±0.07
		Intensive crop rotations <sup>3</sup>	0.42±0.06
Temperate – USA <sup>1</sup>	0.34 (0.24-0.40)		

<sup>1</sup> Mean data from Lal et al. (1999) and the range from West and Marland (2002).

<sup>2</sup> Traditional crop rotations were represented by crop systems with low crop residues input derived by predominance of fallow, soybean or beans.

<sup>3</sup> Improved crop rotations were represented by crop systems with higher crop residues input due to the inclusion of winter and summer cover crops and maize/soybean rotation.

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