EFFECTIVENESS OF THE ZERO TILLAGE SYSTEM ON GREENHOUSE EFFECT MITIGATION IN BRAZIL[1]

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Abstract

The degradation of natural resources has been a major problem in tropical and subtropical environments. In Brazilian agricultural areas, the use of conventional soil management systems, based on disc ploughing, is the main cause of organic matter depletion. Water erosion is one of the causes of this decrease, estimated as being equivalent to an annual loss of 15 million tons of carbon in agricultural areas and in pastures representing annual losses of 700 to 2700 kgC.ha^{-1}. Ploughing is also responsible for rapid CO_2 loss to the atmosphere. Land degradation in these environments has been mitigated with the adoption of the Zero Tillage (ZT) System, due its efficiency in controlling soil erosion, reducing costs and improving the quality of natural resources. Its effectiveness in mitigating greenhouse gas emissions is discussed, based on comparisons between ZT and ploughed soils and considering sampling depth and soil C stock correction for equivalent soil mass. A first approximation of the economic values of the benefits generated by the adoption of ZT showed that the main economic benefit lies in the potential for mitigating deforestation in fragile tropical biomes. The relationship between soil management systems and the greenhouse effect comprises two different scenarios: a) An optimistic one, allowing the maximum mitigation of the Greenhouse effect by reaching 100% of total annual summer crop area in five years as well as the possibility to guarantee food security through the renovation of degraded pastures; b) a pessimistic one, requiring the adaptation of soil use and management practices to the constraints estimated to occur due to global climate changes.

Key words: *land degradation, management systems, water erosion, global climate change, economic impacts, food security.*

Résumé

Efficacité du système de Semis Direct (SD) sur la réduction de l'effet de serre au Brésil.

Dans les régions agricoles brésiliennes, le modèle agricole qui prédomine, basé sur l'énergie fossile, des entrées (engrais et pesticides) chimiques, et une mécanisation intensive

avec charrues et pulvériseurs, est la cause principale de la diminution de la matière organique du sol, associée à l'érosion hydrique. Les pertes annuelles en sol dans les terres agricoles et les pâturages, estimés dans 822.7 M t, sont responsables de la perte des éléments nutritifs de 25.46 M t ou une valeur totale des engrais, en US dollars, de 2.4 M, aussi bien que pour les pertes en matière organique. Cela a été estimé comme être équivalent à une perte annuelle de 15 M t, représentant une perte de 700 à 2700 $kgC.ha^{-1}$. Labourer est aussi responsable pour une très rapide perte du CO_2 vers l'atmosphère. La préparation du sol avec une charrue à soc provoque la libération de plus que 50% du CO_2 incorporé par les résidues de la culture antérieure en seulement 24 heures. Quand les résidus de la culture précédente sont gardés sur la surface, le flux de carbone (C) dans les premières cinq heures a baissé de 35 à 0.2 $g.m^{-2}.h^{-1}$ (**Reicosky and Lindstrom, 1995; Reicosky et al., 1995**).

La forte pression sur l'utilisation de la terre, l'agressivité des pluies tropicales et la susceptibilité à l'érosion des sols tropicaux et subtropicaux sont les causes de la vulnérabilité de ces sols à l´érosion hydrique. La dégradation des terres agricoles représente, tout d'abord, une augmentation de pression sur les autres régions où la biodiversité est critique, avec un fort impact sur l'environnement. Ceci intéresse non seulement la société brésilienne mais aussi le monde entier. La dégradation de la terre dans ces environnements a été ralenti grâce à l'adoption du Système de Semis direct (SD). L'adoption du SD dans l'agriculture brésilienne veut dire une impressionnante réduction des pertes de sol, eau et éléments nutritifs par érosion. La superficie avec SD a évolué d'un million ha, au débit des années 1990, à plus de 17 M ha dans l'année agricole 2001/2002 (**Hernani et al., 2002b**), de la frontière du sud aux régions équatoriales de l'Amazone. Le SD a aussi été adopté dans le culture de canne à sucre et des plantes pérennes (café, citrus, fruits, reforestation, etc.) et dans la rénovation des pâturages dégradés. Adapté aux grandes exploitations mécanisées, aussi bien qu'aux petites fermes avec traction animale, le SD a été un instrument efficace dans la gestion de basin versant, pour la préservation des ressources naturelles - sols, eau et biodiversité.

L'efficacité du SD pour atténuer les émissions des gaz à effet de serre a pour conséquence qu'il devient une puissante stratégie pour éviter le modification du climat du globe (**Batjes & Sombroek, 1997**; **Lal, 1997**). Cependant, les comparaisons entre sols labourés ou SD quant à l'accumulation de C à profondeur restent controversées. Plusieurs formes d'utilisation de terre avant d'installer des expérimentation à long terme et la dimension ou l'emplacement des parcelles dans le paysage peuvent contribuer à la controverse et sont limitant a l'extrapolation de résultats à une grande échelle. Deux aspects très importants sont la profondeur de étalonnage en relation avec des horizons pédologiques homogènes (**Freitas et al., 1998**), et la correction du stock de C dans le sol pour la masse équivalent du sol, considerant l' occurrence d'un processus naturel de consolidation du sol dans l'horizon concerné par le SD, qui sont comparé avec ceux sous végétation naturelle, sous systèmes labourés conventionnel ou sous pâturage. Ces aspects peuvent expliquer pourquoi quelques données obtenues sur parcelles expérimentales où sont comparés des systèmes de gestion du sol ne montrent aucun effet sur l'accumulation du CO_2, qui sont sous-estimé par rapport aux vraies situations du champ (**Derpsch et al., 1991**; **Blancaneaux et al., 1993**). Un facteur clé pour encourager une augmentation du stock de C dans le sol est comment le système de SD est porté, avec l'intégration de tous les meilleurs practices de la gestion qui sont disponibles pour contrôler l'érosion de façon durable et compétitive (**Freitas et al., 2002**)

Une première approximation de la valoration économique des bénéfices dans et en dehors de la ferme, suite à l'adoption du SD, incluant les principaux impacts sur la réduction de l'effet de serre, a montré que la plupart des avantages du SD sont en rapport avec la minimisation de l'érosion hydrique et la maximisation de l'infiltration de la pluie dans le sol (**Landers et al., 2001**). Ils incluent des avantages dans la ferme pour les fermiers (plus hauts revenus, exprimé

comme le valeur de terre et plus bas consommation d'énergie pour pomper l'eau pour l'irrigation) aussi bien que réductions en dehors de la ferme dans dépense publique, dû à la minimisation de l'effet de sédimentation. Les approximations ont montré que le principal avantage économique se trouve dans la possibilité deréduire le déboisement dans les très fragiles Ecosystèmes Tropicaux (Amazone et Cerrado, y compris du Pantanal) dû à l'augmentation de rendement des cultures et du bétail et la rénovation de pâturages dégradés, avec l'usage des principes de SD pour la rotation de cultures annuelles avec les pâturages (**Landers et al., 2001**; **Landers et Freitas, 2001**). Le rapport entre systèmes de gestion du sol et l'effet de serre comprend deux differents scénarios:

a) un scénario optimiste, comprenant la réduction maximale de l'effet de serre en atteignant 100% de la superficie en SD avec les cultures annuelles d'été dans une période de cinq années, aussi bien que la possibilité de garantir la sécurité alimentaire à travers de la rénovation de pâturages dégradés; et, b) un pessimiste, de l'adaptation des practices d'utilisation et gestion du sol aux contraintes qui sont estimé pour se produire à cause des changements du climat du globe terrestre.

L'efficacité du système SD sur la réduction de l'effect de serre nous autorise à la conclusion que le SD est une stratégie effective pour éviter le changement du climat du globe dans les régions tropicales et subtropicales. Les discussions sur le changement du climat devrait prendre en considération l'efficacité du SD pour séquestrer le C.

Mots clés : Brésil, semis direct, séquestration du carbone, réduction des effets de serre, érosion

Effects of conventional management systems

The degradation of natural resources – soil, water and biodiversity - has been a major problem in tropical and subtropical environments, with erosion as the major consequence. In agricultural areas, the use of conventional soil management systems, adapted from temperate regions and mono-cropping, has caused billions of (US) dollars' worth of damage. Recent global estimates show the annual loss of 5,000 billion tons of soil. More than 50 % of this soil loss comes from agricultural areas, and 80 % is from water erosion (**Lal and Stewart, 1995**).

In Brazil, the predominant agricultural model, based on fossil energy, agri-chemicals, and intensive mechanization, mainly driven by short-term economics and productivity goals, has induced inadequate soil management. This has intensified water and wind erosion, resulting from the destruction of soil structure through disaggregation, crusting, compaction and a decrease in infiltration capacity, causing elevated environmental losses.

Recent estimates have indicated annual soil losses for crop and pastures in Brazil (**Santos & Camara, 2002**), in a total of 822.7 M t, comprising 751.6 million tons in annual and perennial crop areas, and 71.1 million tons in natural and cultivated pastures (Table 1). This is a very conservative estimate, since more than 50% of these areas are under an advanced process of land degradation. This means that 247 M tons are deposited as sediments in roads, rivers, reservoirs, wetlands and other colluvial areas, with high socio-economic and environmental impacts. In addition, 171 billion m^{-3} of water does not infiltrate into the soil limiting dry season recharge of hydroelectric and other reservoirs (This was a major contributory cause in the Brazilian 2001 energy crisis).

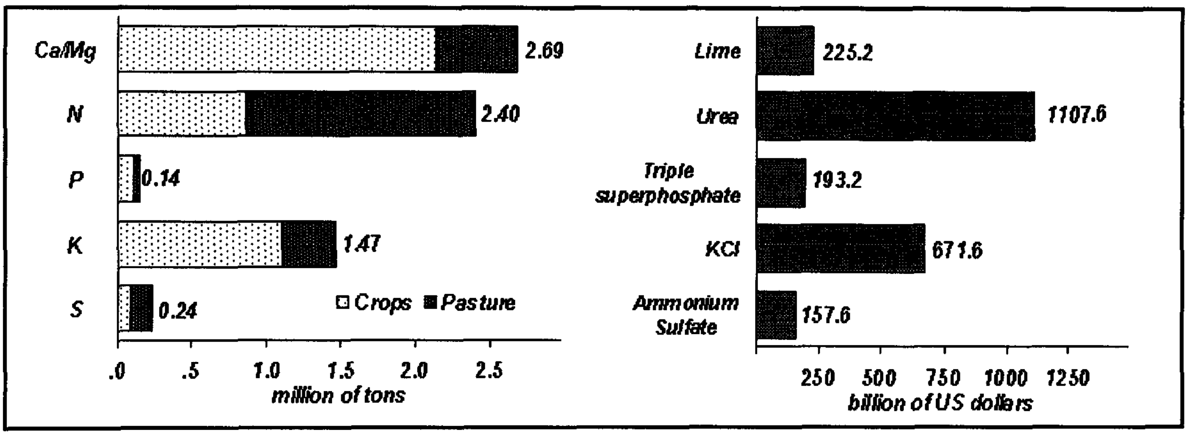
There are many more losses in addition to those of soil and water. Besides soil particles and aggregates, there is a loss of nutrients, organic matter, seeds, pesticides, etc. causing deleterious effects to the environment. Nutrient losses, for example, were estimated 25.46 M t . y^{-1}, or a total value of 2.4 M US dollars when these are costed as fertilizers (Figure 1).

Table 1. Annual Soil and Water Losses by Water Erosion in Brazil (based on Santos & Camara, 2002)

Occupation	Area million ha	Annual Soil Loss		Annual Water Loss	
		Unitary	Total	Unitary	Total
		ton ha^{-1}	million ton	M^3 ha^{-1}	billion m^3
Annual and Perennial Crops	50.1	15,0	751.5	2.519	126.2
Pasture (Natural and Artificial)	177.7	0,4	71.1	252	44.8
Total	**227.8**	-	**822.6**	-	**171.0**

The use of conventional soil management systems, based on disc ploughing, followed by disc harrowing and other combinations, is the main cause of OM losses in tropical and subtropical soils (**Bayer & Mielniczuk, 1999**; **Resck et al., 1998**). This depletion is favoured by intensive tillage, causing breakdown of soil structure, leading to soil crusting and reduced water infiltration, thus exposing SOM to the erosion process. The decrease of SOM in tropical soils was reported by **Silva et al. (1994)** as being of 80 % in sandy soils (less than 15 % of clay content) to 41 % in clayey Ferrasols.

Figure 1 – Total annual nutrient losses and its equivalent value in fertilizers in Brazil (*adapted from* ***Hernani et al., 2002a***).

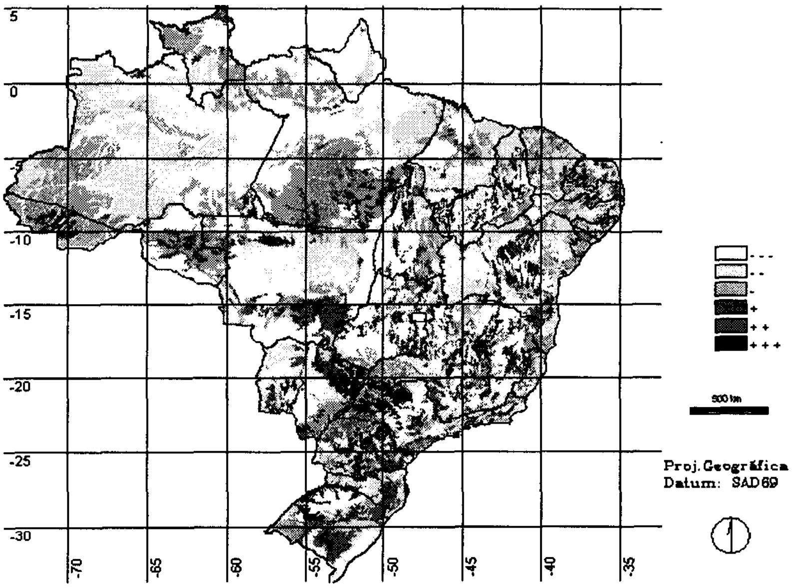


Water erosion is one of the causes of this decrease, as measured by **Hernani et al. (1996)** in experimental plots. SOM losses by erosion where of 476 kg ha^{-1} in annual crop areas and 12 kg ha^{-1} in pastures. Data presented by **Santos & Camara (2002)** shows estimates of annual total SOM loss in Brazil of 23.87 M tons in agricultural areas and 2.26 M tons in pastures. This is equivalent to an annual loss of 15 M tons of C. **Pimentel et al. (1995)** have estimated SOM loss by erosion at 2 $ton.ha^{-1}.y^{-1}$ in a soil with 4 % of SOM. The same authors give an enrichment rate of 1.3 to 5 times for SOM content in eroded versus non-eroded soils. Considering average tropical SOM content as 3.6% (**Resck et al., 1991**) in natural conditions we have, when cropped under conventional systems (loss of 15 $ton.ha^{-1}.y^{-1}$), an annual loss of 700 to 2 700 $kg.ha^{-1}$ of C.

Ploughing is also responsible for rapid CO_2 loss to the atmosphere, as reported by **Reicosky and Lindstrom, 1995**. Mouldboard plough tillage released more than 50% of the total CO_2 incorporated from previous crop residue, in only 24 hours. CO_2 flux during 5 hours was measured as being of 35 $g.m^{-2}.h^{-1}$. When crop residues were kept on the surface (No-till treatment), C flux in the first five hours was 0.2 $g.m^{-2}.h^{-1}$. **Reicosky et al. (1995)** insist that the most effective erosion control is obtained by keeping crop residues on the surface, avoiding any kind of tillage. The positive effects of mulching with cover crop residues on the diminution of soil water erosion has also been extensively studied for Brazilian conditions **(Roth et al., 1986; Derpsch et al., 1991; Muzilli, 1994)**. The strong pressure on land use and the high erosion susceptibility of tropical and subtropical soils are the causes of the widespread high vulnerability of these soils to water erosion, shown in figure 2. The major concern is the fragility of areas in the highlands of the Pantanal region (R. Paraguay basin) and in the headwaters of important rivers, such as those of the Paraguay, Paraná, Araguaia, Tocantins and Amazon. Land degradation in agricultural areas means, first of all, an increase of pressure on other critical biodiversity areas, with strong environmental impacts. This is of concern not only to Brazilian society but also for the whole world.

In tropical and subtropical environments, land degradation has been mitigated with the adoption of the Zero Tillage (ZT) System. Farmer adoption is based mainly on ZT efficiency in controlling soil erosion, reducing costs and improving the quality of natural resources **(Hernani et al., 2002b)**.

Figure 2. Critical Erosion Areas in Brazil, resulting from the relationship between land use pressure and soil susceptibility to erosion ***(Hernani et al, 2002a)***



The adoption of ZT System in Brazilian agriculture means an impressive reduction in soil, water and nutrient losses by erosion. **De Maria (1999)** has worked with all available information on erosion losses and has concluded that ZT adoption means a reduction of 75 % in soil and 25 % in water losses; this represents a drastic reduction in SOM loss. The absence of soil tillage and the high quantity of aerial and root biomass yield result in the sustainability of agricultural production, and a strategic reduction in Greenhouse Gases (GHG) emissions **(Boddey et al., 1996; Lal, 1997)**.

Cropped area under ZT has evolved from one million ha at the beginning of the 90s to more than 17 M ha in the 2001/2002 crop year **(Hernani et al., 2002b)**, stretching from the southern border to the equatorial areas of the Amazon region. It has been adopted also in sugar cane and perennial crop areas (*e.g.* coffee, citrus, other fruits, and forestry) and in the renovation of degraded pasturelands. Comprising large mechanized areas, as well as small farms, with animal traction and mechanized implements; ZT has been a strong instrument in watershed management, conserving soils, water and biodiversity.

ZT as a strategy to avoid global climate change

The effectiveness of ZT to mitigate greenhouse gas emissions has been already reported **(Batjes & Sombroek, 1997; Lal, 1997)**. However, comparisons between ZT and ploughed soils in regard to C accumulation at depth remain controversial. Compared to ploughed systems, significant increments in SOM have being reported for ZT areas **(Bayer & Mielniczuk, 1997a,b; Tognon et al., 1997; Bayer & Mielniczuk, 1999; Resck et al., 1998; Bayer et al., 2000a,b)**. On the other hand, no significant difference of C accumulation at depth was observed between ZT and ploughed soils **(De Maria & Castro, 1993a,b; Freitas et al., 2000; Roscoe et al, 2000; Roscoe & Buurman, 2002)**. Different land use prior to setting up long-term plot experiments, and size or location of plots in the landscape may contribute to controversy and limit extrapolation of results to a large scale. In addition, we have two important aspects: sampling depth and soil C stock data correction for equivalent soil mass, as discussed below.

Soils under ZT significantly accumulate more C at the surface horizon (*eg* 0-5 cm), due to a more efficient mulching resulted from crop rotation with cover crops, protecting the soil against raindrop impact and consequent surface sealing. These factors, combined with an increase of water infiltration capacity, are key to controlling water erosion and thus contributing to soil C accumulation **(Roth et al., 1986; Glanville & Smith, 1988; Blevins & Frye, 1993)**. The sampling issue was thoroughly discussed by **Kimble et al. (2001)** and the importance of soil density and measurement issues have already been reported **(Lal & Kimble, 2001)**. By analysing soil C storage obtained from experimental plots in the Brazilian Cerrado (Table 2), it is observed that data was treated by pre-established soil layer depth, instead of being related to homogeneous pedologic horizons (following **Freitas et al., 1998)**. Authors have reported an accumulation of C in the rounded crumby and subangular blocky surface horizon (A_1/Ap_1), followed by an inversion in the blocky horizon below (A_2/Ap_2/or Ap_2B).

Considering a natural soil consolidation process, implying an increase in density in areas under ZT, compared to those under natural vegetation, conventional ploughed systems, or pasture, as has being reported by **Ellert et al. (2001)** and implies the necessity of expressing data in units of soil c in an equivalent soil mass per unit area, taking soil thickness into account, as presented in table 2. Correction of the data presented by **Freitas et al. (2000)** did result in lower amounts of C accumulation in cultivated soils compared to the soil under natural vegetation (Table 2). However, the difference of C storage between the soil under conventional tillage and the ZT soil was only 0.12%.

Correction for equivalent soil mass in the data reported by **Freixo et al. (2002)**, who evaluated the tillage and crop rotation interactions on soil C accumulation in a Rhodic Ferralsol from southern Brazil (Table 3), resulted in similar contrasts to those observed in the Cerrado soils. The difference between the soil C storage in ZT and CT soils under crop succession were 0.8 MgC ha^{-1} and under crop rotation were 3.0 MgC ha^{-1}. Using equivalent soil mass calculation suggested by **Niell et al. (1997)**, **Sisti et al.** *(unpublished data)* observed similar contrasts but with larger magnitudes (2.2 MgC ha^{-1} under crop succession and 4.1 MgC ha^{-1} under crop rotation). **Sisti et al. (2001)** reported a positive and significant correlation (r^2=0.94; p<0.001) between total soil C and nitrogen emphasizing the important role of legume cover crops in soil C accumulation at depth.

Table 2. Soil C storage (in $Mg.ha^{-1}$) under different tillage systems in a long-term corn-common bean succession in a Clayey Dark-Red Ferralsol from Goiânia, Brazil
(data from Freitas et al., 2000)

	Depth (cm)	Natural vegetation ("cerrado")	Conv. Tillage (heavy disk harrow)	Zero Tillage
Without correction	0-10	26.9	23.5	25.3
	10-20	24.3	25.1	23.8
	20-40	30.7	35.7	35.2
	0-40 cm	***81.9***	***84.3***	***84.3***
With correction[1]	0-10	26.9	25.3	25.7
	10-20	25.3	23.8	22.4
	20-40	30.7	31.1	32.1
	0-40 cm	***81.9***	***80.3***	***80.2***

*[1] Correction for equivalent soil mass proposed by **Moraes et al., 1996** and **Angers et al., 1997**.*

Table 3. Soil C storage (in $Mg.ha^{-1}$) under different tillage and crop systems in a Rhodic Ferralsol from Passo Fundo, Brazil (data from **Freixo et al., 2002**)

	Depth (cm)	Forest	CT[2] succession*	CT[2] rotation**	ZT[3] succession*	ZT[3] rotation**
Without correction	0-5	18.4	9.6	9.8	14.1	13.1
	5-10	15.4	11.6	11.2	10.9	12.0
	10-20	21.8	27.6	23.8	23.0	21.6
	20-30	20.6	19.3	20.5	20.5	19.0
	0-30 cm	***76.2***	***68.1***	***65.4***	***68.5***	***65.7***
With correction[1]	0-5	18.4	7.2	7.3	11.0	10.2
	5-10	15.4	8.1	8.1	9.5	9.6
	10-20	21.8	20.5	19.5	18.8	19.2
	20-30	20.6	21.5	20.0	18.8	18.9
	0-30 cm	***76.2***	***57.3***	***54.9***	***58.1***	***57.9***

*[1] Correction for equivalent soil mass proposed by **Moraes et al., 1996** and **Angers et al.,1997**;*
[2] CT: Conventional tillage: disk plough followed by light disk harrowing; [3] ZT: Zero tillage;
** Continuous wheat (winter crop)/soybean (summer crop);*
*** Wheat/soybean-vetch (winter crop)/maize*

Defining, a priori, a global soil depth to which C should be analysed is not practical (**Watson et al., 2000**); the sampling depth should be below the depth that significant change in C is expected to occur. **Kimble et al. (2001)** offer some general points that must be considered when sampling: (1) always sample a fresh exposure, *i.e.*, not one that has been open for a long time; (2) auger or probe to assess the local variability in the area to be sampled to ensure a representative sample; (3) make sure the sample represents a uniform layer and; (4) thick horizons need to be split. Also, as suggested by **Bergstrom (2001a; b)**, topography, soil series alone or grouped by drainage class provide a framework to assess the influence of management practices on SOC pool on a large scale, representative of farm management units.

SOM has a known effect on stabilizing soil structure and protecting soils by decreasing its susceptibility towards "on site" erosion (**Gabriels and Michiels, 1991**). Additionally, the increase in erosion hazard enhances the loss of SOM (**Lal, 1997**). This may explain why some data taken in experimental plots comparing management systems shows no effect on CO_2 accumulation, underestimated in relation to real farm situations (**Derpsch et al., 1991; Blancaneaux et al., 1993**). A key factor to promote an increase of soil C stock is how ZT is carried out integrating all the best management practices available to achieve efficacious erosion control in a sustainable and competitive way (**Freitas et al., 2002**)

Benefits of ZT adoption – economic impacts

In a first approximation of the economic values of the on- and off-farm benefits generated by the adoption of ZT, **Landers et al. (2001)** included estimates of the main impacts related to mitigation of the greenhouse effect, based on 14 M ha of ZT in Brazil, as well as for a future scenario of adoption in 80% of the area occupied by annual crops in Brazil (Table 4).

Most of ZT benefits are related to the minimization of soil water erosion and maximization of rainfall infiltration. They include on-farm benefits for farmers (higher gross margins, expressed through higher land values and lower energy consumption for pumping irrigation water) as well as off-farm reductions in public spending due to the minimization of the effect of silting. Benefits related to the mitigation of CO_2 emission are dependent on fluctuations of the C market and the negotiation skills available. The above study used a relatively high world market value (US$ 10.90), which now closer to US$4.00 per ton of C.

Table 4. Annual economic impacts of ZT adoption in Million US Dollars

Categories of benefits	**Area under ZT adoption**	
	35%	**80%**
Incremental net benefits of ZT adoption for farmers and irrigation pumping economy	**356.1**	**791.4**
Reductions in public spending	**183.1**	**406.9**
Maintenance of rural roads	48.4	107.6
Treatment for drinking water	0.5	1.1
Reduced dredging costs in ports and rivers	4.0	8.9
Incremental reservoir life	9.2	20.4
Greater aquifer recharge and economy in water use for irrigation purposes	121.0	268.9
Benefits related to CO_2 emission	**63.1**	**140.2**
Carbon credits for fuel economy from adoption of ZT (average reduction of 31 lit ha^{-1} y^{-1}converted in carbon credits (US$ 10.9 per ton of C)	0.6	1.4
Carbon sequestration in soil under ZT (country average of 0.4 Mg ha^{-1} y^{-1})	59.5	132.2
Carbon sequestration due to the accumulation of surface residues (estimated in 3 ton ha^{-1} y^{-1} in subtropical areas and 1 ton ha^{-1} y^{-1}in tropical ones)	3.0	6.6
Benefits to the adoption of integrated ZT crop x pasture rotations (assumed proportional to the mitigation of deforestation in the Amazon and Cerrado Biomes)	**784.0**	**1 742.2**
Total Annual Economic Impact	**1 386.3**	**3 080.7**

The main economic benefit lies in the potential for mitigating deforestation in fragile Tropical Biomes (Amazon and Cerrado, including the Pantanal) due to the increase in crop and livestock production and the renovation of degraded pastures, utilizing the principles of ZT to rotate crops with pastures (**Landers et al., 2001; Landers and Freitas, 2001**).

Scenario Analysis

From the data presented, the relationship between soil management systems and the greenhouse effect becomes very clear. For discussion purposes, two different scenarios were envisaged, as follows:

a. The mitigation or alleviation of greenhouse effect by sequestering C using management strategies to increase ZT adoption in Brazil and in other tropical and subtropical areas worldwide. This scenario requires extensive actions of validation and adaptation of ZT technologies promoting the changing of land use and management paradigms. Considering Brazilian agriculture, an optimistic scenario was presented by **Freitas & Manzatto (2002)** with an annual tax of adoption of 21% allowing to reach 100% of total annual crop area (33.5 Mha) in five years. To accomplish this goal, the following assumptions were made:
    - acceptance by society and government of the relevance of environmental services payments to farmers and/or incentives to research work, extension services and agricultural credit,
    - decoding of existing research knowledge for use by extensionists and farmers;
    - setting up of participatory demonstration units,
    - incentives for re-forestation of fragile areas, identified by erosion hazard assessment, and,
    - agro-ecological zoning to determine acceptable land use, according to land suitability classes, using modified parameters to incorporate sustainable and conservation management systems, and specifically ZT.

Complementing this scenario, there is the possibility to guarantee food security by the renovation of degraded pastures, estimated in more than 80 M ha only in the tropical area of Brazil (**Sano et al., 1999**; **Cassales & Manzatto, 2002**). **Landers & Freitas (2001)** have proposed a scenario where the integration of crop and cattle enterprises under ZT principles make it possible to increase grain, fibber and meat production in Brazil without further deforestation, accommodating all demand-led expansion of agricultural production within the existing agricultural frontier for the next 20 years or more.

This is possible by incorporating the advances in relation to pasture management and cattle production as well as the sustainable and competitive management of annual and perennial crops, improving agricultural profitability. This scenario not only allows higher levels of productivity (with consequent higher potential of C sequestration and the mitigation of negative impacts of conventional crop and pasture management systems of cropping and cattle rising), but also promotes a decrease in (or possible elimination of) the pressure to clear fragile areas of the Cerrado (including Pantanal) and Amazon regions, avoiding de-forestation for agricultural purposes.

b. The adaptation of soil use and management practices to the constraints estimated to happen by the end of the 21st century due to global climate changes, such as increases in temperature, variation in rainfall distribution and air moisture content. . This scenario will require the selection of the most adapted plants (species and cultivars) through breeding programs, and the adaptation of management systems by combining species in rotations, succession and mixed stand systems. This would improve soil fertility (organic matter dynamics, biological activity, soil structure, nutrient cycling, etc.) and ameliorate insect and disease pressures. It will be essential to perform an intensive land use and management planning exercise, combining the best management practices with the most appropriate land classes, maintaining a permanent ground cover and promoting deep root growth, thus improving C content deep in the soil profile for maximum effectiveness in C sequestration.

Conclusion

The effectiveness of the ZT System on GH effect mitigation allows the conclusion that ZT is an efficient strategy to avoid global climate change in tropical and subtropical areas of the world. The results obtained in different areas of Brazil is a guarantee that 100% of ZT adoption in cropping and pasture areas will make it possible to improve C sequestration and mitigate GHG emission to the atmosphere. However, if the most pessimistic forecast occurs, ZT System will be essential to guarantee the adaptation of management systems to the new limiting conditions imposed by climate change. Associated with this, there are numerous benefits of ZT adoption for framers and for society as a whole. Among these benefits, the potential for mitigation de-forestation has to be considered, especially with regard to the Amazon and wet/dry savannah (Cerrado) biomes in South America.

Discussions on global climate change have to consider the efficiency of ZT in sequestering C. This discussion, however, should also focus on ZT's efficiency in minimizing soil and water losses by erosion and in improving soil quality and health, as a way of guaranteeing the sustainability of food production.

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