The impact of plans, policies, practices and technologies based on the principles of conservation agriculture for controlling soil erosion in Brazil

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Abstract

Assessments of land coverage in Brazil indicate that almost 28 % of the territory of 8.5 million-km^2 is occupied with the production of food, fibers, bio-fuels and raw material for agroindustry and different usages. The estimated annual soil loss is of 1.18 billion tons, being 697 million tons from cropped areas and 270.8 million tons from pasture. This paper reports Brazilian efforts to control erosion of the already vulnerable tropical soils. It starts with the setup of a national governmental program for Soil Survey and Usage Interpretation (PRONASOLOS), and the impact of adoption of practices and technologies based on zero tillage conservation agriculture (ZT/CA) and integrated crop-livestock-forest (iCLF) management systems on soil erosion mitigation. ZT/CA and iLPF are present in an area of 32.88 million ha and 11.5 million, respectively, which proofs the success of these policies. The economic impact, estimated considering the complete mitigation, and the removal of highly fertile surface soil by soil erosion if it is not adopted, is estimated in 1.84 billion US dollars. This is a result of determination of farmers, extensionists, technical consultants, agricultural researchers, and professors, to promoting the control of soil erosion in an extensive agricultural area of Brazil.

Keywords: tropical soil, soil survey and usage interpretation, zero tillage conservation agriculture, integrated crop-livestock-forest, economic impact

Introduction

In the context of agriculture, land degradation leads to decreasing of agricultural production, through the reduction of soil quality with a negative impact on soil physical, chemical and biological attributes. In the tropical world the main agent of soil degradation is water erosion, which is a natural process in the formation of landscapes, but it is intensified by the anthropic actions and inadequate land usage. In Brazil, the absence of information on the spatial distribution and type of soil resources, at compatible scales with the agriculture demand, has led to expansion of crops and pasture in areas with low productive capacity or where careful soil management is required. A detailed spatial soil distribution and better knowledge is important to achieve a sustainable land use and reducing soil erosion.

The first step to control soil erosion in the tropical soils is a better planning of land usage according to its agricultural suitability (Ramalho Filho and Beek, 1995). Estimates based on soil maps of Brazilian States indicate that over 5.5 million km^2 or 65 % of the territory are apt for annual and perennial crops (Manzatto *et al.*, 2002).

This paper reports the efforts to control soil erosion in the highly vulnerable Brazilian soils, which starts with the setup of a national governmental program for Soil Survey and Usage Interpretation (PRONASOLOS). In the next three decades, this program will work to overcome the lack of proper information on soil and water resources and to provide means to evaluate them in order to mitigate land degradation processes caused by water erosion, desertification, contamination, surface and subsurface compaction, surface impermeabilization, risk of natural disasters and the emission of greenhouse gases.

Methodology

The estimation of the economic impacts of the adoption of conservation agriculture principles towards soil erosion control considered concepts proposed by Hernani *et al.* (2002a; 2002b), based on costs of liming and nutrient replenishment using fertilizers (organic and mineral).

Results and Discussion

Assessments of land usage in Brazil indicate that around 68 million ha of the 8.5 million km^2 territory are covered with annual and perennial crops, including planted forests, and 167.50 million ha of pastures (forage, natural and planted), in different stages of degradation. The total impact of soil loss is estimated as of 5.2 billion dollars per year in the agricultural areas.

The 1970's models of agriculture in Brazil were not efficient to control soil erosion, mainly due to the intensive usage of mechanization, and major changes were necessary. It was recognized that, for an effective soil erosion mitigation, it was necessary the integration of cultivation practices with biological technologies. The no-till concept refers to direct placement of seeds into the previous crop residues, which is not enough to control water erosion in any climate, and especially in the tropics. Soil erosion mitigation is only achieved when no-tillage, crop rotation (pluri-annual rotation of annual crops with no repetition of crops in subsequent years), permanent soil cover and traffic control are associated. These are the technological pillars of the ZT/CA management system (Landers *et al.*, 2001b; Landers *et al.*, 2013).

According to FAO (2019) the basic principles of Conservation Agriculture (CA) are: minimum tillage and soil disturbance; permanent soil cover with crop residues (straw) and live plants; and, crop rotation, intercropping and root diversity.

The application of these principles may reverse the historically accelerating soil erosion, and degradation of soil organic matter and structure, also increasing soil biodiversity (Landers *et al.*, 2013). The basic principles of ZT/CA are universal, while technical solutions depend on local conditions of soil, climate, relief, and socio economical (Landers, 1999). It is also recognized the impacts of ZT/CA in reducing the emission of greenhouse gases (GHGs) and improving agriculture sustainability. On Brazil, soil carbon sequestration can be approximately 350 kgC $ha^{-1}year^{-1}$ to a depth of 20 cm in the tropical savannahs, and up to about 480 kgC $ha^{-1}year^{-1}$ in sub-tropical regions (Freitas *et al.*, 2007). The emissions of GHG are reduced by decreasing usage of fossil fuels for crop production, chemical fertilizers and lessening N_2O emissions, as well as decreasing soil erosion.

The adoption of ZT/CA as major management system in Brazil is based on principles of sustainability. It integrates high productivity, low consumption of fossil fuels, increase of carbon sequestration, and mitigation of water and wind erosion. The success of these efforts is illustrated by the fact that ZT/CA systems are used in over 50 % of the area with annual crops in Brazil. Data from IBGE's agricultural census (2017) refers to an area of 32.88 million hectares of Brazilian territory (Fuentes Llanillo, 2018).

An evolution of the ZT/CA, the integrated crop-livestock-forest (iCLF) combines annual crops, livestock and forest, which affects positively soil physical and chemical attributes, increasing C, N, water retention, and reducing erosion soil losses. Adoption of iCLF management systems improves environmental, social and economic services and is a promising alternative to recover degraded areas (Lima *et al.*, 2018).

The main consequence of iCLF adoption is the efficient usage of nutrients, agrochemicals and energy, increasing soil biodiversity, and improving soil structure and fertility. It allows recovering degraded pastures and agricultural intensification, thus reducing GHG emissions (Pacheco *et al.*, 2009) while mitigating soil erosion in all Brazilian biomes. Estimations from ICLFI Development Network, by Kieffmann Group (2016) show that iCLF was adopted in 11.47 million ha.

The economic impact of ZT/CA and iCLF adoption was estimated considering reduction in fertilizer that would be lost by water erosion without these systems (Hernani *et al.* 2002b. An economy of 1.4 billion US$ is etimated when ZT/CA is adopted in an area of 32.9 million ha, and with both ZT/CA and iCLF the value is of 1.84 billion US$.

Table 1: Annual cost reduction by mitigation of soil loss with ZT/CA and iCLF management systems.

	Unit Cost	**Annual Cost Reduction**	
	US$/ton	***million ton***	***million US$****
Dolomitic limestone	29.74	3.641	108.31
Triple superphosphate	500.24	0.236	117.82
Potassium chlorate	513.76	0.745	382.95
Urea Fertilizer	446.16	1.181	526.85
Ammonium sulfate	346.11	0.259	89.53
Organic fertilizer	37.86	16.351	618.97
Total			**1,844.44**

** US Dollar - Commercial (average value from Jan 2018 to Jan 2019): R$ 3.698.*

The economic impact of ZT/CA management system on off-farm costs, considering an area of **32.8 million ha,** were estimated in 3.67 billion USD (Table 2).

Table 2: Estimation of economic impact of the adoption of ZT/CA on off-farm costs.

Impacts	Economic Impact (USD)*
A. On-farm benefits (direct to farmers)	**943.7**
Incremental net benefits by adoption of ZT/CA compared to conventional systems due to land value appreciation	882.2
Economy in irrigation water pumping energy	61.5
B. Off-farm reductions in public spending	**164.6**
Maintenance of rural roads	128.3
Municipal water treatment	1.3
Incremental reservoir life	24.4
Reduced dredging costs in ports and rivers	10.6
C. Off-farm environmental cost to society	**487.9**
Increase in water offer due to aquifer recharge	303.2
Carbon credits for diesel economy	1.6
Irrigation water economy	17.5
Carbon credits from decrease in CO_2 emission due to lower fuel consumption, soil and biomass C sequestration	165.7
D. Benefits for mitigating de-forestation with iCLF adoption	***2077.6***
Total Benefits - annual basis	***3673.7***

*re-calculated by Freitas and Landers (2014), based on Landers *et al.* (2001).

Adoption of ZT/CA represents a radical change in agronomical practices, eliminating soil tillage, promoting agrobiodiversity (crop rotations), and keeping soil surface covered with crop residues (Machado; Freitas, 2004; Landers *et al.*, 2001b.

Conclusion

ZT/CA integrates reduction of soil revolving for different use and crop rotation, permanent soil cover, integrated pest, disease and weed management, development of productive and adapted species, varieties and cultivars, rational fertilization systems. This results from determination of farmers, extensionists, technical consultants, agricultural researchers, and professors, making Brazilian agriculture the most sustainable in the world.

The adoption of ZT/CA and iCLF systems leads to **economy of inputs** (fertilizers, seeds and chemicals), fuel and manpower, as well as public resources.

The soil conservation initiative in Brazil is marked by historical farmers and technicians' pioneers, which dedicated years to experimentation with innovative ideas, advancing the soil science towards a sustainable agriculture.

References

De Freitas, P.L. & Landers, J.N. 2014. The transformation of agriculture in Brazil through development and adoption of Zero Tillage Conservation Agriculture. *ISWC Res*., 2(1): 35-46.

De Freitas P.L., Martin-Neto, L. & Manzatto, C.V. 2007. Solos: além de tudo, sequestro de carbono. In: Revista Agroanalysis, Fundação Getúlio Vargas, *Caderno Especial: Serviços ambientais no negócio agrícola*, 27: 04, E15-E16.

FAO. 2019. Conservation Agriculture Principles. In: FAO CA Website. Available at www.fao.org/conservation-agriculture/overview/principles-of-ca/en/ [accessed 10.03.2019]

Fuentes Llanillo, R. 2018. Relation of CA to healthy farms and healthy landscapes. Invited paper presented in 21st World Congress of Soil Science, Rio de Janeiro, Brazil, 2018. Interdivisional Symposia 3.2 - Sustainable soil management. Available in https://www.21wcss.org. [accessed 10/03/2019]

Hernani, L.C., De Freitas, P.L., Pruski, F.F., De Maria, I.C., Castro Filho, C. & Landers, J.N. 2002a. A erosão e seu impacto. In: Manzatto CV, Freitas Junior E, Peres JRR. (eds.). *Uso agrícola dos solos brasileiros.* Rio de Janeiro, Brasil: Embrapa Solos, 174 p. Cap. 5. pp. 47-60

Hernani, L.C., de Freitas, P.L., Denardin, J.E., Kochhann, R.A., De Maria, I.C. & Landers, J.N. 2002b. Uma resposta conservacionista: o impacto do sistema plantio direto. In: Manzatto CV, Freitas Junior E, Peres JRR (eds.). Uso agrícola dos solos brasileiros. Rio de Janeiro, Brasil: Embrapa Solos. 174 p. Cap. 14. pp. 151-161.

Landers, J.N. 1999. How and why the Brazilian zero tillage explosion occurred. Buenos Aires: ISCO. (Proceedings...).

Landers, J.N., Barros, G.S., Rocha, M.T., Manfrinato, W.A. & Weiss, J. 2001a. Environmental impacts of zero tillage in Brazil – a first approximation. In: Congress on Conservation Agriculture. Madrid: FAO-ECAF, V. I, Chapter 34, pp. 317-26.

Landers, J.N., De Freitas, P.L., Guimarães, V. & Trecenti, R. 2001b, The social dimensions of sustainable farming with zero tillage. In: International Conference on Land Degradation and Meeting of the IUSS Subcomission C - Soil and Water Conservation, Rio de Janeiro, Brazil. Paper S6-03. 12 p.

Landers, J.N., Rass, G., De Freitas, P.L., Basch, G., González-Sanchez, E.J., Tabaglio, V., Kassan, A., Derpsch, R. & Friedrich, T. 2013. Effects of zero tillage (no-till) conservation agriculture on soil physical and biological properties and their contributions to sustainability. Proceeding of EGU Meeting 2013, Vienna, Geoph. Res. Ab., Vol. 15, EGU2013-11756-1.

Lima, M.A., Paciullo, D.S.C., Morenz, M.J.F., Gomide, C.A.M., Rodrigues, R.A.R. & Chizzotti, F.H.M. 2018. Grass forage Sci. 1–11.

Machado, P.L.O. de A. & De Freitas, P.L. 2004. No Till farming in Brazil and its impact on food security and environmental quality. In: Lal R, Hobbs P, Uphoff N, Hansen D. *Sustainable Agriculture and the Rice-Wheat System.* ed. : Marcel Dekker, Inc., Chapter 18. pp. 291-310.

Manzatto, C.V., Ramalho Filho, A., Costa, T.C. e C. da, Santos, M. de L.M., Coelho, M.R., Da Silva, EF. , De Oliveira, R.P. 2002. Potencial de uso e uso atual das terras. In: Manzatto CV, Freitas Junior E, Peres JRR. (eds.). *Uso agrícola dos solos brasileiros*. Rio de Janeiro, Brasil: Embrapa Solos, 174 p. Cap.2. pp. 13-21.

Pacheco, L.P., Pires, F.R., Monteiro, F.P., Procópio, S.O., Assis, R.L., Cargnelutti Filho, A., Carmo, M.L. & Petter, F.A. 2009. Soybean crop oversowing used as a technique to suppress weed emergence. *Planta Daninha*, 27(3) Viçosa.

Ramalho Filho, A. & Beek, K.J. 1995. Sistema de avaliação da aptidão agrícola das terras. 3. ed. rev. Rio de Janeiro: EMBRAPA-CNPS. 65p.