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

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April 28, 2020

Abstract

Land use surveys show 30.5% of Brazil´s territory is dedicated to production of food, fibers, biofuels and raw materials; however, soil erosion is the main agent of land degradation and productivity decreasing. This paper reports the impacts of the adoption of conservation agriculture (CA) principles in controlling soil loss by water erosion, where Zero Tillage (ZT) and integrated Crop-Livestock-Forest (iCLF) management systems are the central policies. Annual soil loss potential, estimated for a scenery lacking CA practices, intensive conventional tillage and monoculture, is of 3.0 billion tons, with 29.5% of losses in croplands and 61.4% in rangelands. The economic impact of soil erosion based only on nutrient losses is estimated in 15.7 billion US dollars. Efforts to control water erosion, intensify agricultural production and mitigate the emission of greenhouse gases are the goal of a recent national governmental program for detailed soil survey and interpretation for land use - PronaSolos. Practices and technologies based on CA, such as ZT and iCLF, already adopted in 44.4 million hectares, with an economic impact of 2.3 billion US dollars, will be recommended to reach 60 million ha by the year 2025. Other benefits are maintenance of rural roads, reduction of soil and water pollution, increase of water quality and storage capacity of reservoirs. The success of the program and current achievements with CA in Brazil result from determination of farmers and many actors involved in controlling soil erosion; as well as plans and policies to implement practices and technologies based on CA principles.

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1. INTRODUCTION

In the context of agriculture, land degradation leads to decreasing of production capacity, through the reduction of soil quality with negative impacts on soil physical, chemical and biological attributes. The main agent of soil degradation worldwide is water erosion, which is a natural process in the formation of landscapes but is intensified by anthropic actions such as agriculture. Soil erosion in croplands and rangelands is mainly caused by the soil usage and land management with inadequate agricultural practices; in turn, the water erosion is the main factor responsible for expansion of degraded lands in the world. Water erosion compromises the attainment of high levels of crop production and the intensification of agricultural, as well as the environmental quality of ecosystems, due to water contamination and the reduction of water availability for many usages (Andrade & Chaves, 2012; FAO, 2019) .

Besides compromising the potential of agricultural production and the resilience of different ecosystems, with the loss of land and aquatic biodiversity, soil erosion increases rural exodus due to land degradation, causes silting and contamination of water resources, increases occurrence of floods, decreases the capacity of hydroelectric plants to generate power and increases costs for water treatment. Thus, water erosion was considered one of the most extreme environmental problems of the humanity (Feng et al., 2010). According to Eswaran et al. (2001), soil erosion and desertification are responsible for a decline of productivity of 50% in some croplands and pastures of the world, as a consequence the global annual soil loss is of 75 billion tons, with a cost of about 400 billion US dollars per year. FAO (2015) documents estimate that 33% of the world's lands are degraded. Soil erosion by water also has large economic impacts; thus, agricultural production systems that can provide soil and water conservation are crucial in achieving the sustainable use of these natural resources.

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. Detailed mapping of soil distribution and better interpretation of soil properties are important to achieve a sustainable agriculture and to reduce soil erosion, as land usage and crop/pasture/forest production are intensified. The first step to control water erosion in a regional scale is planning the land use with respect to its agricultural suitability (Ramalho Filho & Beek, 1995) and, at the farm level, it is essential that lands are used according to their capability and following the recommended conservation practices (Lepsch et al., 2015). Evaluations based on existing soil information indicate that over 5.5 million km^2 or 65% of the Brazilian territory have aptitude for annual or perennial crops (Manzatto et al., 2002). On the other hand, degraded lands occupy about 22% of the territory with varying levels of degradation (Bai et al., 2008); thus, programs for recovering these lands and to increase adoption of soil conservation practices and technologies are essential for a sustainable agriculture (Oliveira et al., 2019).

The 1970's models of agriculture in Brazil, based on intensive tillage, monocropping and high inputs of fertilizers and products for controlling pests and diseases, were not efficient to control loss by water erosion. In the 1990´s it was already recognized that, for an effective soil erosion mitigation, it was necessary the integration of cultivation practices with biological technologies and management of crop residues. The initial No-till concept with the direct planting of seeds over the previous crop residues was not enough to control water erosion, especially in the tropical soils. This led to evolution of a land management system in which no-tillage, crop rotation (pluri-annual rotation of annual crops with no repetition of crops in subsequent years), permanent soil cover and controlled traffic are associated.

These are the technological bases of the Zero Tillage / Conservation Agriculture (ZT/CA) management system and they are universal, although technical solutions depend on local soil, climate, relief and socio-economic conditions (Landers, 1999; Landers et al., 2013). The application of these principles may reverse the historically accelerating soil erosion and the degradation of soil organic matter and soil structure (Landers et al., 2013).

The potential soil loss by water erosion for the entire Brazilian territory was estimated at the end of the 1990s as being of 822.6 million tons per year, with 751.6 million tons in the areas with annual and perennial crops and 71.1 million tons in the rangelands (Hernani et al., 2002a). In 2010, these authors estimated that such annual soil losses due had the annual cost of about 6 billion US dollars. This value included losses due to removal of plant nutrients and soil amendments, in addition to other losses generated inside and outside the farm.

To control erosion in the highly weathered Brazilian soils, the evaluation of land capability is essential, which requires detailed surveys of soils, landscape and climate conditions. These demands culminated with the setup of a recent national governmental program for soil survey and interpretation for land usage, the PronaSolos (Polidoro et al., 2016). The PronaSolos program plans, in the next three decades, to overcome the lack of adequate data and to provide the necessary information about soil and water resources. By mapping the soils in detailed scales in the regions prioritized by PronaSolos, it will be possible to carry out appropriated land use planning and mitigating land degradation processes. The division of the rural areas into land management zones will enable the efficient use of the soil, with all the inputs required for crop production, for achieving a sustainable agriculture for large and small farmers. In this way, it will be possible to recommend the most appropriate models for different landscapes and climates, in different regions of Brazil subsidizing the elaboration and implementation of a national soil and water conservation plan.

The PronaSolos will join in national programs toward the adoption of recovering practices and technologies for converting degraded lands into productive crop- and pasturelands, such as, the Plan of Mitigation and Adaption to Climate Changes for the Consolidation of an Economy of Low Carbon Emission in the Agriculture (ABC Plan) (Gurgel & Laurenzana, 2016). In addition to the goals of reducing water erosion and increase soil carbon stock, other objectives of these government programs are to control desertification, water and soil contamination, surface and subsurface compaction, surface impermeabilization and to reduce emission of greenhouse gases and risks of disasters.

A recent FAO (2019) document strengthens the principles of Conservation Agriculture (CA) as following: minimum soil disturbance in the planting row and confined to the planting operation; permanent soil cover with crop residues (straw) and live plants; and crop rotation, intercropping and root diversity. Based on this principles, which were already implemented into the conservation practices adopted by a large number of Brazilian farmers, the objective of this paper is to report the impacts of Brazil´s conservation agriculture initiatives towards the control of soil erosion and the economic effect of adoption of plans, policies, practices and technologies closely linked with the land use intensification, having Zero Tillage / Conservation Agriculture (ZT/CA) and integrated Crop-Livestock-Forest under Conservation Agriculture (iCLF-CA) management systems as the centre policies.

2. MATERIALS AND METHODS

2.1 Assessment of land usage and cover

The land use and cover of the Brazilian territory (8.5 million km^2) was assessed using 2017 data, compiled from different literature sources (Table 1). It is observed that around 80.8 million hectares are covered with annual and perennial crops, including planted forests (mainly Eucalyptus and Pinus), producing food, fibers, biofuels and raw material for agroindustry and other uses. The area dedicated to annual crops – soybean, corn, cotton, beans etc. – sums up to 55.6 million ha. Natural and cultivated pastures, in different stages of degradation, occupy 178.7 million ha; where about 38% of this area is represented by cultivated pastures, mainly with species of Brachiaria (*Urochloa spp.*), Panicum and Andropogon (Macedo, 2009), having a high grazing capacity. However, 36% of the area of pasture are considered degraded and erosion by water is one of the main factors, together with compaction and losses of soil nutrients.

INCLUDE TABLE 1

2.2 Estimates of cost of potential soil losses by water erosion

Potential soil losses by water erosion were estimated considering Brazil's land use and coverage in 2017 (Table 1). In the areas of annual and perennial crops and planted forest the soil loss was estimated considering a low usage of agriculture conservation practices such as contour tillage, terracing and barriers for water contention and using intensive tillage methods, with deep ploughing, disc harrowing and subsoiling, in which the soil is revolved and exposed to heavy and erosive rains, causing the increase of superficial water runoff (Landers et al., 2006). Also, by considering monoculture for annual crops and lack of cover crops in the perennial (Hernani et al., 2002a). The estimative of annual economic impact of soil losses was based on the revision presented by Eswaran et al. (2001) for crop and pasture areas. The estimation of economic impacts of implementing conservation agriculture (ZT/CA and iCLF-CA) principles towards soil erosion control considered the concepts proposed by Hernani et al. (2002a; 2002b), based on the costs of liming and nutrient replenishment by using fertilizers (organic and mineral), as well as fuel and other inputs.

The modelling of evolution of the conservation agriculture systems (ZT/CA and iCLF-CA) was performed using data from the agricultural census (2017) published by the Brazilian Institute of Geography and Statistics (IBGE). The economic impact of using ZT/CA for an area of 14.4 10^9 ha was projected as 1.85 10^9 US dollars, or 129.4 US dollars ha^{-1} $year^{-1}$ (Hernani et al., 2002b). For areas with annual crops and ZT/CA, the mitigation of soil loss was considered from an average rate of 5.6 t $ha^{-1}year^{-1}$ (313.3 million tons in 55.6 million ha) to a value of 2.5 t ha^{-1} $year^{-1}$ when using ZT/CA (Hernani et al., 1999). In the case of the adoption of iCLF-CA, it was considering cultivated pastures (not degraded and in good conditions) with an average loss of 13 t $ha^{-1}year^{-1}$; where the integration of iCLF-CA with the basic principles of ZT/CA reduced soil losses to 2.5 t ha^{-1} $year^{-1}$.

2.3 Estimates of the increase in the area of ZT/CA

The evolution of ZT/CA as a major land management system in Brazil (Figure 1), from 1972/73 to 2017/2018, was calculated from statistics in FEBRAPDP (2020). Data from IBGE's agricultural census, obtained in 2017 (adapted from Fuentes-Llanillo, 2018), shows an area of 32.88 million ha in the agricultural year of 2017/2018, distributed all over Brazilian territory and including cash crops such as soybean, corn, cotton, common beans and wheat, in addition to mixed systems where annual crops are integrated with pasture and forestry.

The ZT/CA time series presented a gap of five years without values measured; therefore, data imputation was performed. Here, we used an annual average between the last and the first data observed, respectively, before and after the missing values (i.e., 2013 to 2017). This type of data imputation is plausible for exponential data (Beretta & Santaniello, 2016) when considering that the values between the missing period, are the important values for filling the gaps (Figure 1).

INSERT FIGURE 1

To forecast ZT/CA data we, first, used the simplest of the exponentially smoothing (SES) method. This method is suitable for forecasting data with no clear trend or seasonal pattern, such as ZT/CA data. Yet, ZT/CA data show a rise in the last few years, suggesting a trend in data. Therefore, we used the Gardner & McKenzie (1985) approach that uses a parameter that "dampens" the trend to a flat line sometime in the future. Methods that include a damped trend have proven to be very successful and are arguably the most popular individual methods when exponential forecasts are required.

2.4 Estimates of the increase in the area of iCLF-CA in Brazil up to the year 2030

Estimations were made from data in the ICLF Network, by Kieffmann Group (2016), the numbers show that iCLF-CA increased steadily in Brazil since 2005 and was already largely adopted, with an area of 11.47 million ha, in 2015. According to the report, in the period between 2005 and 2015/16 there was a twofold growth rate of iCLF-CA adoption; were from 2005 to 2010 the area increased at a regular rate and from 2011 to 2015 there was a greater growth rate. Here, we used the differences in slope among periods and three simple linear models were used to calculate the increase in the iCLF-CA area for 2030. For the first model (Scenario1), we used the average rate considering the period from 2005 to 2010. In the second model (Scenario 2) we used the average rate of the entire period, which is, 2005 to 2015. Finally, for the third model (Scenario 3) we used the average rate of the period from 2010 to 2015. Using these three models we should capture all possible growth for the area of iCLF-CA in Brazil. Therefore, we assume a linear growth for iCLF-CA over the years.

3. RESULTS

3.1 Potential soil losses by water erosion in Brazilian territory

Considering the land use and cover in Brazil´s territory on 2017 (Table 1), it was estimated that, without the adoption of any of the agricultural and conservation practices, the annual potential soil loss is of about 3.0 billion tons, from this total value 29.5% originate in the croplands and 61.4% in pasturelands (Table 2). The estimation of the economic impact of the soil loss, based on the costs of nutrient replenishment with fertilizers (organic and mineral) and liming is evaluated as 15.7 billion US dollars per year for croplands and pasturelands (Table 2). The cost due to soil degradation in US, where soil erosion plays a major role, was estimated as of 44 billion US dollars per year for a total area of crop and pasture of 178 million ha (Eswaran et al., 2001).

INCLUDE TABLE 2

3.2 Economic impact of ZT/CA and iCLF-CA management systems adoption

The estimate of the economic impact of adoption of ZT/CA and iCLF-CA management systems (Table 3) considering the data observed in 2017/2018, shows a value of 2.3 billion US dollars, when taken in account the equivalent fertilizer and lime requirements. This considers an impact of 1.4 billion US dollars due to the adoption of ZT/CA in 32.9 million ha of annual crops and of 0.52 billion US dollars in 11.47 million ha of cultivated pastures (not degraded or with little degradation).

INCLUDE TABLE 3

To mitigate the impact of soil losses due to water erosion and contribute to SOC sequestration and mitigation of GHG's emission, Brazil has adopted public policies and national and regional plans to achieve high productivity and the intensification of agricultural activity, with a significative improvement of environmental quality. The main policies and plans with the projections of results are summarized below:

- Recovery and agricultural intensification in degraded lands, where annual crops are cultivated with adoption of practices and technologies based on the principles of ZT/CA, iLCF-CA and other mixed systems. These actions have the potential of promoting the mitigation of, at least, 90% of the soil losses in 22.8 million ha of croplands.
- Adoption of best management practices (BMPs) based on ZT/CA in 9.2 million ha with sugarcane production, including the rotation with cover crops (ex. crotalaria), grains (soybean, corn), or grasses (Brachiaria) in the renewal of sugarcane plantations. The mitigation of soil losses is estimated in more than 50% during renewal and re-installation of sugarcane plantations.
- Incentive to the recovery and reinsertion of about 64 million hectares of rangelands with some level of degradation, including highly degraded lands (formation of ravines and gullies) and severe loss of animal support capacity, according to the potential agricultural capability, through the establishment of national and regional plans. The ABC plan (Andrade & Freitas, 2019) prognoses is that more than 70% of the degraded rangelands in Brazil will be recovered or changed into croplands by 2030.
- Afforestation and reforestation, mainly with species of economic value and with silvopastoral systems, derived from iCLF-CA, planned for more than 60 million ha of areas reserved for the protection of natural vegetation, according to Brazilian legislation, considering 30% of the environmental protection areas, 50% of Indian reserves and settlement areas and 30% of the *quilombola* areas.

The effect of the plans and policies above in terms of potential of annual SOC sequestration in lands with different use and coverage was calculated using the parameters suggested by Lal et al. (2018) in a perspective of 50 years (Table 3). BMPs with ZT/CA and iCLF-CA involve integrating all the individual agricultural practices and technologies available to guarantee erosion control and to produce annual biomass in a sustainable and competitive manner (Freitas et al., 2000). The estimates point for a total value of annual soil C sequestration varying from 44.63 to 145.95 million tons (Table 4), where the maximum values are in the degraded pastures followed by lands for settlements and annual crops.

INCLUDE TABLE 4

3.3 Impacts of plans, policies, practices and technologies based on ZT/CA and iCLF-CA increasing area

3.3.1 ZT/CA 2030 forecasting

The forecast using ZT/CA data shows that the area will increase about 35.07 million ha in 2030 (Figure 2A). For this scenario the area will increase about 0.18 million hectares year^{-1} and the 95% confidence interval show a range between 16.28 and 53.86. A second forecast (Figure2B) shows that ZT/CA area will reach 34.39

million hectares by 2030, with a 95% confidence interval of 18.88 and 49.90 million hectares. As shown in Figure 2B, this forecast considers the low growth of ZT/CA in the last years to damp the indefinite growth.

INSERT FIGURE 2.

3.2.2 iCLF-CA 2030 forecasting

The scenarios elaborated to predict the increase in iCLF-CA area in Brazil from 2016 to 2030 are illustrated in the Figure 3. The Scenario 1 had a rate of iCLF-CA area increase of 0.72 million hectares per year. Therefore, based on the data for the year 2015 (area of 11.47 million ha) the prediction for 2030 in the Scenario 1 is of 22.27 million hectares of lands with the system. The Scenario 2 had a rate of 0.96 million hectares per year, which is close to the annual increment of 0.97 million hectares reported by ABC Plan (Cordeiro et al., 2015), considering an ICLF-CA expansion area of 5.83 million hectares from 2010 to 2016. Therefore, based also on the data of 2015, the prediction for Scenario 2 is of 25.87.07 million hectares in 2030. Scenario 3 had the higher annual growth rate (1.19 million hectares); thus, the predicted value for 2030 is of 29.32 million hectares of ICLF-CA.

INSERT FIGURE 3

The results of the three scenarios, developed using data from the ICLF Network to predict the increase of area with iCLF from 2015 to 2030, are summarized in the table 5. According to these scenarios, individually, the estimated areas for the year 2030 vary between 22.27 and 29.32 million hectares. Considering an average projection of the three scenarios, figure 4 shows the average increase value of the iCLF-CA area between 2015 to 2030 (solid blue line) and its confidence interval (95% - blue shadow).

INCLUDE TABLE 5

INSERT FIGURE 4

4 DISCUSSION

4.1 Evolution of ZT/CA adoption in Brazil

The evolution of ZT/CA adoption (Figure 1) shows a growth of 290% in the area with ZT/CA in the last 20 years. Initially, 20 years ago, the increase in soil water infiltration led farmers and technicians to neglect the conservation practices and technologies, because they assumed that the no-tillage system alone would be enough to control soil losses by water erosion. The consequences of this actions were the increasing of soil loss, mainly during years with heavy erosive rains. Thus, after 2017/2018 the government agencies policies and plans emphasized that, to mitigate water erosion, the adoption of all three basic principles of ZT/CA, associated with conservation practices such as terracing and controlled traffic, was more than necessary.

4.2 Environmental and economic impact of ZT/CA and iCLF-CA management systems adoption

It is recognized the impacts of ZT/CA in the increase of soil organic carbon (SOC) sequestration, reduction of the emission of greenhouse gases (GHGs) and improving economic and agriculture sustainability. The emissions of GHG are reduced in the ZT/CA by decreasing the use of fossil fuels in the crop production, the efficient application of fertilizers and reduction of N_2O emissions, as well as decreasing soil erosion. Pointed as an evolution of ZT/CA, iCLF-CA also affects positively soil biological, physical and chemical attributes, for example by increasing C and N stocks in the short- and long-term, and water retention, and reducing erosion soil losses. The build-up of SOM improves biological, physical, and chemical soil properties, leading to an increase in crop yields, with reduction of costs with irrigation, fertilizers, soil conditioners and other agricultural inputs (Conceição et al., 2017). The adoption of iCLF-CA also improves environmental, social and economic services and it is a promising alternative to recover degraded areas (Lima et al., 2018; Landers et al., 2020) .

Other impacts of the adoption of ZT/CA and iCLF-CA includes the off-farm effects related by Landers et al. (2001a) considering both direct and environmental benefits, including yield and support capacity decline and land value depreciation in croplands and rangelands due to water erosion, especially due to the intensive soil preparation, monoculture practice and overgrazing. There are also off-farm benefits that implies in the reduction in public spending such as: the maintenance cost of rural earth roads – an annual economy of 3.5 US Dollars in a million ha of crop areas; which implies in a public economy of 280 million US Dollars; the reduction of turbidity and lower cost for water treatment for human consumption, estimated to be of US Dollars 5.80 for each 10 thousand m^3 (based on Carroll, 1997); and, the reduction in reservoir volume storage by silting in dams for hydroelectric power plants and for irrigation projects estimated as being of more than 700 million US Dollars per year (Carvalho et al., 2000).

The adoption of ZT/CA principles in irrigated areas with central pivot, micro-irrigation, drip irrigation or localised irrigation, which comprises 4.84 million ha in 2017, implies in an economy of 10% in water volume and in pumping costs. Landers et al (2001a), considering 10% less in consumptive use of water in annual crop irrigated areas, an annual economy of US$ 20.00 per hectare in need of pumping energy and 800 m^3 ha^{-1} in water volume, valued to be US$ 8.00 per ha. This means that, if ZT/CA adoption occurs in the irrigated area, an annual economy of 38.7 million US Dollars, considering prices of 2001. This implies in less demand of electrical energy and in water.

4.3 Impacts of plans, policies, practices and technologies based on ZT/CA and iCLF-CA (2030 Forecast)

In terms of increasing area, as a result of plans and policies in Brazil, ZT/CA showed a huge growth since 1990; however, from 2012 the increase becomes more conservative, year after year (Figure 2). The possible explosion in the area of ZT/CA in the 90's could be associated with the intensity of sustainability global discussions at those times. At the United Nations Conference on Environment and Development (Rio 92) in 1992, Brazil had a significant presence in the environmental discussions and showed a commitment to different articulations and debates toward adoption of the sustainable technologies. However, considering scenarios 2 and 3, through public and private incentives and intensification of land use, the forecast in Figure 2A might be possible. Yet, an exponential growth would not be expected, but a constant positive growth until 2030. On the other hand, considering the forecasts in Figure 2B, the scenario 1 could be more appropriate when the increase of ZT/CA is based on GHG's mitigation and SOC sequestration purposes and might depend on acceptance by society and policymakers. This scenario could flatten the curve of ZT/CA growth and the forecast shown in Figure 2B might be possible.

The impacts of plans and policies for the iCLF management system, based on forecasts with the three scenarios, predict for the year 2030 that 95% of the iCLF-CA area will be between 22.99 and 28.74 million hectares. Such forecast results and the known data growth can contribute to the idea that iCLF is a technology in expansion, with great potential at a continental-scale level and it is growing fast. The ease of combinations between land management systems, the highest productivity by hectare and the adaptability in different environments, turns the iCLF-CA technology to be a sure bet for the future sustainable development of agriculture. Taken in account that the principal characteristic of iCLF is the variety of components and plant species that could be used in the system, this increase in diversity is aligned with most ecological theories (Grime, 1998; Craven et al., 2018; da Luz et al., 2019; Jonsson et al., 2019; Geneletti, Scolozzi, and Esmail, 2018). This has a high relevance in terms of conservation agriculture, due to the role of biodiversity increasing for improvements of carbon storage, nutrient cycling, soil preservation, and climate change; while maintaining food and fiber productivity for the society.

5. CONCLUSION

The impacts of policies and plans established at the national and regional level by the Brazilian government and the efforts of public and private institutions to bring farmers to use the practices for controlling soil erosion and toward the massive adoption of ZT/CA and iCLF-CA management systems under conservation agriculture in Brazil, allow to forecast the following advances:

- Reinsertion of areas of degraded pastures into a sustainable agricultural production system. This will promote significant increase in agricultural production and other ecosystem services, while preventing soil erosion increase to a larger extent and avoiding the deforestation of new areas for agricultural production.

- For the year 2020, the positive economic impact of system ZT/CA and iCLF-CA in preventing water erosion is estimated in 2.3 billion US dollars for Brazilian farmers.
- The updating of the National Soil and Water Conservation Program, in progress, will increase the use of conservation practices and technologies for attending different needs of the farmers.
- The information from PronaSolos Program will, in the first four years (2021-2024), increase the quality of soil data available not only to scientists but to farmers and decision makers in Brazil. This information will make ZT/CA and iCLF-CA management systems even more efficient in controlling soil loss by water erosion and land degradation.

All these efforts are a result of the determination of farmers, extensionists, technical consultants, agricultural researchers and professors and private organizations, in promoting soil erosion control practices in an extensive area of Brazil. The success of plans and policies which allowed the adoption of practices and technologies based on ZT/CA and iCLF principles, if maintained in a conservative scenario, may reach to 60 million of hectares of agriculture land by the year 2025. In the process, the Brazilian agriculture will become one of the most sustainable in the world.

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TABLE 1 Area of land use and coverage in Brazilian territory, based on 2017.

Land use and coverage	**Area %**	**Area million ha**
Annual crops [a,b]	6.5	55.6
Sugarcane[b]	1.1	9.2
Perennial and semi perennial crops and planted forests[a]	1.9	15.9
Total Crops and Planted Forests	**9.5**	**80.8**
Natural pasture[a]	5.6	47.3
Degraded pasture[c]	7.5	63.7
Cultivated pasture[a, b]	7.9	67.7
Total Pasture	**21.0**	**178.7**
Natural vegetation areas (Conservation Units, Indigenous Land and Public Forests) [d] +	21.5	183.1
Protected Areas (Settlements, environmental protection areas and *quilombolas*) [d]	15,6	132,9
Natural vegetation areas in rural properties[e]	25.6	218.2
Natural Forests (Conservation Units, Indigenous Land and others)	**62.7**	**534.2**
Unvegetated natural landscapes[f]	6.1	52.3
Cities, mining etc. [f]	0.6	5.5
TOTAL	**100.0**	**851.49**

[a]Based on IBGE (2019);[b]Based on LOPES (2020);[c]Based on Lapig (2017);[d]Based on GITE (2017);[e]Based on Miranda et al., 2017;[f]Based on Projeto MapBiomas (2020)+ Does not include overlap areas found between Conservation Units and Indigenous Lands (based on GITE, 2017)

TABLE 2. Potential annual soil loss estimates under different land uses and coverage in Brazil

Land use and coverage	**Annual soil loss**	**Annual soil loss**	**Annual soil loss**	**Annual soil loss**
	t ha^{-1}	**million t**	**million US$**	**US$ ha^{-1}**
Annual crops	15.0[a]	834.6	4298.5	77.3
Sugarcane	5.6[b]	51.4	264.9	29.8
Perennial, semi perennial crops and planted forests	0.8[a]	13.3	68.6	4.3
Total Crops and Planted Forests		**899.4**	**4631.7**	**57.3**
Natural pasture	3.4[c]	160.9	828.6	17.5
Degraded pasture	22.4[c]	1427.9	7353.7	115.4
Cultivated pasture	4.2[c]	284.9	1467.2	21.7
Total Pasture		**1873.7**	**9649.5**	**54.0**
Natural vegetation (Conservation Units, Indigenous Land and Public Forests)	0.4[d]	73.2	377.1	2.1
Protected areas (Settlements, environmental protection areas and *quilombolas*)	0.9[d]	119.6	615.8	4.6
Natural vegetation in rural properties	0.4	87.3	449.6	2.1
Natural Forests		**280.1**	**1442.5**	**2.7**
Unvegetated natural landscapes	0.0	0.0	0.0	0.0
Cities, mining etc.	0.0	0.0	0.0	0.0
TOTAL		**3053.2**	**15723.7**	**18.5**

[a]Based on Hernani et al. (2002a);[b]Based on Correa et al. (2016);[c]Based on Santos et al. (1998);[d]Based on authors' estimatives.

TABLE 3. Annual cost reduction by mitigation of soil loss with ZT/CA and iCLF-CA management systems considering the equivalent fertilizer need (adapted from Hernani et al., 2002b)

Commercial product	**Unit Cost**	**ZT/CA adoption area**	**ZT/CA adoption area**	**iCLF-CA adoption area**	**iCLF-CA adoption area**	**iCLF-CA adoption area**	**ZT/CA + iCLF-CA adoption area**	**ZT/CA + iCLF-CA adoption area**	**ZT + iC ad ar**

	US$ t-1	32.88 million ha million ton	32.88 million ha million US$	11.47 million ha million US$	11.47 million ha million ton	11.47 million ha million US$	44.35 million ha million US$	44.35 million ha million ton	44 mi lio ha mi US
Dolomitic limestone	37.00	2.9	106.31	106.31	1.0	37.09	37.09	4.5	16
Triple superphosphate	550.25	0.2	102.27	102.27	0.1	35.68	35.68	0.3	16
Potassium chlorate	549.96	0.6	323.48	323.48	0.2	112.84	112.84	0.9	50
Urea fertilizer	520.02	0.9	484.57	484.57	0.3	169.04	169.04	1.5	75
Ammonium sulfate	396.20	0.2	80.88	80.88	0.1	28.21	28.21	0.3	12
Organic fertilizers	30.00	12.9	387.07	387.07	4.5	135.03	135.03	20.2	60
Annual Cost (in US Dollars)	**Annual Cost (in US Dollars)**	**Annual Cost (in US Dollars)**	**1,484.58**	**1,484.58**		**517.89**	**517.89**		**2,3**

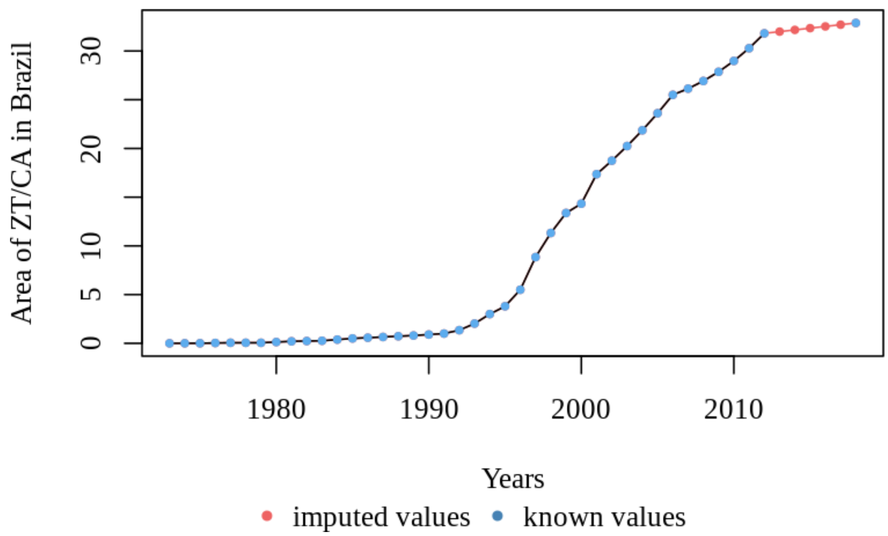
TABLE 4. Potential of annual soil carbon sequestration according to land use and coverage in Brazil (based on Lal et al., 2018)

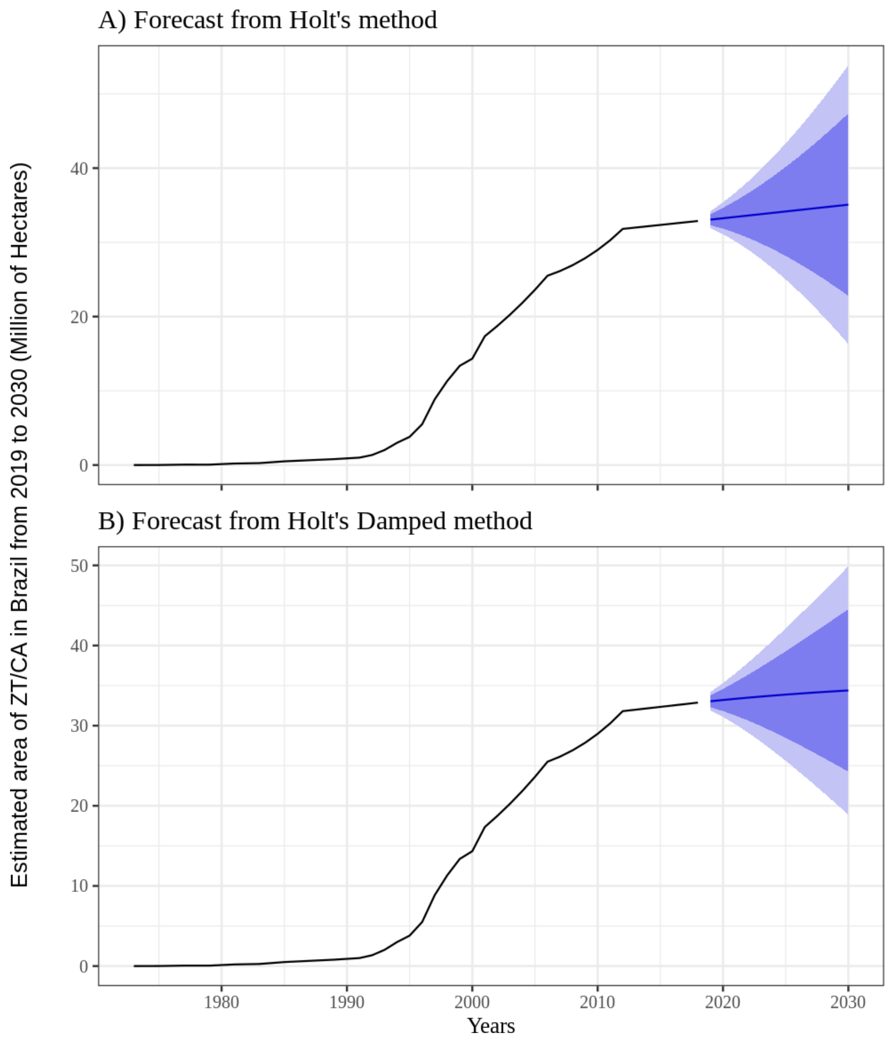
Land use and coverage	Total area	Area selected	Annual SOC Sequestration Rate	Annual SOC Seques Rate
			min	max
	million ha	*million ha*	*t ha^{-1}*	*t ha^{-1}*
Annual crops	55.6	22.8	0.1	1.0
Sugarcane plantations	9.2	4.6	0.1	1.0
Natural pastures	47.3	33.1	0.3	0.4
Degraded pastures	63.7	63.	0.05	0.75
Environmental protection areas	41.7	12.5	0.5	1.0
Lands destined for settlements	88.4	44.2	0.5	1.0
Areas of *quilombolas*	2.7	0.8	0.5	1.0
TOTAL				

TABLE 5: Scenarios of area with iCLF-CA in Brazilian territory, between 2015 and 2030

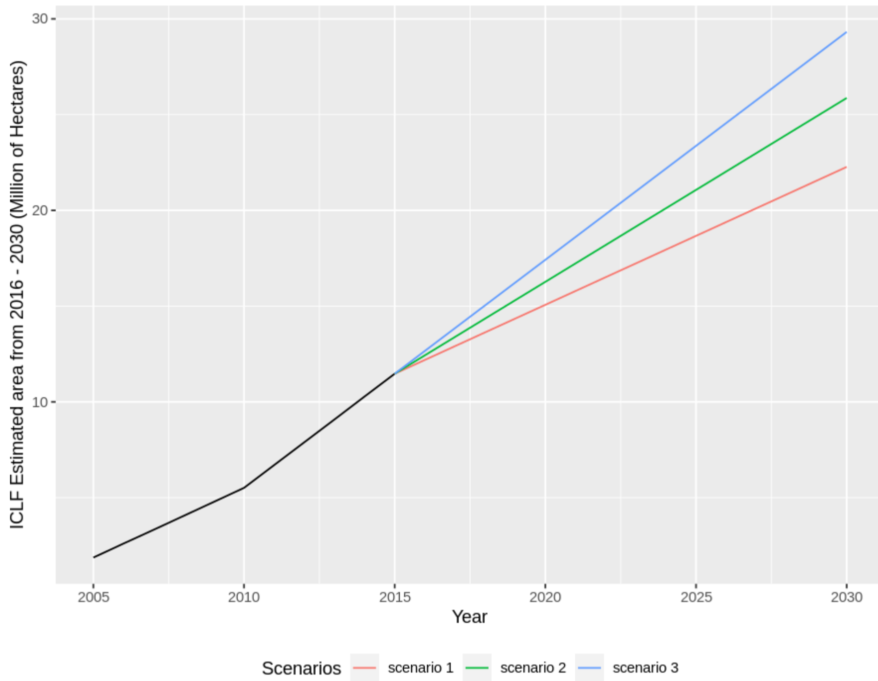
Year	Scenario 1	Scenario 2	Scenario 3	Year	Scenario 1	Scenario 2	Scenario 3
2015	11.47	11.47	11.47	**2023**	17.23	19.15	20.99
2016	12.19	12.43	12.66	**2024**	17.95	20.11	22.18
2017	12.91	13.39	13.85	**2025**	18.67	21.07	23.37
2018	13.63	14.35	15.04	**2026**	19.39	22.03	24.56
2019	14.35	15.31	16.23	**2027**	20.11	22.99	25.75
2020	15.07	16.27	17.42	**2028**	20.83	23.95	26.94
2021	15.79	17.23	18.61	**2029**	21.55	24.91	28.13

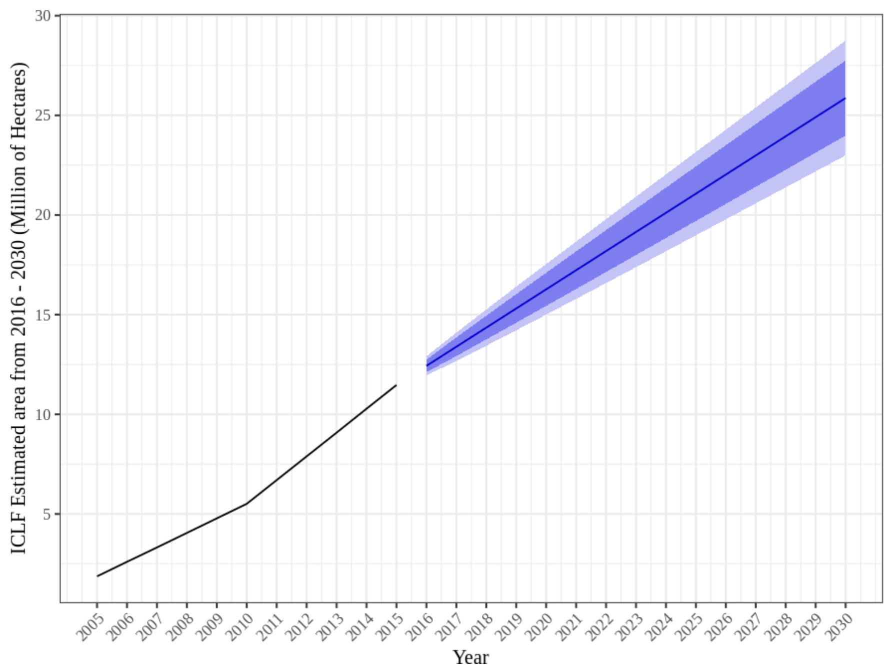
2022	16.51	18.19	19.8	**2030**	22.27	25.87	29.32





A) Forecast from Holt's method
B) Forecast from Holt's Damped method
Estimated area of ZT/CA in Brazil from 2019 to 2030 (Million of Hectares)
Years
0
10
20
30
40
50
1980
1990
2000
2010
2020
2030


ICLF Estimated area from 2016 - 2030 (Million of Hectares)
Year
Scenarios
scenario 1
scenario 2
scenario 3


ICLF Estimated area from 2016 - 2030 (Million of Hectares)
Year