Twelve years of soil preservation and rehabilitation at Rio do Peixe watershed, promoting conservation agriculture

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Abstract

The overarching goal of this study is to test innovative monitoring strategies for agricultural properties at watershed towards effectively locating erosions and correcting them, through the implementation of changes in soil management strategies. The purpose is to recover and restore degraded areas, and promote conservation agriculture. The results are, assessed by remote sensing and water quality indicators. In 2019, twelve years were completed of inspection/monitoring at Rio do Peixe watershed. From 2007 to 2017, 14,076 ha, were inspected at Vera Cruz sector, using the Conventional CDA methodology, with 94 properties having been notified. In Ocauçu, a total of 82 properties were notified, in a total surface of 9,027 ha. In Marília, the Innovative CDA Methodology was used, which allowed the inspection and rehabilitation of 52 properties, across 27,775 ha, from 2017 to 2018. After the notifications, the owners presented the conservationist technical projects for each property, which were, implemented using conservation practices, such as: improvement of vegetation cover and crop rotation, to control laminar erosion; and agricultural terracing, divergent channels and containment basin, to control gullies erosions. This work promoted a transformation from degrading agriculture to conservation agriculture, with degraded pastures having been altered into agricultural areas, with the implementation of the No-tillage. Pastures were recovered through the Integrated Crop-Livestock System, and occupancy rate was increased by 31%. This work has demonstrated to benefit Watershed farmers, by increasing their productivity and consequently the profit, as well as the local communities, improving the quality of water that supplies the region.

1 INTRODUCTION

The São Paulo State Secretariat for Agriculture and Supply (SAA) is responsible for the regulation of soil use and conservation, as well as the combat against soil erosion. Through the Coordination of Agricultural Defense (CDA), it enforces the Law on Use, Conservation and Preservation of Agricultural Soil - State Law nº. 6.171/88 - (São Paulo, State, 1988), with the purpose of monitoring and controlling soil use and conservation.

This agency has been carrying out this work for 20 years, with very positive results, with inspections carried out mainly in watersheds. Approximately 18 million hectares of the surface of the state of São Paulo is occupied by agriculture, with 330 thousand agricultural properties. During that period, from 2000 to 2019, 772,000 hectares were inspected, with 19,846 agricultural properties having been notified and agroecologically rehabilitated (Vischi Filho et al., 2019).

The CDA Diagnostic methodology uses conservation law as a tool, and considers the watershed as the ideal work unit for carrying out this type of activity. The watersheds play an important role in regulating the water balance, as well as housing agricultural production, and promoting rainwater storage , which seeps into the soil and is available to rivers throughout the year (Lal, 1994; Vischi Filho et al., 2018 and 2019).

The lack or deficiency of vegetation cover in crops results in degradation of the watershed, leading to erosive processes that cause the silting of the watershed water network and interfering in the quantity and quality of the water (Rodrigues et al., 2015). The first principle of soil conservation is soil cover, whether vegetation or mulch. Agricultural practices such as the use of varieties that provide larger plant coverage of the soil, reduce the direct impact of raindrops on the soil surface, hence reducing the loss of soil , water, organic matter, and nutrients due to hydric erosion (Silva et al., 2005; Rodrigues et al., 2015; Merten et al., 2016).

The inappropriate use of agricultural soils causes the gradual loss of its productive capacity, and the contamination of water resources by sediments resulting from the erosion process (Araujo, et al., 2007; Lelis & Calijuri, 2010). The last decades have been characterized by drastic changes in land use and occupation in the region, which Zalidis et al. (2002) considered one of the main driving forces for environmental degradation, especially on soil and water. This is a result of the absence, or flawed implementation, of conservationist practices in the cultivation areas of agricultural properties, which is commonly observed in Brazil, mainly in pasture areas (Menezes et al., 2009). The irrational management of the soils compromises the vegetation cover, the production and the ecosystems' balance (Santos et al., 2007). For each soil and crop, the most fitting strategy is recommended, having an impact in the reduction of the hydric erosion (Silva et al., 2009).

The second principle of soil conservation is to avoid that the surface run-off regime goes from laminar to turbulent and, for that, the construction of an agricultural terracing system is carried out, which has the function of sectioning the length of the ramp and promoting the infiltration of soil water. According to Pruski (2006), the more the soil surface is protected by vegetation cover, against the rain action, the lower the susceptibility to erosion. Studies by Minella et al. (2007) to identify the origin of sediments in watersheds concluded that the areas of crops are the main sources of sediments, and suggested that programs for the implementation of conservationist management of soil practices are essential. By adopting adequate management and mitigation actions to recover the impacted areas, there will be an improvement in water quality of the watersheds (Araújo et al., 2009). The ultimate product of soil conservation is its contribution to minimizing floods during periods of heavy rainfall and increasing water availability in the annual dry period.

In this work on the inspection of Rio do Peixe watershed, the type of intervention aimed at transforming conventional and soil-degrading agriculture into conservationist agriculture, implementing conservationist technical projects that contemplated this novelty. Conservation Agriculture is an agricultural system that promotes the maintenance of permanent soil cover, minimal soil disturbance or no-tillage, and the diversification of plant species. This increases biodiversity and natural biological processes below and on the soil surface, contributing to higher the efficiency in the use of water and nutrients, and an improvement and sustainability agricultural production (FAO, 2019).

The use and conservation of the soil at Rio do Peixe watershed was inspected for a period of 12 years, ending in 2019 in particular sections I, II and III, located in Vera Cruz, Ocauçu and Marília. This work aimed to test innovations for diagnosis of agricultural properties; to locate erosions; and to correct them, with modification in soil management strategies. The overarching goals was to transform the degraded agricultural properties at Rio do Peixe watershed into restored properties, promoting conservationist agriculture, and evaluating the results through remote sensing and water quality indicators.

2 MATERIALS AND METHODS

2.1 Study Area

This work was carried out in the sections of Rio do Peixe watershed, located in Vera Cruz, Ocauçu and Marília cities, SP, Brazil, at coordinates S22° 14'52.68 ", W49° 44'59.97", start and end at coordinates S22° 18'13.28 ", W50° 2'54.22", Datum WGS 84 (Figure 1).

The climate of the region is humid subtropical, Cwa type according to the Köppen-Geiger classification, with temperatures above 29.7°C in the warmest month and below 10.6°C in the coldest month, , and average annual rainfall of 1,193 mm.

The predominant soils are: Red-Yellow Ultisol Abrupt, moderate horizon A, sandy/medium texture and Litolic Entisol, eutrophic (Santos et al., 2018). The geological formation consists of rocks from the Bauru Group, covered by neocenozoic sediments (Bezerra et al., 2009). The predominant relief is smooth undulating in the western plateau of São Paulo and in the depression; and strongly undulating in the escarpments (Itambé) that separate the plateau from the depression.

2.2 CDA Conventional Diagnostic Methodology

The CDA inspection/diagnosis methodology (conventional) has been being developed since 1999 by the technical staff of Agronomist Engineers; first published in 2003, it was improved in 2017, and received the designation of Innovative CDA Diagnostic Methodology (Vischi Filho et al., 2019). This was urged by the need of strategic action to respond to an increase in demand. A range of technological innovations were tested, including the use of a model aircraft, helicopter, and drone; however, it was only when this new work methodology was implemented that the results were promising. The CDA Innovative pilot project was carried out at Rio do Peixe watershed, on a 53,000 hectare stretch, located in Vera Cruz, Ocauçu and Marília cities.

Inspection and agroenvironmental restoration works in Rio do Peixe watershed have been ongoing since June 15th, 2007. Inspections have been carried out in all properties that compose these three sectors of watershed. CDA Conventional methodology was applied, which consists of planning an operation with the delimitation of watershed in a topographic map scale 1:50.000; preparing a mosaic of aerial images to be used in the field, "in loco", to assist in the localization strategy; and, visiting all the watershed properties. Ultimately, the properties are visited using the "checklist" (official CDA document for Soils), in which erosions and other forms of degradation are included, in compliance with conservation legislation (São Paulo State, 1988).

Erosions are georeferenced using a Global Positioning System (GPS) receiver, classified, photographed (photos that will compose a photographic report) and noted on the "checklist". The data generated in the diagnosis is used to compose the processes relevant to each agricultural property visited. The owner of the area hires an Agricultural Engineer who prepares a technical conservation project for the restoration of the degraded area, respecting in such projects the class of land use capability (Lepsch et al., 2015), for this property.

The conservation project is, then, analyzed by the CDA Staff, who approves it or not, sending it for corrections if necessary (physical project, on paper). If approved, it is taken through to implementation stage, by the farmer, who enforces correction and remediation of the soil damage and erosion at that location. The CDA Staff, in this work, was composed of four Agricultural Engineers who worked for a week, on a monthly basis. They visited each property two to five times during the implementation of the project; the first time during the diagnosis, thereafter monitoring the execution of the technical project, and, at last, to release the property after the works. Once the project is implemented, the soil is preserved and the property becomes more profitable, as productivity is increased. This methodology was applied to two sections of this watershed, defined as: section I, located in Vera Cruz, SP, Brazil, with an area of 14,076 ha (monitored from 2007 to 2011); and section II, located in Ocaucu, SP, Brazil, with an area of 9,027 ha (monitored from 2011 to 2015).

2.3 Innovated CDA Methodology

In this CDA operation, as well as in other projects implemented throughout the territory of the State of Sao Paulo, we were faced with the difficulty of covering the 330 thousand agricultural properties in the state, and a new strategy urged to be developed. Hence, a new methodology for inspection was adopted - the Innovated CDA Methodology - which was applied in watershed section III, in Marilia, with an area of 27,775 ha (monitored from 2017 to 2018).

This methodology consists of preparing the diagnosis in the office, using the databases of the Rural Environmental Registry (CAR, 2017) and, then, opening and saving the georeferenced "shapefile" with the property limit. Information about the owner and the property was retrieved from the Animal and Plant

Defence Management System (GEDAVE, 2017). The CAR and GEDAVE information are spatialized in Google Earth(r) Pro, (current aerial images), allowing an interface with databases, through which we are able to perform a diagnosis, and an inspection by remote sensing. Within the perimeter of the property, which shapefile was imported into Google Earth(r), the diagnosis begins with a visualization of the erosions, followed by inserting a georeferenced GPS point on this erosion, drawing a polygon of the outline of this erosion, classifying the erosion according to soil conservation legislation (Sao Paulo State, 1988) and preparing an Excel(r) spreadsheet with the following information: number of georeferenced GPS points, erosion type, description of the erosion (Table 2), and erosion surface area (ha). This work is carried out throughout the property's perimeter.

Once the diagnosis by remote sensing is completed, a coloured aerial image is saved (in JPEG format), as well as the spreadsheet in Excel(r), and they are made available to the CDA Staff, who will, then, visit the property and go straight to the erosion site, as it is geo-referenced, without the need to inspect the site to identify an erosion. The presence of the erosion is investigated and, if present, checked against the description in the Excel(r) spreadsheet. If the erosions agree with the data on the spreadsheet, the information is maintained; if they differ, the information on the spreadsheet is corrected. Once all the points on the spreadsheet have been visited, , and the erosions photographed, we have real data on the soil situation of the agricultural property. The data is incorporated in the notification that is handed to the owner and, after this stage, the procedures are identical to the conventional CDA methodology: the property owner hires an Agricultural Engineer, who prepares a technical conservation project to restore the degraded area.

2.4 Vegetation Cover Indicators

To validate the new methodology, some indicators were used to assess the results obtained through the implementation of soil conservation actions. Improvement in the vegetation cover, and changes in soil and water management practices were evaluated by comparing the state of the art (before evaluation/action - T1) with the results obtained (after the implementation of the technical projects - T2), using the historic images tool in Google Earth(r) Pro (years: 2002, 2006, 2012, 2013, 2017 and 2018) to evaluate the post-agro-environmental restoration of the properties (Figure 2).

2.5 Water Quality Indicators (WQI)

The assessment of soil losses and sediment input to the river, due to the action of soil erosion, were evaluated by water quality indicators, which were, then, evaluated by Turbidity through the Standard Methods for the Examination of Water and Wastewater - 2130 B method (SMWW a). Suspended Solids were analysed according to the 2540 D method (SMWW b). The content in Phosphorus was analysed using the United States Environmental Protection Agency (EPA) 6010D method (USEPA), and the content in Organic Carbon through the 5310 C method (SMWW c), measured from periodic analyses of the Rio do Peixe water.

2.5.1 Data Collection

The samples were extracted from the watercourse, at a station located downstream from the areas where the watershed has the highest density of cultivated areas, and they were collected by the Sao Paulo Environmental Company (CETESB, 2020), once a month, in the months of February, October, and December. Sampling followed the 1060 and 9060 methods of the Standard Methods for the Examination of Water and Wastewater (SMWW d), at the collection point with code 00SP21438PEIX02100 / UGRHI 21 (coordinates: S22deg18'13.62" - W50deg2'53.62").

2.5.2 Water Quality Indicators

Water Quality Indicators were selected based on the turbidity, because it expresses the sediment input in the water body due to erosion, and the transport of these particles towards it. The months for sampling were elected for being the ones with a higher probability of erosion, considering the rainfall data, indicating the months of February, October, and December as the ones with the highest rainfall averages. The data collected by Setzer (1985) was used to support the assessment of the the turbidity and suspended solids in the water.

2.5.3 Water Quality Graphics

The data were obtained in two periods, considered as treatments, being:**T1** - data referring to the period BEFORE the working diagnosis and erosion control, considering the information from 2000 to 2007; and**T2** - data referring to the period AFTER the working diagnosis and erosion control, considering the information from 2008 to 2018. The improvement in water quality was assessed by these indicators, which were tabulated and compared through graphics prepared for each indicator, for the T1 and T2 treatments (Figure 3).

3 RESULTS

The work carried out by the Sao Paulo State Secretariat of Agriculture to enforce the legislation, encompassed actions of erosion diagnosis and correction, at agricultural properties located at Rio do Peixe watershed, (sections Vera Cruz, Ocaucu and Marilia), which correspond to 53 thousand hectares. It is an honourable work that looks after the well-being of society and benefits the farmers of the Rio do Peixe watershed, and the entire local community, who have benefited from its development, namely through the improvement of the quality of the water that supplies the cities, mainly Marilia (216,684 inhabitants) and Presidente Prudente (227,072 inhabitants), which collect water from Rio do Peixe for public supply.

3.1 CDA Conventional Diagnostic Methodology

From 2000 through 2007, the water in Rio do Peixe watershed was monitored, through sample collection and performance of analyzes that functioned as a control (T1) of the two treatments used.

From 2007 to 2011, 14,076 ha were diagnosed in Vera Cruz city. From 2011 to 2015, 9,027 ha were inspected in Ocaucu, adding up to 23,103 ha, in these two sections (I and II), that is, 224 ha per month, for 103 months. In Marilia, in 2017, 27,775 ha were diagnosed, which were monitored in 2018, with the implementation of conservation projects in 52 agricultural properties.

3.1.1 Vegetation Cover Indicators

In section I, in Vera Cruz, 94 agricultural properties were notified, out of a total of 176 properties, where Conservation projects were implemented. These included the planning of innovative measures, such as improving the vegetation cover of pastures using Integrated Crop-Livestock Systems in of their restoration. In cropsm, in crops, No-tillage and bioengineering were implemented, in addition to the usual practices, such as agricultural terracing, containment basins and road readjustments (Figure 2). In Ocaucu, section II, 82 agricultural properties were notified.

3.2 Innovated CDA Methodology

In Marilia, section III, using the Innovative CDA Methodology (Vischi Filho et al. 2017 and 2018), 20 large agricultural properties and 32 small properties were inspected, in just nine months, with a total surface of approximately 27.7 thousand hectares. From January to November 2017, 27,775 ha or 3,086 ha were diagnosed and evaluated, per month. This methodology allows a detailed evaluation of an area, which, using the old methodology, would take 103 months to be carried out (8 years and 7 months), instead of the nine months in which the work was actually developed, therefore

Erosions and other soil degradation processes are reported in Table 2. These inspections, which were already carried out, have received the conservation technical projects for the areas and these have been implemented.

3.2.1 Vegetation Cover Indicators

The improvement in vegetation cover, resulting from the changes in the soil and water conservation management practices, were confirmed by the comparison of aerial images from before the work was carried out (2002) and after the work was carried out –(2013, 2017, 2018 and 2019) (Figure 2), that is, after the conservationist projects have been implemented. At this point, the areas were already recovered, the erosions were under control, and the i conservationist practices that transform soil management had started to be applied, in the direction of Conservation Agriculture practices.

3.3 Land Use and Occupation

The conservationist practices adopted were: improvement of vegetation cover, through direct planting in the straw or management of pastures by correcting and fertilizing the soil; crop rotation: Integrated Crop-Livestock System; and bioengineering. Mechanical practices were also implemented for the control of gully erosion, such as agricultural terracing, containment basins and divergent channels for the conduction of run-off to the drainage channels and bottom drain, as well as disciplinary measures, such as capture, relocation and dispersion of rainwater contributions from dirt roads (Figure 2). After the farmers were notified, we have observed that they were more aware, and made an effort to implement conservation practices on the properties, as a preventive measure. Inspecting the use and conservation of the soil is important, not only for the preservation of the soil and water but also for increased profit earned by the rural producer (Table 3). In most agricultural properties where pastures were restored, farmers occupied additional 31% of their lands, therefore generating higher income from their activities.

The "in loco" survey for land use and occupation (Table 2) demonstrates that the following crops predominate at the watershed: pastures, with 30,472 ha; coffee, with a surface of 2,798 ha; fruit (mango, coconut, and citrus), with 136 ha; eucalyptus, with 95 ha; vegetables, with 60 ha: passion fruit, with 15 ha; annual crops (corn and beans), with 181 ha; sugar cane, with 37 ha; and preserved forest, with 10,606 ha, covering the slopes of the geological formation known as "Itambe".

3.4 Water Quality Indicators (WQI)

Analysis of the Water Quality Indicators (Turbidity, Suspended Solids, Phosphorus and Organic Carbon) confirmed the improvement in the water quality, as an effect of the control/minimization of erosive processes and sediments carried to the watercourse (Figure 3).

3.4.1 Turbidity

The Turbidity of the water, monitored from 2000 to 2007, before the work was carried out (BEFORE - T1), presented average values of 192 NUT (Nephelometric Units of Turbidity), against the average values of 102 NUT, for the period from 2008 to 2018, after the completion of the work (AFTER - T2), representing a 53% drop in the average values. For the T1 treatment, the average values of February and December were higher than the Conama standard of 100 NUT (Conama, 1986) (Figure 3A). In the T2 treatment, the average values were 102 NUT, except for February 2009, 2014, 2017 and 2018; October 2009, 2012 and 2018; December 2009 and 2015 (Figure 3B).

3.4.2 Suspended Solids

The suspended solids monitored from 2000 to 2007 (T1) presented average values of 297 mg l-1 (milligrams per litre), against the average values of 132 mg l-1, evaluated from 2008 to 2018 (T2), representing a 44% drop in the average values.

3.4.3 Total Phosphorus

The content in phosphorus evaluated from 2000 to 2007 (T1) presented average values of 0.18 mg l-1 (milligrams per litre), against the average values of 0.14 mg l-1, evaluated from 2008 to 2018 (T2), representing a 78% drop in the average values.

3.4.4 Organic Carbon

The content in Organic Carbon measured from 2000 to 2007 (T1) presented average values of 9.60 mg l-1 (milligrams per litre), against the average values of 5.19 mg l-1, evaluated from 2008 to 2018 (T2), with a 59% drop in average values.

4 DISCUSSION

4.1 Land Use and Occupation

The predominant crops in the inspected sections of the watershed were Pasture, Natural Forest and Coffee. The natural forest, considered the best vegetation cover, is present in an area corresponding to 21.16% of the surface of this stretch of Rio do Peixe watershed., In a watershed of 11,000 ha in Botucatu, with relief similar to Rio do Peixe watershed, Santos et al. (2014) found 1,109 ha of natural forest, corresponding to 9.95% of the watershed area. These results correspond to less than half of the results of the present work, indicating that, in this stretch of Rio do Peixe watershed, the forest is much more preserved.

In what concerns the pasturs of the studied area, there is an occupation of 30,472 ha, amounting to 60.81% of the total area of the watershed (Table 1). Such results are similar to those of Lima et al. (2004), who inspected 43,228 ha of pasture in a watershed in Ilha Solteira, SP, where it amounted to 66.79% of the total surface. In this work, one of the positive examples was the restoration of an agricultural property in Ocaucu, SP, with a degraded pasture area of 500 ha. After carrying out this work, these 500 ha were transformed into an agricultural area with no-tillage system, intended for annual crops, with rotation: brachiaria straw, soybeans, corn and wheat in winter (crop change and soil management). This represents the implementation of a new conservationist technology in the region.

4.2. Vegetation Cover Indicators

The images from Google Earth(r) Pro confirmed the effectiveness of the actions implemented in the pasture area where an erosive process had taken place (Figure 2A and 2B). An plan of agri-environmental adequacy was applied, to contain the erosive processes and control the erosion in the area, which was accomplished with the construction of containment basins on the pasture areas. There was an improvement in the visual aspect of the area, compared to soil conservation strategies, in which case it was proven that pasture management with the use of containment basins favored the restoration of the area, and the return of potential soil productivity.

Figures 2C, 2D, 2L and 2M effectively demonstrate that the change in management of coffee plantations provided a positive change in the landscape. In addition to improving the landscape with more intense vegetation cover (Figures 2D and 2M), there was an improvement in potential crop productivity. In the coffee culture, what contributed to the improvement of the soil conditions was the adequacy of the crop to the relief, and recovery of soil fertility. The soil conservation techniques applied in this case were sufficient to control the erosive processes.

Image comparison of Figures 2E and 2G showed that the agricultural terracing built in the area under scrutiny was efficient in controlling erosion processes at the property. According to Araujo et al. (2009), with the use of appropriate management measures and erosion mitigating actions, along with the restoration of the impacted areas, there will be an improvement in water quality and control of sediment production, minimizing silting and consequently, there will be an almost complete environmental restoration.

The comparison of aerial images, from before (T1) and after (T2) the treatment, was used to assess the efficiency of the results obtained. The same method was used by Bezerra et al. (2012), who used it to compare the vegetation cover and the water potential in the soil, with the purpose of monitoring and restoring degraded areas. The photographic comparison, in addition to a supervised classification, allowed to monitor the development of the vegetation cover with grasses, as well as their relation to the soil's water potential. According to Menezes et al. (2009), the use of remote sensing permitted the identification of areas already affected by inadequate management, with degraded pastures. These authors also highlighted the fact that native vegetation has been largely converted into pasture. Figures 2K and 2O illustrate the mechanical control of erosions, as the construction of dams and terraces transforms the previously degraded landscape into a pasture with productive capacity (Figures 2J and 2N). Figure 2J shows an old and eroded road that carried sediments to the bed of Rio do Peixe, and which was corrected with the construction of terraces (Figure 2K).

It is noteworthy that there are practices focused on the conservation of pastures, which represent a large part of the Rio do Peixe watershed section in addition to promoting important benefits for soil conservation. This can further enhance the income for producers since, with conserved pasture, there is a higher volume of biomass and, consequently, a chance for higher animal density. An example of this is the case of pastures recovered by Integrated Crop-Livestock Systems (LIS) where the management was modified through the replacement of the varieties of grass, and by providing pasture with quality plant mass during the dry periods. This resulted in an occupancy rate of five Animal Units (AUs) per ha, as evidenced by the evaluation of 10 properties, where there was an average growth of 31% in the occupancy rate, compared to the original situation, i.e. before carrying out the inspection work. This is corroborated by the study of Albernaz & Lima (2007) who evaluated two sub-watersheds occupied by pastures in Lavras, MG, adopting conservationist practices: level planting, terracing, containment basins and liming maintenance. They have also suggested that at Ribeirao Santa Cruz sub-watershed (SW), more conservation practices are adopted than at SW Agua Limpa, and the exposure of the soil to degradation was higher at SW Agua Limpa. A similar result was observed by Zolin et al. (2011), who documented that the largest relative reductions in soil loss occurred under scenarios of conserved pasture, indicating that the optimization of soil conservation can be accomplished by adopting conservationist management practices for pasture recovery. According to Rodrigues et al. (2015), who analysed the role of vegetation in water interception and erosion control, at Rio Paraiso watershed, in Sao Manuel, SP, and the uncovered soil showed a 98.09% increase in sediment production, when compared to soils with vegetation cover.

4.3 Water Quality Indicators (WQI)

4.3.1 Turbidity

The analysis of the turbidity, suspended solids, phosphorus and dissolved organic carbon (Figures: 3 - A, B, C, and D)has demonstrated with confidence that the data from treatment T2 are more uniform or stable, than in T1, for these indicators. Figures 3A and 3B, which refer to water turbidity, express that, in the years that preceded the implementation of the work (T1) and the years that followed it (T2), on average, water turbidity was lower in the months of February and December, in T2.This difference observed in T2 can be explained by the decrease in the supply of sediments in the watercourse. This may be due to the effects of the change in soil management, with the adoption of conservationist practices and erosion control, through the implementation of technical projects at the 228 properties that were restored with conservationist agriculture, through the developed work (Figures 2B, 2D, 2E, 2G, 2I, 2K, 2M and 2O).

A similar result was found by Souza & Gastaldini (2014), who observed that land use significantly influenced the water quality parameters. In areas considered to have a higher percentage of agriculture and with problems related to erosion the parameters of turbidity and suspended solids were higher before the implementation of the works. This land use, without adopting conservationist practices, can be considered as the one with the largest potential for erosion.

4.3.2 Suspended Solids

The highest values for suspended solids were recorded in the T1 treatment (Figure 3C), when compared to T2 (Figure 3D). In February, all values were larger than 100 mg l-1 (milligrams per litre), with an average of 252 mg l-1 for that month. The same happened with the values of October, 222 mg l-1, and in December, with an average of 416 mg l-1. In T2, the values were more uniform, with averages of 126, 163 and 107 mg l-1, with only a peak of 696 mg l-1 observed in October 2012 (Figure 3D), though still below the peaks recorded for T1 with a peak of 884 mg l-1 observed in in October 2006, and another of 1850 mg l-1 in December 2003 (Figure 3C).

The results of suspended solids for the rainy season were lower than those described by Setzer (1985), who evaluated soil losses and their relation to turbidity, as well as water parameters in several watersheds in the state of Sao Paulo. Setzer's results expressed average annual rates for suspended solids in the rivers of Sao Paulo as slightly lower than 150 mg l-1, rising to almost 300 mg l-1 in the rainiest months, and lowering to less than 50 mg l-1 in the driest months.

The results of the work show that there was a significant decrease in suspended solids after the adoption of conservationist practices and the restoration of agricultural properties. Rodrigues et al. (2015) documented that the runoff coefficient was low in the presence of vegetation, resulting in larger infiltration and better flow regularity; also, they observed that erosion and carried sediments increased on unprotected soils, changing the dynamics of water on the soil.

4.3.3 Total Phosphorus

The total phosphorus dissolved in water in T1 (Figure 3E), was higher than those recommended by CONAMA Resolution 20/86, which is 0.025 mg l-1), compared to T2 (Figure 3F). The values of phosphorus recorded in T2 were 0.10, 0.16 and 0.16 mg l-1, in the months of February, October, and December, respectively, were below the values of 0.21, 0.13 and 0, 21 mg l-1, except for October. The values observed in T1 were higher than those recorded in T2, except for the peaks recorded in December 2010 and October 2009, and 2012, which reached more than 0.30 mg l-1, even below the peaks that occurred in T1 in 2001, 2002, 2003 and 2005, which reached 0.50 mg l-1, in December 2005 (Figure 3E).

These values are lower than the ones obtained by Donadio et al. (2005), who evaluated the water quality in a watershed in Taquaritinga, SP, where the predominant soil is the Ultisol, and the average values of phosphorus in the water, in the driest period of the year, was 1.58 mg l-1 and, for the rainy season, was 4.32 mg l-1.

Pinheiro et al. (2014) assessed soil use and occupation, and its relation to water quality, in two sub-areas of Rio Duas Mamas watershed in Santa Catarina, documenting phosphorus content of 27.3 and 41.6 mg l-1 , which are higher than the results found in the present study. This may be explained by the fact that, in SW2, there were banana plantations and annual crops, despite the large percentage of remaining natural forest, in both cases.

4.3.4 Organic Carbon

Values of organic carbon dissolved in water (C), were higher in T1, with averages of 9.76, 10.50 and 8.55 mg 1^{-1}, in the months of February, October and December, respectively, reaching values of C above 19 mg 1^{-1} in 2000. In treatment T2, the average carbon values retrieved were 6.25, 5.88 and 4.90 mg 1^{-1}, for the same months, ranging between 4.9 and 6,2 mg 1^{-1} (Figure 3H); while in T1, the phosphorus content ranged between 8.5 and 10.5 mg 1^{-1} (Figure 3G).

This confidently demonstrates that the amount of C in the water, after the implementation of the project, was lower than before. Hence in this case, the conservationist practices implemented have contributed to a smaller amount of eroded sediments, which corroborates the results of Silva et al. (2005) since, in their study, the organic C was the main component of the largest part of the eroded sediments, emphasizing the need for conservationist practices that reduce the erosive action of rain, maintaining this organic fraction in the soil.

5 CONCLUSIONS

The monitoring of Rio do Peixe watershed, carried out from 2007 to 2019, which included inspections, diagnostics, and restoration of agricultural properties, is transforming them into conservationists, preserving the soil and water, and taking care of the well-being of the local communities.

Implementation of the Integrated Crop-Livestock Systems, with a change in soil and pasture management, increased the occupation rate of areas with pastures, by 31%, compared to the original situation.

The Innovated CDA Methodology presents a positive yield of 1377% in comparison to the conventional CDA Methodology, saving capital and the human resources of Agricultural Defense.

In these twelve years of work at Rio do Peixe watershed, new technologies have been developed for the site, such as Bioengineering, No-Tillage, and Integrated Crop-Livestock Systems, a fact that has changed the habit of how to treat natural resources of large farmers in the region.

The agro-environmental monitoring and restoration methodology is feasible and can contribute to the management and monitoring of the watersheds, in addition to transforming conventional, degrading, agriculture, into conservation agriculture.

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Figure 1. Study site at Rio do Peixe watershed. Brazil, Sao Paulo State. Rio do Peixe watershed and watershed Sections

Figure 2. Images of the work area before the project implementation (A, C, F, H, J, L, N - images of 12/05/2002 Google Earth(r)), and after the implementation of soil conservation practices (B (year 2013), D (2013), E (2019), G (2017), I (2018), M (2017) e O (2019), images of Google Earth(r)). A, erosion in a very deep furrow (gully); B, erosion controlled with the construction of containment basins; C, incorrect management of coffee crop; D, with a change of management tool, transformation of the landscape; E, erosion controlled with construction of terraces; F, erosion in very deep furrow (gully); G, transformation of the landscape, with gully control; H, erosion and silted river; I, landscape transformation, by crop management change that decreases the river silting (detail); J, path with erosion, very deep furrow (gully); K, erosion control with construction of terraces; L, incorrect management of coffee crop, with several erosion (detail); M, control of gullies with the change of coffee management (detail). N, Large erosion gully. O, gully controlled with the construction of terraces (Adapted from Vischi Filho et al., 2016).

Figure 3. Turbidity (A, B, Conama 100 NUT standard), suspended solids (C, D), phosphorus (E, F, Cetesb standard 0.025 mg l-1) and organic carbon (G, H) in water collected in Rio do Peixe, considering the years 2000-2007 (before), and following the implementation of the project from 2008-2018 (after) (Adapted from Vischi Filho et al., 2016).

Table 1. Erosions and other soil degradation found at Rio do Peixe watershed during diagnosis

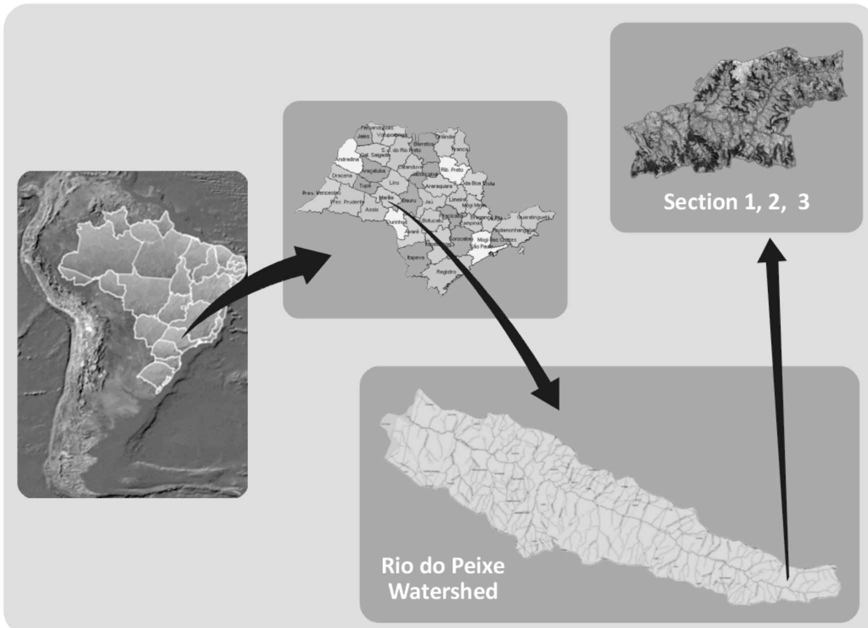
Municipality	**Vera Cruz**	**Ocauçu**	**Marília**
Erosion Type	**Area (ha)**	**Area (ha)**	**Area (ha)**
Laminar Erosion	1270	2035	880
Ravine	259	76	57
Gully	263	106	245
Physical, Chemical and Biological Soil Degradation	1	5	13
Drainage meadow construction	70	73	85
Total Area (ha)	**1862**	**2294**	**1282**

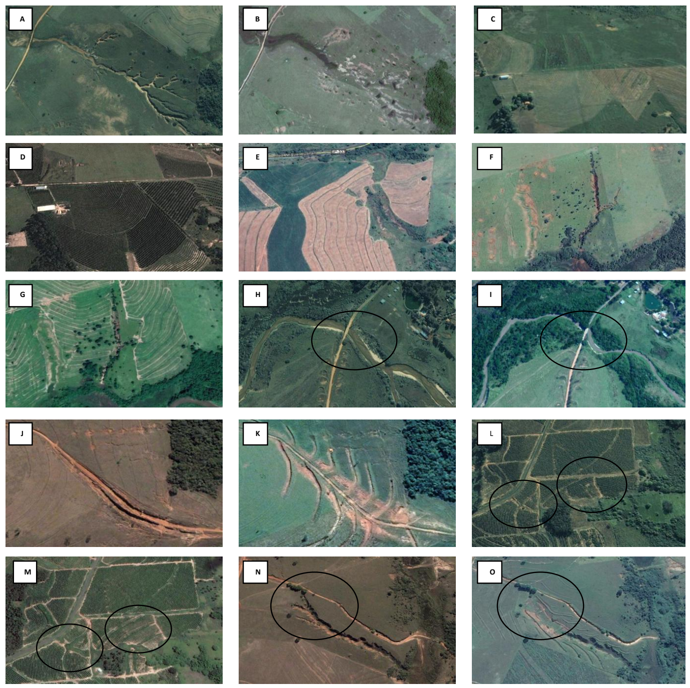
Table 2. Land Use and Occupation in Rio do Peixe watershed

Municipality	**Vera Cruz**	**Ocauçu**	**Marília**
Crops Grown	**Area (ha)**	**Area (ha)**	**Area (ha)**
Coffee	2232	521	45
Pasture	9799	5726	14947
Vegetables +	14	36	10
Annual crops ++	12	69	100
Passion fruit	13	11	1
Eucalyptus	41	33	21
Sugar cane	8	26	3
Fruit trees	106	25	5
Manioc	20	312	939
Natural Forest	1214	1745	7647
APP §	449	408	3836
Others ¶	168	115	221
Watershed Area	**14076**	**9027**	**27775**

+ Vegetables: pumpkin, lettuce, cabbage, parsley, chive. ++ Annual crops: corn, soybean, wheat. § Permanent Preservation Area. ¶ Others: roads, rivers, farms improvements, warehouse.

Table 3. Cattle herd evolution in Rio do Peixe watershed. 2009/2010 prior to the work completion. 2016/2017 after pastures recovery





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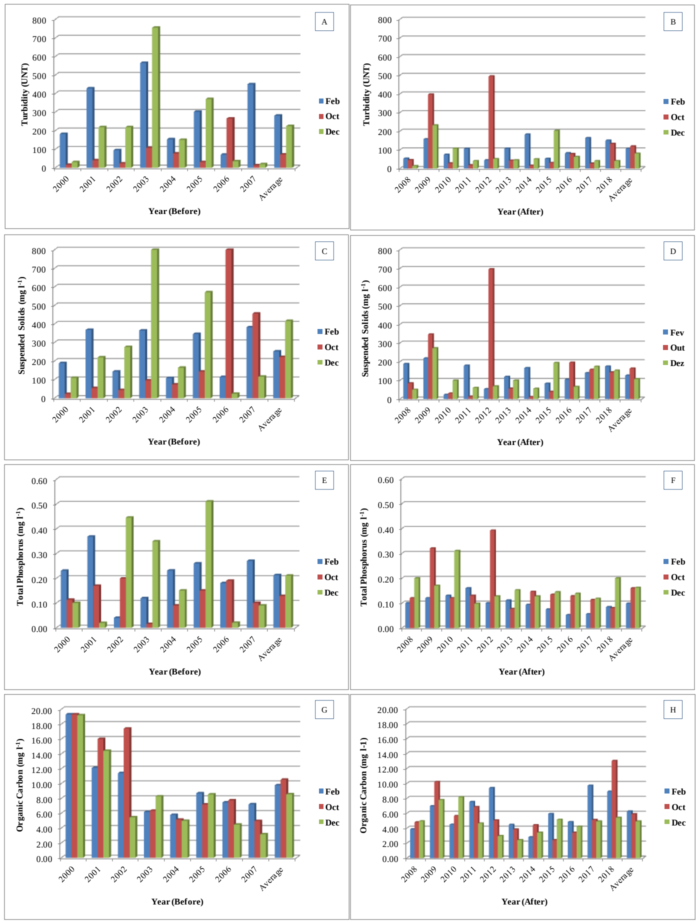

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