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Soil governance as a requirement for agricultural land conservation: a historical overview[1]

Governança do solo como requisito para conservação das terras agrícolas: uma visão histórica

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ABSTRACT - This study is a historical overview of land governance initiatives implemented in Parana state, Brazil, since the 1970s, ranging from the work carried out by research institutes to government-sponsored programs. These initiatives encouraged the development of technologies and farmers' widespread adoption of conservation practices. Furthermore, they highlight the factors that brought soil and water conservation to the forefront in discussions on agriculture. This bibliographic review was based on information in research papers and programs developed in Parana. We show that extensive work on management planning and natural resource conservation was undertaken in Parana to strengthen soil governance. The initiatives implemented in watersheds and the development of the no-tillage system represent considerable achievements. However, it was not always that straightforward. As time progressed, the false perception – mainly among farmers – that the erosion problem had been solved led many farmers to neglect soil conservation practices, and in some cases, to abandon agricultural terracing, contour farming, and crop rotation. This resulted in a resurgence of problems related to environmental degradation, aggravating erosion and causing losses of soil and water, with the concomitant environmental damage. In this regard, we describe the means deployed in a new strategy to stimulate a resurgence of effective soil governance based on public policies and public-private partnerships to promote soil and water conservation.

Key words: Agricultural research. Public policy. Soil and water management and conservation. No-tillage system. Public-private partnerships.

RESUMO - O objetivo do estudo é oferecer um resgate histórico do conjunto de ações em governança do solo implementados no estado do Paraná, desde a década de 1970, que vão dos trabalhos desenvolvidos pelos institutos de pesquisa, aos programas governamentais. São ações que possibilitaram o desenvolvimento de tecnologias e a ampla adoção de práticas conservacionistas pelos produtores. Além de indicar os fatores que deram base para a retomada das discussões, em período recente, sobre conservação do solo e da água. Como fontes de informações foram utilizados relatórios de pesquisa e dos programas desenvolvidos no Paraná, empregando o método de revisão histórico-bibliográfica. Verificou-se que foi executado um amplo trabalho de planificação de uso, manejo e conservação dos recursos naturais no Paraná, denotando a construção de uma governança forte em solo e água. Destacam-se no Paraná as ações realizadas em microbacias hidrográficas, pelo pioneirismo do seu enfoque, duração e dimensões, e o desenvolvimento do Sistema Plantio Direto. Contudo, nem tudo foi sempre linear nessa evolução, uma vez que com o passar do tempo foi se constituindo a falsa percepção – principalmente entre os produtores – de que o problema da erosão já estava solucionado. Em consequência disso, muitos agricultores passaram a negligenciar práticas de conservação do solo com uso de terraços, o abandono das operações agrícolas em nível, bem como a rotação de culturas. Tais condutas reavivaram problemas conhecidos e graves de degradação, acentuando os processos de perdas de solo e água pela erosão, e seus prejuízos associados. Neste contexto, descreve-se os instrumentos que estão sendo utilizados em uma nova estratégia paranaense para a retomada de uma efetiva governança do solo, por meio de políticas públicas e de parcerias público-privadas na promoção da conservação de solos e água.

Palavras-chave: Pesquisa agrícola. Políticas públicas. Gestão e conservação do solo e da água. Sistema plantio direto. Parcerias público-privadas.

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INTRODUCTION

Brazil is one of the most important global producers and exporters of food, fibers, and biofuels. The driving force behind the growth of Brazilian output was the intensification of its agriculture through technological innovation. In Brazil, the state of Parana has been outstanding in terms of both agricultural productivity and natural resource conservation. However, in the early 1970s Parana faced a terrible challenge, with large tracts of fertile land threatened by soil erosion as a result of inappropriate agricultural practices. Since the soil is an essential resource for agricultural production, this problem, if allowed to continue, could compromise both agriculture and the local economy in Parana. In the following decades, good soil management drastically reversed the erosion process by raising awareness of the importance of conservation and the sustainable use of natural resources.

Soil governance involves policies, strategies, and decision-making processes at national, state, and local government levels, related to how the land is used (JUERGES; HANSJÜRGENS, 2018; MONTANARELLA; VARGAS, 2012). Soil governance requires national and international collaboration between governments, local authorities, companies, and citizens to ensure the implementation of coherent policies that promote practices and methods for regulating the use of soil resources to prevent degradation and conflicts between users. Although there is no national policy specifically designed for integrated soil and water management, several aspects related to soil governance are backed by Brazilian environmental legislation, such as the 1981 National Environmental Policy, 1997 National Water Resources Policy, and 2012 Native Vegetation Protection Law (known as the new Brazilian Forest Code).

The soil governance measures put in place to reverse the degradation of agricultural land under threat in Parana included public policies, government programs, and scientific research. The Agricultural Research Institute of Parana (IAPAR), founded in 1972, was responsible for conducting regional studies to increase our knowledge of erosive processes and develop control technologies, providing information and technology data for dissemination to Parana state farmers. The transfer of these technologies began in 1977, under the auspices of the rural extension service, which played an outstanding role in spreading the word.

Initially, agricultural terraces were the main strategy for controlling soil erosion. Subsequently, practices such as crop rotation, minimum tillage (MT), and no-tillage (NT) were incorporated (FUENTES-LLANILLO *et al*., 2021). Combining NT, crop rotation and permanent soil cover led to the no-tillage system (NTS). However, it was soon confirmed the NTS alone could not control erosion, and many farmers began to remove agricultural terraces (GARCIA; RIGHES, 2008; SILVA; DE MARIA, 2011). The result was a significant increase in water erosion problems, even in areas where NTS was already established.

This study details how researchers and rural extension initiatives were implemented in Parana, as well as the action needed to ensure that advances in conservation practices are ongoing. The study aimed to provide historical overview of state-of-the-art soil governance initiatives in Parana and their role in developing new technologies and conservation measures to minimize erosion.

AGRICULTURAL USE, DEGRADATION, AND SOIL CONSERVATION IN PARANA STATE

The occupation of the state of Parana was characterized by various economic cycles, always closely related to the agricultural sector, both before and after its political emancipation in 1853. The economic cycles revolved around gold, muleteering (regionally known as tropeirismo, which involves mule trading and the transport of products using troops of pack animals), yerba mate tea, timber, and coffee. From the 1920s to the 1950s, timber and yerba mate exports were strong and cattle were raised extensively on natural pastures. In the 1960s, coffee plantations were the main source of foreign currency. Parana ranked number one as the largest coffee producer state, with a global market share of 28% in the 1961-1962 growing season (KATZMAN, 1978; NICHOLLS, 1970).

During the first three centuries of its foundation, Parana was settled from the coast to the Second Plateau (Campos Gerais), with no significant change in the landscape and a predominance of grazing and subsistence agriculture. From the beginning of the agrarian colonization of the state, around 1820, the native forest that originally covered Parana was gradually eliminated. According to Maack (1953), before the 1920s land use was limited to the production of timber and yerba mate tea, a plant native to the biome, from which leaves and stalks are harvested to produce beverages.

At the beginning of the 20th century, the native vegetation of Parana, which consisted mainly of different types of forest, began to shrink due to logging and the expansion of coffee plantations. In the 1920s, native vegetation covered 85% of Parana (MAACK, 2012). In less than half a century this vegetation almost disappeared, with only 5% of native cover remaining in 1980. In 1990, due to the continuous expansion of land settlement, native vegetation occupied only 2.6%, consisting of national parks and other protection and conservation areas (CIGOLINI; MELLO; LOPES, 1998).

Yerba mate tea was one of Parana's main agricultural products until the first decade of the 20th century when drop in exports led to logging in areas traditionally allocated to yerba mate. In economic terms, timber ranked second on the list of Parana's agricultural products between 1916 and 1925. During this period, coffee growing intensified in the northern region of the state, although there was a slowdown in this trend following the crisis of 1929 and the consequent drop in coffee prices on the international market (MAGALHÃES FILHO, 1972).

Coffee returned to prominence in Parana from 1940 onward, mainly due to the expansion of agricultural areas in the north and west of the state (NICHOLLS, 1970). Coffee had its heyday in the 1960s when Parana was the largest producer state in Brazil (CARVALHO, 1999; KATZMAN, 1978). According to Maack (1969), the expansion of coffee growing in northern and western Parana was the main cause of the rapid disappearance of tropical and subtropical forests in the state between the 1930s and 1960s.

Although coffee growing constitutes a permanent form of land use, Kronen (1990) reported that it was during the period of traditional coffee growing that the first records of erosion and degradation problems in Parana's agriculture began to appear. As coffee is a perennial permanent crop in terms of land use, the processes of soil degradation and erosion during this period occurred gradually. Severe frosts in the coffee-growing regions of Parana in 1969, 1972, and mainly 1975 almost totally decimated coffee plantations in the state, with production dropping to almost zero. This led to an acceleration in the replacement of coffee growing under the traditional model (monoculture or plantation), a trend that began in the 1960s. As a result of government programs to rationalize agriculture, traditional coffee production was replaced by annual crops, mainly soybean–wheat in intercropped systems, based on the technological development that ensued after the Green Revolution.

Fostered by subsidized government credit, the green revolution entailed modernizing traditional agriculture by applying a set of product and process technologies, including the intensive use of chemical inputs (fertilizers and pesticides), improved plant varieties, and mechanization. Thus, as the land was turned over to other crops in the north of the state and new areas established in the west, which at that time was an internal agricultural frontier consisting of native vegetation, agriculture in Parana quickly incorporated the Green Revolution model in grain production and led farmers in the region to predominantly adopt intensive soil tillage.

During this period, two main factors aggravated erosion in agricultural lands in Parana: 1) coffee growing, which occupied a large area of agricultural land at the time; and 2) annual cropping which expanded significantly. Although a perennial crop, traditionally grown by following the contours of the land and using terraces (contour farming), coffee plantations were subject to severe erosion in highly susceptible areas, such as the sandy soils (in the Arenito Caiuá region and predominant in the northwest of the state). The area under annual cropping expanded significantly and consisted mainly of soybean–wheat succession double under conventional tillage (CT). CT involves a sequence of soil tillage operations, using plowing and harrowing to prepare the seedbed and control weeds. In Parana, it usually entailed using a heavy harrow or disc plow as primary preparation, followed by two or more lighter harrows (MERTEN *et al*., 2015), resulting in excessive soil disturbance and poor vegetation cover, making the land highly susceptible to erosion, regardless of the type of soil. Thus, originating at the end of the 1960s, these soil conservation problems in Parana caused considerable concern for the federal and state governments and some farming sectors and rural producers (CHAGAS; ICHIKAWA, 2009).

However, from the 1970s onward, the management of soil and water resources under conventional tillage, especially under soybean–wheat intercropping, proved disastrous. This model encouraged farmers to simply transfer technologies developed for temperate climates directly to the tropics, with no modification. According to Brum (1988), this involved intensive soil preparation. According to Derpsch *et al*. (1991), the soil was tilled and consequently exposed to the elements twice a year. After tillage, the soil was exposed to rainfall, and since tilling entailed plowing and harrowing, this system accelerated the process of erosive soil degradation in Parana. In addition, the technology available at the time for disease control encouraged farmers to burn wheat crop residues after harvesting, reducing the amount of mulch and protecting the soil against erosion. These predominant agricultural practices (burning wheat residues, lack of crop rotation, and intensive soil preparation) boosted and accelerated erosion, posing a threat to the potential productivity of Parana's soils (SORRENSON; MONTOYA, 1989).

SOIL MANAGEMENT AND CONSERVATION INITIATIVES INTRODUCED BY THE PARANA AGRICULTURAL RESEARCH INSTITUTE (IAPAR) FROM 1972 TO 1999

Aiming to find solutions to the problem of soil erosion in Brazil, technical and scientific cooperation between the Brazilian and German governments began at the end of the 1960s (CASÃO JUNIOR; ARAÚJO; FUENTES-LLANILLO, 2012). An agreement was drafted between the then Southern Agricultural Research and Experimentation Institute (IPEAME), headquartered in the municipality of Colombo-PR and with ties to the Brazilian Ministry of Agriculture (MA), and the German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit – GTZ), with support from by Imperial Chemical Industries (ICI). Its main aim was to develop research initiatives for soil conservation, implemented at IPEAME experimental stations located in Ponta Grossa and Londrina. The main region involved in this partnership was Parana.

Initiatives were developed to modify the soil management methods in use and degrading agricultural land. Amado and Eltz (2003) reported that, during the 1970s, each metric ton of grain resulted in a loss of 10 metric tons of soil per hectare (ha). In Parana, nutrient losses due to erosion amounted to 121 million dollars a year (TELLES; GUIMARÃES; DECHEN, 2011).

At the same time, some farmers in Parana who were also concerned about the adverse effects of erosion began to look to conservation technologies being developed and trialed in Europe and the United States. Herbert Bartz was one of the leading producers in the municipality of Rolandia in northern Parana.

In 1972, the Parana Agricultural Research Institute (IAPAR) was set up as a public foundation with ties to the State Office of Agriculture and Supply (State Government). In 1973, the Brazilian Agricultural Research Corporation (Embrapa) with ties to the Ministry of Agriculture (Federal Government) was set up to replace IPEAME. These two initiatives were to be expanded and systematically structured in Parana.

In 1975, IAPAR implemented its Soil Management and Conservation Research Program, intending to study and improve management systems adapted to the different soils in Parana to control erosion. The first technical commissions included representatives from producer associations, professionals, cooperatives, and banks. Erosion could be reduced using level terracing instead of sowing down the slope of the land (CASÃO JUNIOR; ARAÚJO; FUENTES-LLANILLO, 2012). A team of 25 researchers drew up integrated recommendations for soil management and conservation, with improvements to no-tillage, providing technical support for the implementation of government programs to encourage conservation agriculture in Parana.

IAPAR's erosion research program was thorough. Experimental plots were set up in different physiographic regions in Parana (Figure 1). The soil types were selected to represent most of the pedological diversity of Parana and the management systems deployed. One of the first science and technology projects implemented by the IAPAR Soil Management and Conservation Program was developed in partnership with GTZ. This project was titled "Minimization of the erosive process by identifying causes and acceptable levels of soil loss under various management systems". The project was implemented from 1975 to 1992 and focused on identifying systems of land use and soil management that would reduce the losses of soil, water, and nutrients by erosion. Another project ("Control of soil erosion in the state of Parana") implemented from 1977 to 1985, aimed to recover and conserve the productive potential of Parana's soils degraded by the expansion of agriculture (DERPSCH *et al*., 1991).

The collaborative network led to the achievement of important advances in the research work, with the instigation of what came to be known as the no-tillage system (NTS). This system was disseminated in an attempt to control erosion and encourage water conservation in Parana. NTS is based on three principles: 1) direct planting, i.e. disturbing the soil only in the furrow or drill hole; 2) crop rotation; and 3) maintaining permanent ground cover (FUENTES-LLANILLO *et al*., 2021). It was recommended that NTS be combined with other conservation practices, such as contour planting and agricultural terracing.

It was also necessary to gather and disseminate information on the quantification of water erosion in Parana as a basis for the initiatives promoted by the National Soil Conservation Program (PNCS) and the Integrated Soil Conservation Program (PROICS). To achieve this objective, IAPAR implemented a set of trials aimed at quantifying soil and water losses for different soil types, climatic conditions, and soil use and management. These trials consisted of plots under natural or simulated rainfall conditions, set up from 1976 to 1999 in various municipalities (Table 1 and Figure 1).

Conservation techniques initially focused on controlling runoff by mechanical means, such as contour planting and agricultural terracing. Later, when erosion processes were better understood, erosion control strategies evolved to combine other cropping practices, such as crop rotation and the use of green manure, and soil preparation, such as minimum tillage (MT), to increase water infiltration and thereby reduce the volume of surface runoff.

As erosion control practices were improved, no-tillage emerged as an alternative. This cropping system dispenses with the plowing and harrowing used under the CT, using implements for sowing directly in practically undisturbed soil. This method became widespread as dedicated equipment and methods were continually improved, and farmers in Parana noticed that it was very efficient in reducing water erosion, simplifying operations, and cutting production costs (TELLES; DECHEN; GUIMARAES, 2013).

The outcome of the research showed that NT alone could not control erosion losses. It was only with the consolidation of the no-tillage system (NTS) that erosion losses (0.4 Mg ha^{-1} yr^{-1}) were cut by 99% compared to conventional tillage (up to 30 Mg ha^{-1} yr^{-1}) (MERTEN *et al*., 2015). In Parana, soil erosion losses represented a cost of up to US$ 242 million per year (SORRENSON; MONTOYA, 1989; TELLES; GUIMARÃES; DECHEN, 2011). The positive outcome of using NTS made it popular among producers (FUENTES-LLANILLO *et al*., 2021). However, although NTS was extremely effective for controlling soil losses, compared to CT it was not equally effective for controlling water losses.

Figure 1 - Municipalities in the state of Parana with experimental erosion plots set up by IAPAR from 1976 to 1999

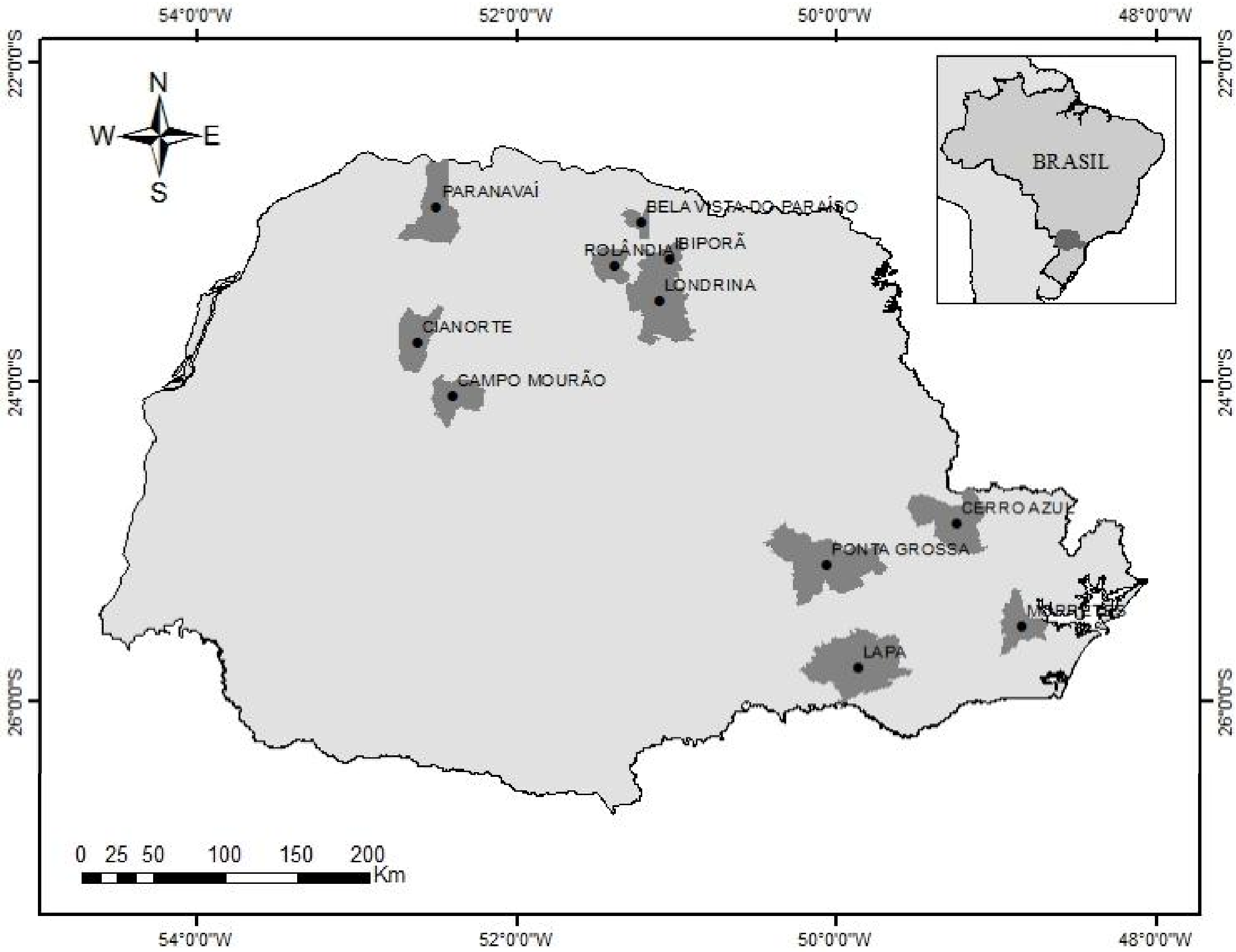

Table 1 - Location and characteristics of trial erosion plots set up by IAPAR for research on soil management and conservation from 1976 to 1999

Municipality	Period	Rainfall	Plot size	Slope	Soil	Soil preparation
			(m^2)	(%)		
Bela Vista do Paraíso	1976 - 1990	N	38.5 and 77	4	PVA	CT, MT and NT
Campo Mourão	1985 - 1991	N	38.5 and 77	4	LV	CT and NT
Cerro Azul	1985 - 1994	N	38.5	34	PA	CT and NTS
Cianorte	1985 - 1994	N	38.5	24	LV	CT and NT
Ibiporã	1987 - 1991	N	38.5	12	NV	CT
Lapa	1985 - 1994	N	38.5 and 77	24	CX	CT
Londrina	1976 - 1999	N and S	38.5 and 77	6	LV	CT and NT
Morretes	1985 - 1994	N	77	36	PVA	CT
Paranavaí	1981 - 1991	N	38.5 and 77	4	LV	CT
Ponta Grossa	1977 - 1998	N	38.5; 77; 5,000 e 10,000	6.9; 7.1 e 8.1	LV	CT, MT, and NT
Rolândia	1977 - 1981	N	38.5	8	NV	CT and NT

Notes: N – Natural rainfall (rainfed farming). S – Simulated rainfall. PVA – Argissolo Vermelho-Amarelo. LV – Latossolo Vermelho. PA – Argissolo Amarelo. NV – Nitossolo Vermelho. CX – Cambissolo Háplico. CT – Conventional tillage. MT – Minimum tillage. NT – No-tillage

The success of NTS in controlling erosion led many farmers to remove agricultural terracing from their land, in part based on the farmers' belief that maintaining soil cover, an integral part of NTS, would be sufficient to adequately control erosion. Additionally, from the farmer's point of view, terraces are problematic for planting, spraying, and harvesting using the increasingly heavy machinery currently available on the market, and this is a trend in the agricultural machinery industry. As a result, water erosion problems returned, even in areas where the NTS was already consolidated.

Other factors also converged to aggravate the problems of the soil erosion process. These included failure to implement crop rotation, excessive heavy machinery traffic, and operating agricultural machinery under inadequate soil conditions, leading to a shortage of crop residues and aggravated soil compaction. Hillside cropping and the removal or inadequate maintenance of agricultural terracing reduced water infiltration and increased runoff, causing further erosion (FREITAS *et al*., 2021; LONDERO *et al*., 2021).

PUBLIC PROGRAMS AND POLICIES FOR SOIL MANAGEMENT AND CONSERVATION IN PARANA

Faced with Parana's uncontrolled soil erosion, in 1969 the Federal Government submitted a request for technical assistance submitted to the General Secretariat of the Organization of American States (OAS) so that a study on erosion control could be conducted in northwestern Parana, and a technical agreement was signed in 1971 with the Brazilian National Department of Sanitation (DNOS) and the Southern Region Development Superintendence (SUDESUL). In 1971, pioneering studies began in Parana. The highest priority was the control of soil erosion, initially in urban areas and the northwestern region of Parana. Although focused on erosion control in urban areas, the study found that the problems were related to the inadequate use of agricultural land in the region, due to erosion in pastures, coffee growing, and annual cropping, usually without terracing. The area covered by the study, limited to the sandy soils (Arenito Caiuá region), was 50,000 km^2, around 25% of Parana's surface area. Measurements carried out by the project team for different types of land use and slopes showed high levels of soil loss (ROMEIRO, 1998). In trial plots in the Arenito Caiuá area carried out by IAPAR from 1978 to 1988, the soil loss was estimated at 57 Mg ha^{-1} yr^{-1} (MERTEN *et al*., 2016). The strategy adopted for the Northwestern Project consisted mainly of constructing terracing to control surface runoff, combined with appropriate land use. The study provided the basis for the Special Program for the Control of Urban Soil Erosion in Northwestern Parana (Pro-Noroeste), implemented from 1975 to 1984.

Pro-Noroeste covered an area of 67,455 km^2, encompassing 161 municipalities in the northwest of the state, to control and prevent erosion. Technical measures to control water erosion were disseminated through trials in watersheds in the municipalities of Campo Mourão in 1980 and Nova Santa Rosa from 1981 to 1982. This initiative combined three projects: administration and monitoring related to project coordination, inspection, and supervision activities; urban erosion control to manage and prevent water erosion in an urban environment; and controlling water erosion in rural areas (reduction and prevention). In addition to its pioneering spirit, this initiative encompassed a wide range of municipalities whose agricultural potential accounted for around half of Parana state's primary production.

Additionally, in 1975 the National Soil Conservation Program (PNCS) was launched and lasted until 1987. PNCS aimed to combat water erosion and ensure the development and adoption of conservation practices throughout Brazil. Priority areas for the implementation of PNCS were selected based on specific legislation applicable to areas suffering severe erosion. In Parana, 208,031 ha were mandatory under the aforementioned legislation, including 34,186 ha in the municipality of Paranavai; 26,970 ha in Toledo; 61,045 ha in Campo Mourao; 51,070 ha in Ponta Grossa; and 34,760 ha in Rolandia.

Almost parallel to the PNCS, the state government of Parana launched the Integrated Soil Conservation Program (PROICS), implemented from 1976 to 1980 in partnership with the federal government and other entities, including the Brazilian Coffee Institute (IBC), rural trade unions, banks, and private corporations. PROICS was based on providing credit facilities, research, technical assistance, and adaptation to mechanization. It consolidated Parana state's conservation policy with two main objectives: controlling water erosion through conservation practices and focusing on viable economic exploitation, mainly by deploying terracing and using the watersheds as units of scale for conservation planning. These initiatives boosted the state's annual agricultural production by 8.7% compared to a national annual increase of 7%. In addition, with terracing and level planting, the program covered approximately 2.3 million ha, serving around 72,000 rural properties in 130 municipalities.

Until the mid-1980s, it was widely believed that soil conservation simply meant terracing. However, studies conducted by soil science groups later in the 1980s reported that terracing only controlled runoff, and needed to be combined with other conservation practices. One way to prevent runoff entails increasing water infiltration capacity, and this was accomplished mechanically by scarification, together with cropping practices, such as cover crops and crop rotation, combined with minimum tillage (DERPSCH *et al*., 1991).

The Integrated Soil Management Program (PMIS) was implemented in Parana from 1983 to 1986, coordinated by the State Agriculture Office, and sought to overcome remaining technical problems in PROICS and encourage farmers to use adequate soil management to conserve natural resources. The soil conservation strategy was based on using the land according to its capability classification, as well as conservation management that encouraged farmers to adopt structural practices, such as terracing, and soil conservation for unpaved roads. Non-structural practices, such as minimum tillage, cover crops, and crop rotation were also encouraged. These initiatives were intended to optimize farmers' incomes and conserve natural resources.

Between 1987 and 1990, the Parana State Agriculture Office introduced the Integrated Soil and Water Management Program (PMISA), to boost farmers to adopt soil and water conservation management, especially through the implementation of conservation agriculture. This concept was combined with the following technical strategy: increasing ground cover to reduce the impact of rainfall on the soil surface; increasing water infiltration to reduce surface runoff and increase water availability in the soil profile; and controlling surface runoff to reduce rill erosion. Several incentives were offered, and Parana state funding was a basic requirement for implementing the program, mainly to support research and rural extension services for developing and disseminating conservation practices among farmers based on a watershed planning approach. The municipalities of Toledo (Western region) and Maringá (Northwestern region) were pioneers in these initiatives (CASÃO JUNIOR; ARAÚJO; FUENTES-LLANILLO, 2012). Although the program advocated the integration of a set of practices to conserve natural resources, ongoing water erosion and the urgent need to control it, especially in the West, North, and Northwest regions of Parana, meant that the program focused on the ongoing use of mechanical practices, together with cover crops and green manure, soil amendment, and reforestation. The PMISA covered around 1,000 watersheds in an area of approximately 2.5 million hectares in Parana.

With financial support under an agreement signed between the World Bank and the Parana State Government, the Parana Rural Development Program (Parana Rural) was implemented between 1989 and 1997, with extensive coverage. Parana Rural included a subprogram for Soil Management and Conservation, to control water erosion and reversing the severe degradation of natural resources at that time by deploying plant-based, edaphic and mechanical conservation technologies, with the specific aim of increasing vegetable production and boosting agricultural productivity and farmers' incomes.

This subprogram facilitated the implementation of conservation initiatives in over 2,400 watersheds, encompassing 7.1 million hectares, directly benefiting 210,000 rural producers (BRAGAGNOLO; PAN; THOMAS, 1997). Parana Rural succeeded in achieving an average reduction of 50% in the turbidity indices of the urban water supply, and in some areas, the reduction was 80% (ROLOFF, 1996). The main outcomes of the Parana Rural program were a significant drop in average water turbidity index, increased crop productivity by boosting potassium, carbon, and phosphorus levels in the soils of worked watersheds, and high adoption rates for the recommended conservation practices, especially among producers working small (up to 50 ha) and medium-sized (51 to 100 ha) properties (FLEISCHFRESSER, 1999). Furthermore, the achievements of Parana Rural were also due to the wide range of factors taken into account, including the organizational dynamics of production systems, the diversity of available natural resources, and socioeconomic characteristics that persuaded producers in each region to embrace innovative farming methods. This, combined with direct action by the extension and research organizations in each location, allowed strategic and technological solutions to be found to minimize the impacts in each particular region; the introduction of economic, social, and environmental improvements; the preservation of local features; promoting behavioral changes; and the theoretical approaches of stakeholders.

Parana Rural was acknowledged by the United Nations Food and Agriculture Organization (FAO) as one of the most effective initiatives aimed at the sustainability and competitiveness of agriculture in tropical and subtropical areas, and in 1999, at the 10 th Conference of the International Soil Conservation Organization (ISCO), held at Purdue University, Indiana, United States, the program was highlighted as a model strategy for the conservation and preservation of natural resources. Parana Rural introduced a new socioenvironmental rationale for land use and soil governance.

The experience acquired with the implementation of Parana Rural highlighted the importance of integrating farmers, extension and research entities, universities, and government in the implementation of public policies if they were to achieve effective outcomes, with a better balance between economic, social, and environmental factors as problems in the field come to light and participation in choosing practical solutions, increasing stakeholder commitment. However, if new knowledge is to reach rural producers, it is essential to know how extensive the programs are and the best means of communication to attract farmers' interest.

Conceived as a continuation of Parana Rural, the Parana 12-Month Program (Parana 12 Months) ran from 1998 to 2006, with the main objective of providing family farmers with an efficient and competent knowledge base on the use of resources, alleviating rural poverty by creating jobs, increasing rural family income, recovering the soil and other natural resources and modernizing family farming. In common with Parana Rural, Parana 12 Months was financed under an agreement between the State Government and the World Bank. However, in

Parana 12 Months, the emphasis moved away from soil conservation and the program was restricted to the regions least served by Parana Rural, with strategies mainly focused on combating rural poverty. Thus, the focus moved toward improving housing and rural living conditions and increasing the technical and economic efficiency and competitiveness of family production units through the intensification, diversification, and verticalization of agricultural production systems. That said, under Parana 12 Months, initiatives were taken to increase plant cover and water infiltration, and control surface runoff and pollution.

These initiatives show the importance of the role played by state and federal public institutions in controlling erosion and establishing policies to reduce the degradation of agricultural land in Parana. These programs and public policies not only impacted farmers' expectations in terms of yield, but also the speculative aspects, as it was realized that, with the adoption of conservation practices, successive economic gains would be increased, both in terms of yield and increased valuation of agricultural land (MICHELLON; REYDON, 2003; TELLES; REYDON; MAIA, 2018).

THE RESUMPTION OF SOIL CONSERVATION RESEARCH IN PARANA

Soil erosion research initiatives in Parana coincide with the formation of IAPAR. After 20 years of continuous studies in the state's main regions, know-how and technologies were developed to minimize the effects of erosion, given the advances in intensive agricultural production techniques observed over the last two decades. Research and development implemented during the 1990s and 2000s by IAPAR focused on NT and NTS quality (CASÃO JUNIOR *et al*., 2006).

Although efficient in reducing soil losses, including helping to increase agricultural productivity and profitability (FUENTES-LLANILLO *et al*., 2021), soil conservation technologies and practices such as NTS have not shown the same efficiency in controlling runoff (DE MARIA, 1999; KAUFMANN *et al*., 2014; MERTEN *et al*., 2015). Thus, due to the significant expansion of NTS in Paraná and the widespread use of heavy agricultural machines and implements (creating problems for contour farmers) (BERGAMIN et al., 2010), questions have been raised regarding the use of mechanical methods to control soil erosion, involving mechanical field practices to control the movement of water over the soil surface, which include agricultural terracing, waterways, silt fences, sediment pond stabilization structures and gully control. It was understood that NTS would be sufficient to control erosion, but in light of the outcomes, the use of agricultural terracing began to be questioned and considered unnecessary (GARCIA; RIGHES, 2008; SILVA; DE MARIA, 2011). Agricultural terraces were indiscriminately removed by farmers, a phenomenon that intensified substantially from the 2000s onward (CAVIGLIONE *et al*., 2010). Note that, at the same time that terraces were being removed, the soil´s management and conservation research team at IAPAR was being dismantled. In spite of this, research continued to highlight the importance of the planning and use of soil conservation practices (agricultural terraces and contour farming), since there was enough data to show that NT alone did not control surface runoff. Farmers will always adopt practices that simplify work and cut production costs (TELLES *et al*., 2022).

In addition, for at least a decade, many farmers came to trust in the efficiency of NTS and began to mechanize agricultural operations (sowing, crop treatments, and harvesting), driving machinery over the land, and even on slopes, contrary to the recommendations set forth. They justify this by claiming that the use of contour farming as recommended increased fuel consumption compared to slope farming (LEVIEN *et al*., 2011), in addition to the fact that slope operations are more efficient. As a result, erosion increased in agricultural areas in the state of Paraná, after successfully controlling the problem in the 1990s.

Faced with this serious situation, in 2009 IAPAR conducted a study to compare the agricultural terrace spacing parameters recommended by IAPAR and by the Campinas Agronomic Institute (IAC), simulating the partial and total removal of terraces. Measurement was based on the Revised Universal Soil Loss Equation (RUSLE) to simulate soil losses under conditions of high and low erosivity under NTS and CT (CAVIGLIONE *et al*., 2010). The authors confirmed that terraces should be kept in place under NTS as an important way of controlling surface runoff, especially under conditions of intense rainfall, compacted soils, and insufficient residual cover (< 6 t ha^{-1} year^{-1}). Following these guidelines, the State Office for Agriculture and Supply (SEAB) published a normative resolution, establishing criteria for the allocation of terraces under NTS for farmers in Parana, serving as a basis for state inspection by the Parana State Agricultural Defense Agency (ADAPAR). However, farmers were found to be strongly resistant to keeping terraces in place, mainly due to the size of the machinery currently used in agriculture, which is difficult to maneuver on level ground. In addition, farmers believe that agricultural terraces reduce cropping areas and have therefore stopped using them.

The need to increase labor productivity using heavy agricultural machinery, combined with market pressures tightening the production timescale, helped simplify farming practices. However, these changes impaired the system's capacity to control water erosion and mitigate pollutant runoff into bodies of water. As a result, rural producers lose out on the productive capacity of the soil, and society suffers water resource contamination (DIDONÉ; MINELLA; EVRARD, 2017). In recent years, several public and private entities directly involved in the resurgence of agricultural soil erosion in Parana have requested technical support from IAPAR to stimulate discussion of the problem, including its legal aspects.

Therefore, now is the time to redeem Parana's reputation and review the steps taken to build the current conservation technical base, and summarize the factors that contributed to the earlier success of public policies for conserving natural resources in the state. We also report on the work undertaken by IAPAR. This research body is the institutional coordinator of the state's agricultural research network formed by federal and state agricultural research institutes, academic institutions, private research institutes, and other civil entities that joined forces to resume erosion research in Parana. Below are descriptions of initiatives such as Repensa, Ibitiba, Prosolo, Redeagropesquisa, and PronaSolos, illustrating the concerted approach to resume soil management and conservation research projects in different regions, including the establishment of new parameters for mechanical soil erosion control methods.

Repensa project

The aim of the Repensa project (2009 to 2013), bringing together IAPAR, Londrina State University (UEL), and other entities funded by the National Council for Scientific and Technological Development (CNPq), was to verify state-of-the-art erosion research in Brazil. In light of heavy soil and water losses, a technical survey was carried out to check out soil management practices in different regions of Parana in 2013, and the team's diagnosis confirmed the need for further research to support the spacing recommendations for terraces under NTS, taking account of both soil and water losses to correctly dimension these structures. The survey was carried out by a multidisciplinary team comprising specialists from IAPAR, the Federal University of Rio Grande do Sul (UFRGS), the University of Leuven (Belgium), UEL, IAC, EMATER-PR, SEAB, ADAPAR, and Itaipu Binacional, and assessed the current state of soil erosion in four regions of Parana (South Central, Northwest, North and West), covering the state's main agricultural areas. The team found that the main reasons for recurring erosion problems at all the locations visited were related to poor coverage of crop residues exposing the soil under NTS; the inadequacy of structures to control runoff (absence of agricultural terraces and waterways); slope farming; lack of location planning and lack of adequate maintenance of unpaved roads; agricultural exploitation incompatible with the land's capability; and an increase in the frequency of erosive rainfall.

During a field survey carried out by IAPAR in 2013, a team of experts from Brazil and abroad concluded that the problem of soil erosion in Parana had worsened in previous years, mainly due to the abandonment of best practices for soil use, management, and conservation, i.e. practices that had been implemented during the transition from CT to NT, and mainly the mechanical methods of soil erosion control. As a result of this diagnosis, in 2014 IAPAR established a partnership with the Soils Department at the Federal University of Santa Maria (UFSM), which already had a project in progress to monitor the impact of soil and water conservation practices using the watershed-scale approach instead of Wischmeier plots (FREITAS *et al*., 2021; LONDERO *et al*., 2021). A similar project was therefore launched by IAPAR to continue erosion studies in Parana, along the same lines as a project implemented in the state of Rio Grande do Sul.

Ibitiba Project

The Ibitiba project was a partnership between IAPAR and Itaipu Binacional, implemented from 2015 to 2020, involving eight action plans (research, development, and technological dissemination projects targeting agricultural systems). The action plan with the highest funding entailed monitoring soil and water losses in the agricultural system. Studies were carried out at two locations in the Western and Northern regions of Parana: the first in a watershed located in the municipality of Toledo, a tributary of the Sao Francisco Verdadeiro river watershed, and the second in a local watershed in the municipality of Cambé, a tributary of the Ribeirao Vermelho river. The experiments were divided into two paired zero-order catchments and agricultural slopes. The sloping areas were used to compare portions under NT, one without terracing and the other with terracing and farmed by the technical recommendations. Collectors were installed in both areas to monitor soil losses, runoff, rainfall, and other indicators to determine the soil's water dynamics. The aim was to validate storm-runoff models, as well as the mechanical methods used for soil erosion control.

The theory is that hydrosedimentological monitoring in small watersheds (first-order rivers) and at other locations will help researchers, public agencies and farmers develop accurate water infiltration models based on watershed conditions in Parana, different soil types, and mechanical methods to control erosion. Generating better-suited hydrological parameters should help to improve the design of soil and water conservation structures.

Prosolo and Redeagropesquisa

As sectors linked to agriculture came to recognize that the upsurge in erosion processes in Parana's agricultural soils required corrective measures, a set of structural measurements were needed to resume soil and water conservation, thereby ensuring that agricultural productivity in Parana was sustainable. Based on the experience gained in previous soil and water conservation programs, public-private initiatives in integrated projects are necessary for successful soil and water conservation to generate greater benefits to rural producers and society, based on the commitment resulting from participatory involvement.

Under the Integrated Soil and Water Conservation Program (Prosolo) instituted in Parana by State Decree 4966 in 2016 and coordinated by SEAB, administrative and technical management is shared by public and private sector entities. The objectives of Prosolo are (i) to raise awareness in the farming community producers and provide training for people involved in conservation agriculture; (ii) to disseminate conservation technologies; (iii) to integrate government and civil institutions to control erosion; (iv) to boost yields through soil recovery; and, v) to achieve a balance between agricultural production and the conservation of natural resources.

As a requirement for local governments to participate in the project, the Prosolo project entailed setting up municipal committees for agricultural soil conservation. Farmers could also volunteer to participate individually and receive funding for soil and water conservation on their property, benefiting from the dissemination and transfer of technologies resulting from the research and updates of soil and water conservation legislation. Under the umbrella of Prosolo, research institutes and universities set up the Parana State Agricultural Research and Applied Training Network (Redeagropesquisa). Its research brief included hydrosedimentological studies on a watershed scale, similar to the measures implemented by IAPAR under the Ibitiba project in Toledo and Cambé, and extended to the municipalities of Ponta Grossa, Guarapuava, Dois Vizinhos, and Maringá.

Redeagropesquisa aims to develop projects focused on monitoring water quantity and quality in agricultural areas, standardizing procedures to generate robust data to provide a basis for improving the design tools necessary for soil and water conservation. These research objectives were supported through Public Call for Bids 01/2017 - Parana State Network for Supporting Agro-research and Applied Training (Araucaria Foundation/SETI-PR/SENAR-PR), with both public and private funding. Institutions such as IDR-Parana, Itaipu Binacional, SEAB, Superintendence of Science, Technology and Higher Education (SETI-PR), Agriculture Federation of the State of Parana (FAEP), Ocepar System, Parana Agribusiness Defense Agency (ADAPAR), Agricultural Workers Federation of the State of Parana (FETAEP), Brazilian Federation of Direct Tillage and Irrigation (FEBRAPDP), Brazilian Society of Soil Science (SBCS) – Parana Division, Association of Municipalities of Parana (AMP), Sanepar and Copel are all partners of Prosolo.

This new approach involving the formation of a dedicated research network with broad participation of entities and institutions in Parana seems to be an effective way of helping to combat erosion problems and make progress in technologies for adapting to new production patterns.

PronaSolos program

Brazil is the fifth largest nation on the planet in terms of surface area, covering approximately 8.5 million km^2, but not enough is known about its soil characteristics. Based on the need to expand our knowledge to boost agricultural production and manage national climate risks and food security, the Brazilian National Soil Program (PronaSolos) was set up in 2018 by the federal government, coordinated by the Ministry of Agriculture, Livestock, and Supply (MAPA), to map the country's soil in its entirety.

PronaSolos, instituted by Presidential Decree in 2018, aims to generate survey data and classify soils on a minimum scale of 1: 100,000. At present, less than 5% of the national territory has been surveyed with this level of detail. The program is administered by a strategic committee headed by MAPA and an executive committee headed by Embrapa Solos.

The level of information on Brazilian soil types is in stark contrast with that of other large agricultural producer countries, such as the United States, whose territorial soils have been almost entirely mapped in detail. The environmental heterogeneity of Brazil in terms of climate, soil, and topography, and the relative diversification of research and technological advances and transformations in mechanical, electronic, biological, and chemical terms, related to agricultural production, require complex solutions and a combination of conservation techniques specific to different situations. Standardized and simplified solutions are not adequate to solve current problems. PronaSolos will have its platform for gathering the information generated, enabling researchers, rural producers, and the population in general to access Brazilian soil data free of charge. This will provide a reliable basis for future soil governance.

CONCLUSIONS

1. Vigorous economic and population growth in the state of Parana has been sustained at the cost of widespread environmental degradation. The land originally covered, for the most part, by forests has been turned over for agricultural crops and pastures. In the first few decades of the 20th century, erosion was already happening in Parana's agriculture, but the environmental liability of intense farming and deforestation in Parana became more evident from the 1970s onward. The erosive process engendered by inappropriate soil management was identified as the cause of soil and water degradation, and pressure was applied to implement measures for its control. Various sectors of society joined forces and called for state

measures implemented by public programs and policies considered necessary to conserve natural resources;

2. Initially, conservation programs focused on practices to control runoff through the use of agricultural terracing. Later, when erosion processes were better understood, control strategies also embraced farming practices, such as crop rotation and the use of green manures, and alternative methods of soil preparation, such as cropping practices capable of increasing water infiltration into the soil. The next step was to improve farming practices and the no-tillage system emerged and became very popular among farmers as a way of reducing soil losses. No-tillage also simplified or lowered the number of cropping operations necessary, reducing the workload and cutting production costs. Because of ongoing initiatives implemented in Parana in the 1970s, this Brazilian state attracted much attention from researchers eager to analyze its soil and water conservation initiatives and the development of conservation agricultural practices, including the no-tillage system. Note that these initiatives involved extensive planning for the use, management, and conservation of renewable natural resources, with the watershed scale as a reference. This highlights the importance of an adequate institutional framework, especially in terms of well-structured research and extension agencies to guarantee a successful outcome for the implementation of public policies focused on the use, management, and conservation of natural resources and maintaining the level of public environmental awareness;
3. The lessons learned from the implementation of these policies in Parana show that adequate governance (political, technological, and operational) is required to effectively attain strategic goals and achieve lasting successful outcomes. Despite the acknowledged progress made in the implementation of these policies, erosion and associated environmental problems still cause concern, due to disregard of or non-compliance with the technical guidelines for land conservation, already well established by research and current legislation. Farmers' failure to adopt integrated conservation practices, evidenced mainly by the partial or total removal of agricultural terracing and the replacement of contour farming by slope farming, has accentuated soil degradation in the state. This highlights the need to strengthen soil governance strategies and resume public-private initiatives focused on soil and water conservation to boost the sustainability of agriculture in Parana.

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