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Review

Benefits of Conservation Agriculture in Watershed Management: Participatory Governance to Improve the Quality of No-Till Systems in the Paraná 3 Watershed, Brazil

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Citation: Mello, I.; Laurent, F.; Kassam, A.; Marques, G.; Okawa, C.M.P.; Monte, K. Benefits of Conservation Agriculture in Watershed Management: Participatory Governance to Improve the Quality of No-Till Systems in the Paraná 3 Watershed, Brazil. *Agronomy* **2021**, *11*, 2455. https://doi.org/10.3390/agronomy11122455

Academic Editor: Carlos Cantero-Martínez

Received: 9 October 2021
Accepted: 24 November 2021
Published: 1 December 2021

Abstract: Adoption of best soil and water management practices is desirable for sustainable production intensification. However, farmers have difficulties in adopting them within a system approach to management, missing out on positive results for themselves and for society. A partnership between the Brazilian No-Till Farmers Federation and Itaipu Binacional authority adopted a participatory management strategy, as proposed by the National Water Resources Policy, allowing important decisions regarding the use of water to be made in participatory Watershed Committees, to address such farmers' difficulties. In this paper, we review the development and application of the Participatory Quality Index approach based on the principles of conservation agriculture to improve the quality of no-till systems in the Paraná 3 watershed within the Cultivating Good Water program. We analyze the available documentation and experiences of the program's executors, highlighting the results from the perspective of sustainability of multiple uses of water in a watershed.

Keywords: direct seeding; erosion; conservation; water quality; rotation; crop diversity

1. Introduction

No-till farming as an approach for managing crops and production systems has its roots in the first half of the 20th century when in 1943 Edward Faulkner stated that there was no scientific reason to plow the soil [1]. In the studies on machinery developed for direct seeding in 1973 and later [1–3], it was highlighted that from experiments conducted at the Rothamsted Experimental Station, England, in the second half of the 1940s, soil preparation was considered dispensable, as long as there was no competition by weeds. In Brazil, the first record of no-till seeding dates back to 1969, with the implementation of the first no-till crop area (1 ha) on an experimental scale in Não Me Toque, Rio Grande do Sul, by professors Newton Martins and Luiz Fernando Coelho de Souza from the Universidade Federal do Rio Grande do Sul [1,4]. At the farm level, the pioneering record in Brazil belongs to the farmer Herbert Bartz who, after learning about the first experiences of the pioneer producer Harry Young in the United States, imported a machine with tools capable of carrying out direct seeding into untilled soil. In October 1972, the first sowing with a machine was carried out with tools capable of direct seeding of what came to be known in Brazil as direct planting in straw [5]. These experiences were copied and replicated in the most diverse regions in Southern Brazil, as the concern of most technicians and sectorial policies at the time was the increase in erosion processes resulting from soil preparation with intensive tillage in the heavy tropical rainfall environment. The impact of these processes was very severe on arable soils. A study conducted in latosols in the state of Rio Grande do Sul [6] showed that, depending on the erosivity of the rains, soil losses in the conventional tillage system can be more than 24 t ha^{-1} yr^{-1}. Fuentes-Llanillo [7] quotes several authors who stated that conventional tillage production entails losses of more than 20 t ha^{-1} yr^{-1} of topsoil. As the eroded soil material is carried away across the landscape, it brings with it sediments, solutes, agrochemicals and microorganisms that end up impacting the quality and quantity of water resources, and the hydrological functioning of watersheds. In Ruedell's words [8] (p. 115) cited by De Mello [9]:

> "In conventional tillage systems, the soil that should be the support for the productive system is relegated to a background and quickly destroyed. The nutritional imbalance and impoverishment that occurs in the soil from this, makes plants highly dependent on the placement of large amounts of fertilizers and correctives, increasingly incurring production costs and environmental degradation."

Salton et al. [10] stated that the greatest difficulty is raising awareness among farmers about the importance and need for adopting a no-till system. Calegari [11] stated that the farmer's immediate vision of the crops they sell hinders a systemic approach in which cover crops contribute to optimizing the cost-benefit ratio of a production system in the medium- and long-term. Derpsch [12], describing the critical steps to no-till adoption, sums up this challenge as follows:

> "When new technologies are being extended to farmers, the conditions for the utilization of technology have to be met. It should be taken into consideration that if farmers are to adopt innovations, they must want to, they must know how to and, they must be able to follow recommendations."

The proposal with a participatory methodological approach is focused on understanding the local bottlenecks to provide a collaborative environment between the stakeholders, aiming at the full adoption of the no-till system by farmers. This paper illustrates the case of the development and application of the Participatory Quality Index (IQP) of the no-till system in a Brazilian watershed (Paraná 3 watershed), drawing from the lessons learned based on the local experiences and results. The objective is to describe the formulation and application of the participatory methodology of IQP to evaluate the quality of the no-till system in the Paraná 3 watershed, and its effectiveness in contributing to integrated management of water resources.

The paper aims to contribute to agriculture development by organizing potential no-till strategies to improve crop productivity and water use efficiency, hence addressing some of the key sustainability difficulties faced by farmers. The contribution is also aligned to the implementation of the National Water Resources Policy in Brazil because it provides relevant criteria and directives for water use management, allowing important decisions to be made in the Watershed Committees regarding the management and use of water in agricultural land.

2. History and Context of Study Area

In comparison to the conventional tillage system, the no-till system is a sustainable alternative for the producer. This system is not only a way of seeding without disturbing the soil, but also a combination of well-ordered succession of agricultural practices capable of decreasing the cost of production and increasing the quantity and quality of harvested products while conserving and improving soil health and function to enhance the generation of ecosystem services.

According to De Mello [9], the generation of income and the improvement in quality of life resulting from the use of a no-till soybean-based production system in the Northwest region of Rio Grande do Sul state in Brazil represents the realization of the right to development for its population, given it benefits not only those directly involved, as producers, researchers, agronomists, and companies, but also the society. By maintaining soil-mediated ecosystem services for future generations with no-till crop production, society contributes to both economic and social development, securing the basic human rights of access to food and quality of life.

The constant evolution of agricultural research in water and soil management, and the successful adoption of no-till and related practices to mitigate the erosion processes in agricultural lands, were very important for the development of sustainable production systems in Brazil. The movement in favor of the use of the no-till approach to farming was led by the farmers themselves through many initiatives.

The paper presents the case of the Itaipu watershed, or the Paraná 3 watershed, which illustrates a set of actions to improve soil and water management based on no-till agriculture and the advantages it brings to farmers and society. Itaipu dam complex is situated in one of the largest South American rivers, the Paraná River, at the border between Brazil and Paraguay, and part of the greater La Plata watershed. The Itaipu dam reservoir stores approximately 1.9×10^{10} m^3 (19,000 hm^3) of water feeding a 14,000 MW electric generating powerplant. Despite its large reservoir lake, the dam is operated as a run-of-river generator, with no significant energy storage fluctuation.

All the smaller watersheds of the left bank of the Itaipu lake constitute the Paraná 3 watershed (8000 km^2) (Figure 1). According to the Koppen classification, the area is under sub-tropical climate (Cfa), with average temperatures under 18 °C in the coldest month with infrequent frost, and above 22 °C during the warm summer months. The annual rainfall varies from 1550 mm in the far north (Guaira area) to 2125 mm in the south of the watershed (Cascavel area). The soils, mainly Oxisols, are derived in most part from basaltic bedrock, and some from sandstone, and are naturally deep, highly weathered, and well-drained. Topography is mainly rolling terrain, mostly with gentle long slopes. There are two main cropping seasons, the summer season from October to March and the winter season from April to September. The main summer crops are soybean and maize, with other associated crops such as sunflower, cotton and cassava. The main winter crops are wheat, barley and oats [13].

Figure 1. Location of Itaipu dam, and the Paraná 3 watershed and its municipalities, IBGE [14].

Runoff and erosion from conventional tillage agriculture has led to high rates of soil erosion and to high sediment load in the water courses in the watershed. It also led to increased fluxes of nitrogen and phosphorus from fertilizers, and of pesticides into the surface water system. These processes lead to both premature filling and eutrophication in the Itaipu lake, each being a serious threat to hydropower production and to the integrity of the infrastructure [15].

The siltation and pollution processes in the lake resulting from land degradation (nutrients leaching and soil organic matter depletion) and erosion in the watershed has concerned the Itaipu Binacional hydroelectric plant located in Foz do Iguaçu in the Paraná state since its inauguration in 1984, prompting actions towards environmental protection. In 1996, through the Environmental Action Division, the Itaipu Binacional authority, sought information on the no-till system of agricultural land use from the Paraná Agronomy Institute (IAPAR, which is currently part of the Paraná Rural Development Institute–IDR-PR) and FEBRAPDP, aiming to publicize the system's advantages for the producers in the watershed, as well as for the reservoir and the Itaipu dam complex as a whole. Among other actors, IAPAR and FEBRAPDP contributed to building a technological validation program in the municipalities of the left bank watersheds (referred to as the Paraná 3 watershed) to increase the adoption of direct seeding by agricultural producers and to improve the practices associated with the no-till production system.

In 2000, FEBRAPDP and Itaipu Binacional established a partnership to update and improve the program to up-scale no-till agricultural land use in the region. Numerous events contributed to the development of no-till land use in the region. Global specialists in sustainability were present in some of these events, contributing to the debate and establishment of actions in favor of no-till adoption. Robust investments in field validation, training of technicians and producers, and the training of farm workers resulting from this partnership, allowed the adoption of no-till land use to evolve in the Paraná 3 watershed to the point of reaching 89% of the watershed area used for the production of annual crops in the 2005/2006 harvest [16].

Even with these adoption rates, the water monitoring system in the Paraná 3 watershed continued to record a significant presence of sediments and diffuse pollutants such as nitrogen and phosphorus, responsible for eutrophication of the Itaipu lake. Collectively, deforestation, runoff and intensive soil tillage have affected water quality in water courses and the Itaipu reservoir. These practices have led to extremely high rates of soil erosion, reaching 50 t $ha^{-1}yr^{-1}$, and to high sediment loads flowing through water courses (Figure 2), into the Itaipu reservoir, and in downstream water. This has caused severe eutrophication in parts of the reservoir (Figure 3) and premature sediment filling (Figure 4) of the reservoir [15].

Figure 2. Water course in Paraná 3 watershed with high sediment load, December 2010 (source: Francois Laurent).

Figure 3. Eutrophication in Itaipu reservoir, September 2010 (source: Ivo Mello).

Figure 4. Sediment deposition and eutrophication, mouth of river São Francisco Verdadeiro where it enters Itaipu reservoir (source: Ivo Mello).

In August 2002, FEBRAPDP included as a priority in its strategic planning to promote the adoption of no-till seeding within a cropping system that would also meet certain quality standards. By avoiding soil tillage and implementing crops with no-till seeders, several grain production areas in Brazil have significantly contributed to reducing soil erosion. However, farmers were not always practicing the no-till system as had been defined, i.e., no-till seeding through soil mulch or straw cover in diversified cropping. The concept of the no-till system or conservation agriculture was established by the Food and Agriculture Organization of the United Nations (FAO) in 1998 as an application of a set of three interlinked management principles as follows [17]:

Principle 1: Continuous lack of or minimal mechanical soil disturbance through the practice of no-till seeding and weeding. This practice reduces soil erosion, preserves its organic matter and promotes soil biological processes and functions.

Principle 2: Permanent biomass soil cover with at least 30% soil cover through the practice of retaining crop biomass, stubble mulching and cover cropping. Maintaining a protective cover of vegetative mulch cover on the soil surface reduces weeds, protects the soil from the effects of extreme weather phenomena, serves as substrate for soil microorganisms and soil biological processes and functions, contributes to nutrient cycles and helps to preserve soil moisture and prevents its compaction.

Principle 3: Species diversification through rotations and/or sequences and/or associations of at least three crop species ideally. A well-designed cropping system with rotation, sequences or associations enhances soil structure, promotes a variety of soil flora and fauna that contributes to nutrient cycles and better plant nutrition, and helps to prevent pests and diseases.

Emphasizing the need to promote sustainable production intensification and build food security for the planet, FAO in its Save and Grow publication [18] states that production systems for the sustainable intensification of food and agriculture production should offer a variety of productivity, socioeconomic and environmental benefits for producers and society as a whole, including high and stable production and income, adaptation and reduction of vulnerability to climate change; improvement in ecosystem functions and services; and reduction in greenhouse gas emissions and carbon footprint. These production systems must be based on the application of the three interlinked principles of CA so that the production systems simultaneously provide: (a) increased agricultural productivity, improved natural capital and ecosystem services; (b) high efficiency rates in the use of basic inputs including water, nutrients, agrochemicals, energy, soil and labor; and (c) use of natural and modified biodiversity to build systemic resilience to biotic, abiotic and economic stresses.

3. Itaipu Binacional and Sustainable Generation of Hydroelectric Energy

The Brazilian general directorate of Itaipu established a new strategic plan in 2003, systematically incorporating sustainability concepts into hydroelectric power generation, electing, as provided for in Brazilian legislation, the Paraná 3 watershed as its planning unit to develop the social and environmental programs. Law no. 9.433/1997 [19] of the National Water Resources Policy has among its foundations water as a public domain good, endowed with economic value, whose priority uses are human supply and animal watering and whose management must take the hydrographic watershed as a territorial unit.

In 2003, Itaipu Binacional authority created the program called Cultivando Água Boa (CAB) or Cultivating Good Water {20]. It comprised a set of social and environmental initiatives related to the region's water security, the conservation of natural resources and biodiversity, and the promotion of quality of life in the communities in the program's area of influence. Through a broad process of awareness, mobilization and information, the aim was to promote changes in the modes of organization, production and consumption, and care with water, thus enabling a more sustainable future for communities. Based on territorial planning in the watershed, and the decentralization of decisions through watershed committees, the CAB established municipal management committees that discussed and endorsed the actions in the management of the watershed program. The 2003 Annual Report of Itaipu Binacional [20] describes the CAB program as follows:

> "Within a new model of territorial management by watershed and sub-basin and matrix management by projects, Itaipu implemented the Cultivando Água Boa/Porã Program. This program considers the need to maintain the quantity and quality of water in the reservoir, including acting in the sources of tributary rivers of the tributary basins in the region, in partnership with other users of water resources, and in the conservation of soil and riparian forests. To complement the environmental management of the territorial extension of the basins to preserve soil quality and seek the sustainable development of communities, several environmental projects were developed to restore forest reserves, encourage

organic agriculture and no-till system, as well as alternative crops and medicinal plants."

In this program, participatory governance was adopted, which consists of a new paradigm instituted by the National Water Resources Policy [19], in which stakeholders are invited to participate to discuss solutions to reach an objective. During the identification and formulation of these solutions, different points of view that reflect different interests are debated and the solution found, which will be the one that expresses the greatest commitment by the stakeholders.

Participatory water governance was a paradigm shift in the governance of decision-making processes. Thus, the old forms of governance in the public and private sectors have gradually been replaced by a new way of governing, due to the rapid changes in conditions at the global and national levels. These changes, which have taken place around the world in recent decades, are due to a variety of factors, cited by Michalski et al. [21], that include, but are not necessarily limited to, deeper and accelerated global integration, increased free trade, higher levels of education, rapid scientific and technological development in almost every field, revolutions in information and communication technologies, institutional innovations, growing demographic diversity within and between countries, incessant pressures exerted by economic, social and political dynamism, changing social perceptions, institutional values and structures and growing demand by those who had been ruled yesterday to become the rulers of tomorrow.

Demonstrating these participatory practices and articulation between agriculture and water management, between farm level and watershed level, a technical cooperation agreement signed in 2004 between Itaipu and FEBRAPDP laid the foundations of the Participatory No-Till System Quality Index (in Portuguese: IQP–Índice de Qualidade Participativo) Project within the scope of CAB program [22]. The goal was to improve the performance of the no-till system by addressing the difficulties of farmers to adopt CA systems. A methodology for measuring indicators was a necessary tool to make farmers understand that the no-till CA system practices are good and more profitable.

At the beginning of 2005, within the scope of this technical cooperation agreement, specialists who had the knowledge and expertise to investigate and validate practices and technologies associated with the no-till CA system gathered. As a result, the baseline questionnaire for farmers was prepared to identify the indicators to assess the quality of the no-till production system at the farm level. During the period 2005–2009, several initiatives contributed to the formulation of the IQP model in the context of technical cooperation between FEBRAPDP and Itaipu authority, under the umbrella of the CAB Program guidelines, which aimed at improving the quality of the no-till system in the Paraná 3 watershed. The IQP model was developed and tested between 2010 and 2012 to evaluate the quality of the no-till system practices and how to improve them based on a better understanding of farmers' realities.

The IQP model was made available by the FEBRAPDP and Itaipu Binacional partnership, through the International Hydroinformatics Center of the Itaipu Technological Park Foundation (CIH/FPTI). The IQP model is a tool that allows quality assessment of the production system used by individual farmers on a production plot, and to discuss with them the ways to improve the system quality considering various criteria. The conceptual basis for the compilation and availability of the IQP is the Multipurpose Technical Registry (CTM).

The CTM is a logical and standardized method of relating alphanumeric and cartographic databases belonging to different institutions. The joint and synchronized work makes it possible to generate a broad vision, and assess the regional and urban characteristics of a jurisdiction, identify land demarcation problems and conflicts in land use, and define a coherent tax policy, among many other aspects. It is a tool based on several thematic maps, including land structure, land use, slope, river network, etc., which allow the technician to have a clear view of what is on each property, what can be produced, and options for production [23]. Mariani [24] states that CTM is an information system that integrates diversified data, to satisfy the needs of various socioeconomic sectors; represents an integrated information system at a given spatial scale. It should be understood as a system of registration of real estate property, made in a geometric and descriptive way, constituting, in this way, the most agile and complete vehicle for the parameterization of the explored planning models, always supported in terms of structuring and functionality [24]

The CAB program through the CIH/FPTI generates a CTM as a support database for actions and activity planning for the application of the IQP related activities. The CTM-IQP database fed with the farmer's responses related to their management on the cropland where, through an algorithm developed by crop management specialists, the system assigns scores from 0 to 10 that allow the farmer and the advisor to have an idea of the quality level of the assessed management of a given activity in relation to the highest possible quality, considering current knowledge. The benchmarking for each of the indicators chosen to form the IQP is established by agronomic science based on the principles of CA to intensify the production and use of production inputs and the natural resource base in a sustainable way.

The conceptual model of the IQP assessment tool is based on the Management Assessment System of the Gaucho Quality and Productivity Program (PGQP) [25]. The PGQP is a qualification program aimed at improving the products and services of companies in Rio Grande do Sul state, Brazil, aiming to benefit the end consumer. This program is structured based on the Fundamentals and Criteria for Excellence in Management prepared by the National Quality Foundation, Brazil, which, among other aspects, identify the processes related to information and knowledge as important for an effective business management system [26].

4. Participatory Quality Index (IQP)

To build the IQP model, the first step was the establishment of benchmarking of best management practices (BMPs) considering the context of the watershed region, called the Paraná 3 watershed, contributing to the Itaipu reservoir. The contributions of experts and discussions held in events such as the Symposium on No-Till system and the Environment organized by FEBRAPDP, culminated in 2006 with the publication of the book Sistema Plantio Direto with Quality, a product of the IAPAR (currently IDR-PR) and Itaipu Binacional partnership [27]. Developed with the aim of making available the best existing scientific knowledge in favor of increasing the quality of the no-till system for farmers in the Paraná 3 watershed, this publication was used as the basis for the IQP scoring system.

In the context of the CAB program, the municipalities established Management Committees that work like watershed committees for the program's actions. The CAB program, in its initial phase, developed a mapping system for the smaller or micro-watersheds that make up the Paraná 3 watershed, to allow for the georeferencing of the program's actions. In conjunction with the Coordination Board of Itaipu Binacional and the FEBRAPDP team, six micro-watersheds and their respective municipalities were elected in the Paraná 3 watershed, namely:

1. Ajuricaba–Marechal Candido Rondon
2. Buriti–Itaipulândia
3. Facão Torto–Entre Rios do Oeste
4. Pacuri–Santa Helena
5. Sanga Mineira–Mercedes
6. Toledo–Toledo

The central issue that should govern management is the integration of the various aspects that interfere with the use of water resources and their environmental protection. The watershed unit allows this integrated approach. According to Yassuda [28], the watershed is the place of interaction of the water resources with the physical environment, the biotic environment, and the social, economic and cultural environment. Within the scope of the development project of the IQP, the participatory culture was developed through the municipal management committees, such as the watershed committees, established in the National Water Resources Policy. A magazine (Revista) [29] with general information about the importance of investing in the quality of no-till system was established for the watershed. Accessible language was used to make it easier for management committee stakeholders to understand and associate the benefits of an adequate CA-based soil management system with the protection of water resources. The importance of BMPs such as those embedded in no-till system was highlighted. Meetings were held with the management committees where participants from the public, municipal government and water users attended. The methodology and objectives of the IQP program are described in [30]. At the meetings called for this purpose by the six municipalities with their management committees, the continuation of the ongoing project was approved. The interaction of the various representatives was the object of analysis and guidance for the next steps. According to the program's report,

> "The idea was to emphasize that the entire process takes place in a participatory manner, where the farmer is the actor, the centerpiece of the program, and his opinion is taken into account for the continuity of the work".

The participatory approach presupposes the need to meet social and cultural requirements, preserving and qualifying the relationships between subjects, and seeking better living conditions and well-being. Participation in this methodology established the condition of respect for the real situation of each community and the prerequisite for preserving the identities built during its history. The possibility of adding economic value associated with the appreciation of the community and the idea of environmental preservation, guided the participatory attraction.

After the consent of the municipal management committee (comitê gestor) of the watersheds under study, a technical event of 'open knowledge leveling' for the general public was promoted for the interested public, where specialists in the various areas of knowledge, that included good practices in favor of the quality of the agricultural production system, presented the scientific bases to support debates and level knowledge. Events were held at the headquarters of the association of farmers in one of the six micro-watersheds that are the object of the project, where farmers and their technicians were motivated to debate the theoretical themes of good practices as part of their field realities. Such occasions served as the basis for consolidating the first diagnostic questionnaire to be applied to a sample of producers from each of the micro-watersheds. This questionnaire was adapted from a proposal discussed in 2007 with a group of experts/scientists knowledgeable about good practices aiming at the quality of no-till systems with the participation of IAPAR, FEBRAPDP and Itaipu Binacional.

In February 2010 the FEBRAPDP field team interviewed 237 producers (Table 1). In addition to applying the diagnostic questionnaire [31], the set-up of the IQP program was explained. In April 2010 the results of the questionnaires were delivered in each of the six micro-watersheds, always in the farmer's environment (association or community center).

Table 1. Number of farmers interviewed during the situational diagnostic.

County	Micro-Watershed	Number of Farmers Interviewed
Marechal Cândido Rondon	Ajuricaba	46
Mercedes	Mineira	28
Entre Rios do Oeste	Facão Torto	43
Itaipulândia	Buriti	19
Santa Helena	Pacuri	29
Toledo	Toledo	72
Total		237

The data collected through the questionnaire were: extent of the no-till production area, period of adoption of the no-till system, qualification of the no-till system, level of satisfaction with the system, difficulties and problems encountered. The importance of the system and conservation operations were organized in graphs to illustrate the no-till state of art for each of the six micro-watersheds [32].

With a pedagogical booklet [33] which explains the pillars or core practices of the no-till system and the goals of the IQP methodology, the farmers instigated by data from the questionnaire, where each one knows their respective situation and understands where they belong in the various indicators raised, are motivated to debate and suggest which are the most important points to be worked upon by the IQP development program. In these workshops, the products of each micro-watershed were named "Indicator Baskets" where the farmers chose, from their point of view, which ones were the most important to improve the quality of their no-till systems on an ongoing basis. Furthermore, in these opportunities, three to four producers (approximately 5% of the total) per micro-watershed either voluntarily joined or were elected among their peers to be part of the monitoring group for the evaluation of the indicators prioritized by the participatory workshops.

With the diagnoses, prioritized indicators and the monitoring group established, the project team of consultants were able to consolidate a new diagnostic questionnaire that includes the identification of the state-of-the-art of the indicators and facilitate their insertion in the CTM database.

The new questionnaire was built considering the perceptions of farmers and includes the collection of general identification data of the producer and their property, and information regarding the direct planting of the property and each plot [34].

5. The No-Till Participatory Quality Index (IQP) Matrix

The program team of consultants and field technicians developed a proposal for calculating the scores and weights of each indicator to measure how close the is farmer evaluated by the program to the benchmarks or idea positions related to good practices to improve their no-till systems.

IQP results from a matrix where the indicators (Table 2) chosen by the participatory process are computed according to the questionnaire responses considering the weights of each one of them, finally resulting in a score from 0 to 10.

Table 2. IQP Index composition with weights for each indicator.

Indicators (Ii)	Weighting Factor (Fi)
Rotation intensity–RI	1.5
Rotation diversity–RD	1.5
Residues persistence–RP	1.5
Tillage frequency–TF	1.5
Terrace adequacy–TA	1.0
Conservation efficiency–CE	1.0
Balanced nutrition–BF	1.0
No-till adoption time–AT	1.0
IQP = Ii × Fi	

According to their origin, the indicators were grouped in relation to (1) crop rotation, (2) minimum soil disturbance, (3) soil and water conservation, (4) plant nutrition, and (5) the farmer's commitment to the no-till system. These are explained in the following sections.

5.1. Crop Rotation

The importance of the diversity of species cultivated in rotation or sequence and the maintenance of permanent soil cover, through living vegetation or straw and stubble (biomass), both dependent on the adequate rotation of commercial and cover crops, is responsible for at least 50% of the benefits of no-till system. This is due to effects on spontaneous plants or weeds, pests, diseases, biodiversity, soil organic matter, soil physical and chemical properties. To capture the effects of rotation, regardless of the individual species that could be used regionally, they were grouped into the following functional groups:

- Rotation intensity—RI

Indicator assesses the degree of living soil coverage during a given period. Regardless of the species, the simple presence of living crop culture means (a) greater protection of the soil surface, and (b) the frequency of production of new straw or biomass to replace the previously returned biomass, which decays over time. In addition, the almost permanent presence of living roots preserves macro pores and creates new ones, in addition to promoting an environment conducive to the recycling of nutrients, maintenance of rhizosphere biodiversity and balance between the more and less oxidizable fractions of organic matter. The benchmarking, or ideal situation, for the western region of the Paraná state, is the production of commercial and/or cover crops in all possible cropping systems: summer season (main), off-season and winter season.

- Rotation diversity—RD

It assesses the degree of diversity present in the rotation, due to its importance for minimizing problems with weeds, insect pests and diseases and the exploration, by roots, of different volumes of soil, thus facilitating the recycling of nutrients. Furthermore, crop cultures of different species promote soil microbiological diversity. The benchmark of species presents during a given period depends on the soil and climate characteristics of a given agroecological region. In the western region of Paraná state, it is possible to plant a wide range of annual species. Despite the great diversity of possible species, especially cover crop species, the arbitrarily suggested regional benchmarking is four species in a three-year period, due to the common use of only few species.

- Residue persistence—RP

It assesses the degree of persistence or durability of straw or biomass on the soil surface, as the larger and the longer the soil surface is protected from the effects of rain and runoff, in addition to reducing temperature variation, avoiding harmful extremes, improving the microbial and mesofauna soil environment. This is a key element of the no-till system and, together with living or dead biomass coverage, forms one of the pillars of its sustainability. The durability of straw or stubble biomass depends on its initial mass, its resistance to decomposition, temperature, and humidity. The resistance to decomposition, in turn, depends on its C:N ratio, being higher the greater the ratio. For this reason, the grass family (*Poacea* spp.) contains plants that result in more persistent straw. This led to the arbitrarily defined regional benchmarking of two-thirds of the three annual possible crops being grasses. This degree of prevalence of grasses in the rotation or sequence is based on conditions predominantly favorable to the decomposition of straw or stubble biomass in the region, typically due to higher temperatures and availability of water. Table 3 presents the crop rotation indicators and how to calculate them.

Table 3. Crop rotation indicator calculation.

Crop Rotation (in 3 Years)						
Indicator	**Ab**	**Input Data**	**Base**	**Formula**	**Critical**	**Ideal**
Intensity	RI	NC = number of crops in three years (except fallow)	9 = number of possible crops in three years	RI = NC/9	NC = 5 IR = 0.56	NC = 9 IR = 1.0
Diversity	RD	CD = different species occurring in the rotation	4 = ideal number of species in three years	RD = CD/4	CD = 2 DR = 0.5	CD = 3 DR = 1.0
Residue persistence	RP	GR = number of grasses in rotation (except grasses for haymaking or silage)	6 = ideal number of grasses in three years	RP = GR/6	GR = 3 PR = 0.5	GR = 6 PR = 1.0

Red = Management needs improvement; Green = Good management.

5.2. Minimum Soil Disturbance

Avoiding the mechanical preparation of land for crop establishment is one of the pillars of sustainability of the no-till system, as it preserves the soil cover by straw and stubble biomass and minimizes the oxidation of soil organic matter. However, farmers' incorrect perception that tillage is necessary after a few years of no-tillage due to compaction, or the presence of hard-to-control spontaneous plants (weeds), has resulted in relatively frequent soil tillage, usually by scarification. However, there is a large amount of evidence indicating that the longer the period under no-till, the better is the quality of soil. Thus, the frequency of land preparation for seeding can be used as an indicator that is inversely related to the quality of the no-till system.

- Tillage frequency–TF

Studies indicate the stabilization of soil organic matter content with a continuous no-till system (systema plantio direto, SDP) between five and 12 years, for soil and climate like that of the western region of Paraná state. Therefore, it is suggested that this indicator be evaluated based on the proportion between the time without soil mechanical preparation and the time considered sufficient for the stabilization of the soil system. The benchmark for this indicator is arbitrarily set at six years. Furthermore, in the region it is relatively common for the producer to carry out mechanical land preparation for sowing in a particular area, i.e., in the headlands, due to the perception that compaction is greater in the headlands of the cropped field where the maneuvers with machinery and equipment occur. Here, it is assumed that the headland area corresponds to about 20% of the crop area, with 80% remaining unprepared or without any tillage. Table 4 presents the indicator and how to calculate it.

Table 4. Minimum soil disturbance indicator calculation.

Tillage						
Indicator	**Ab**	**Input Data**	**Base**	**Formula**	**Critical**	**Ideal**
Tillage Frequency	TF	IEP = interval between tillage (years) No-till: IEP = Base Tillage only headboards: IEP = Base × 0.8 (assumption: 80% of the area no-till)	6 = number of years to almost stabilization of the system	TF = IEP/6	0.5	1

Red = Management needs improvement; Green = Good management.

5.3. Conservation Practices

Conservation practices must prevent erosion and minimize water runoff from the land. Even though soil losses are relatively low in a no-till system without terracing, it is necessary to maximize water infiltration into the soil and the positive externalities of no-till system to water quality. The slopes in the western region of Paraná state are long, and the terrain is gentle to undulating. This topography, associated with the high intensity of rainfall in Paraná state, requires specific conservation care to avoid the formation and concentration of surface runoff, facilitating water infiltration through its storage. The assessment of the adequacy of water and soil conservation practices is carried out by two indicators:

- Terrace adequacy–TA

This indicator is evaluated by the presence or absence of terracing at level and, when present, due to its effectiveness in containing surface runoff, based on the overflow frequency, a way to assess the capacity of the space between the terraces to capture and infiltrate rainwater. More precise criteria exist, such as measuring the spacing and dimensions of the terraces, which require field determinations, that goes against one of the assumptions for the indicators. Table 5 presents the indicator and how to calculate it.

Table 5. Terrace adequacy indicator calculation.

Conservation Practices							
Indicator	**Ab**	**With Terraces: Frequency of Overflow in 5 Years**			**No Terraces**	**Critical**	**Ideal**
Terraces adequacy	TA	<2 times TC = 1	2 or 3 times TC = 0.5	>3 times TC = 0	TA = 0	0.5	1

Red = Management needs improvement; Green = Good management.

- Conservation efficiency–CE

In addition to terracing, other factors may be affecting erosion and runoff. In the region, downhill seeding and soil compaction are factors that facilitate these processes, so their presence or absence influences soil conservation. In addition, other factors related to conservation may be present, so the presence or absence of visible signs of erosion should also be used to obtain an indicator of the state of soil conservation. Table 6 presents the indicator and how to calculate it.

Table 6. Conservation efficiency indicator calculation.

Conservation Practices									
Indicator	**Ab**	**Input Data**				**Base**	**Formula**	**Critical**	**Ideal**
Conservation efficiency	CE	Operations at level	Absence of visible signs of erosion	Uncompressed headboards	Uncompacted crop	4 = number of possible indicators	CE = ΣICi/4	0.5	1
		CEi = conservation indicator *i* Absent: CEi = 0 Present: CEi = 1							

Red = Management needs improvement; Green = Good management.

5.4. Plant Nutrition

Plant nutrition must be balanced to enable high crop yields, thus maximizing biomass production. At the same time, it is necessary to avoid excess application of nutrients, especially of phosphorus, to minimize the possibility of it being carried away by erosion and runoff into streams and Itaipu reservoir. In the western region of Paraná state, there is good availability of manure, whose use is beneficial to soil quality. However, this use should be accompanied by fertility management strategies involving soil sampling and, ideally, nutrient balance as a criterion for fertilizer application.

- Balanced nutrition–BN

Balanced nutrition was defined as the indicator of adequate crop nutrition in a no-till system, assessed by the presence or absence of best practices in plant nutrition-use of animal manure, application of chemical fertilizer and correctives based on soil analysis and balance of nutrients. Table 7 presents the indicator and how to calculate it.

Table 7. Balanced nutrition indicator calculation.

Plant Nutrition								
Indicator	**Ab**	**Input Data**			**Base**	**Formula**	**Critical**	**Ideal**
Balanced nutrition	BN	Manuer use	Fertility management	Nutrient balace	3 = number of possible indicators	BN = ΣINi/3	0.3	1
		INi = nutrition indicator *i* Absent: INi = 0 Present: INi = 1						

Red = Management needs improvement; Green = Good management.

5.5. Farmer's History

In addition to the percentage of area managed with no-till by the producer, the time that the farmer uses the technology in most cases is directly proportional to the quality of the production system. The longer the SPD is in use, the better the quality of the system should be. Through this indicator, an evaluation of the producer's commitment to avoid the main cause of technology regression is attributed, which is to carry out soil preparation again with tillage.

- Adoption Time–AT

This indicator is evaluated by the percentage of the land area being used with tillage and the proportion of the time the producer practices the SPD in relation to the longest time identified in the region, to regionalize the index and adapt to different locally adhered cropping cultures. Table 8 presents the indicator and how to calculate it.

Table 8. Adoption time indicator calculation.

Farmer's History						
Indicator	**Ab**	**Input Data**	**Base**	**Formula**	**Critical**	**Ideal**
Adoption time	AT	T = Time practicing NT (years)	22 = longest SPD practicing time identified regionally	HC = T/22	0.3	0.6

Red = Management needs improvement; Green = Good management.

6. Application of the Consolidated Questionnaire

When applying the questionnaire, the field technician registers with a GPS device the geographic location of the farm property and of the production plots that are subject to evaluation of the quality of the no-till system.

The field information entered in the computational system and developed by the CIH/FPTI (CTM/IQP) feeds the program's database which, through the algorithm proposed by the methodology, calculates the six indicators and totals the IQP score, issuing a report called Evaluation of the Quality of the No-Till System.

This report summarizes the information computed through the diagnosis by providing the scoring matrix in relation to the program indicators, the farmer's ranking position in relation to his micro-watershed neighbors and with the producers of the other micro-watersheds considered (all located in the Paraná 3 watershed). The report then describes the strengths and the items to be improved by each of the farmers with government support to set up a continuous improvement plan such as the four phases of the Plan-Do-Check-Act (PDCA) Cycle [35] as follows.

- P (plan): selection of a process, activity or machine that needs improvement and elaboration of clear and executable measures, always aimed at obtaining the expected results.
- D (do): implementation of the prepared plan, and monitoring of its progress.
- C (check): analysis of the results obtained with the execution of the plan and, if necessary, re-evaluation of the plan.
- A (act): if successful, the new process is documented and becomes a new standard.

Based on this information and the suggestions from field technicians, the report ends with the establishment of actions to improve the quality of the no-till system, called "Attitudes Agreement". The PDCA Cycle, also known as Shewart Cycle, Quality Cycle or Deming Cycle, is a methodology whose basic function is to aid in the diagnosis, analysis, and prognosis of organizational problems, being extremely useful for the solution of problems [35]. Few instruments are as effective in the search for improvement as this method of continuous improvement, considering that it leads to systematic actions that speed up the achievement of better results to guarantee the survival and growth of organizations [36].

7. Results and Discussion

7.1. IQP Results

In the first half of 2010, the CAB program field team applied the Consolidated Questionnaire to the plots of the producers in the monitoring group in the six micro-watersheds. The field data released on the Quality no-till Technical Register platform provided by the CIH/FPTI generated the scores for each indicator and, finally, the IQP was calculated for 25 farmers (Table 9).

Table 9. Results of IQP at farm scale, for 25 farmers interviewed [22].

Farmer	Watershed	Indicators								IQP	Classification	
		RI	RD	RP	TF	TA	CE	BN	AT		Watershed	General
Renato Alegretti	Pacuri	0.89	1.00	0.83	1.00	0.50	0.75	1.00	0.59	8.40	2	7
Rudi Bonato	Pacuri	0.67	0.50	0.50	0.42	0.50	0.75	0.67	0.82	5.90	4	22
Cleto	Pacuri	1.00	0.75	1.00	1.00	1.00	1.00	0.67	0.59	8.90	1	3
Walmor Shoemann	Pacuri	0.78	0.75	0.67	0.75	0.50	0.50	0.67	0.68	6.80	3	19
Ademir Neufeld	Ajuricaba	0.78	0.75	0.50	0.42	0.00	0.50	0.67	0.36	5.20	4	24
Vilson Strach	Ajuricaba	0.78	0.75	0.67	1.00	0.00	0.75	0.67	0.68	6.90	3	18
Odacir Rupulo	Ajuricaba	0.89	0.50	0.83	1.00	0.50	1.00	0.67	0.68	7.70	2	10
Eugenio Wolfer	Ajuricaba	1.00	0.25	1.00	1.00	1.00	0.75	0.67	0.50	7.80	1	8
Helio Luiz Vogt	Facão Torto	0.67	0.50	0.67	1.00	1.00	1.00	0.67	0.36	7.30	2	14
Marcos Strach	Facão Torto	0.89	1.00	0.67	0.75	0.50	0.75	0.67	0.68	7.60	1	11
Paulo Back	Facão Torto	0.67	0.50	1.00	0.00	1.00	1.00	0.33	0.50	6.10	4	21
Carlos Gallas	Facão Torto	0.67	0.50	0.50	1.00	1.00	0.75	0.67	0.50	6.90	3	17
Aquiles Orlando	Toledo	1.00	1.00	1.00	1.00	1.00	1.00	0.67	1.00	9.70	1	1
Celson Isoton	Toledo	0.78	0.75	1.00	1.00	1.00	1.00	0.67	1.00	9.30	2	2
Geraldo Weicheimer	Toledo	0.78	1.00	0.83	0.75	1.00	1.00	0.67	0.91	8.60	4	5
Gilberto Orlando	Toledo	0.78	0.75	0.67	1.00	0.50	0.75	0.67	0.73	7.40	7	13
Marcos Lucini	Toledo	0.78	0.75	0.67	1.00	1.00	0.50	0.67	0.82	7.80	5	9
Natalicio Capeletti	Toledo	0.89	1.00	0.67	1.00	1.00	1.00	0.67	0.68	8.70	3	4
Roque Lucini	Toledo	0.67	0.50	0.50	1.00	1.00	1.00	0.67	0.80	7.50	6	12
Edson Franz	Mineira	0.78	1.00	0.50	1.00	0.50	0.75	0.33	0.68	7.20	1	16
Artur Avila	Mineira	0.89	0.75	0.17	0.42	0.00	0.75	0.67	0.05	4.80	3	25
Osmar Rechi	Mineira	0.67	0.75	0.50	0.75	0.00	0.50	0.67	0.36	5.50	2	23
Milton Dillmann	Buriti	0.78	0.50	0.67	1.00	0.50	1.00	0.67	0.68	7.30	2	15
Ilario Wendung	Buriti	0.89	0.75	0.83	1.00	1.00	1.00	0.67	0.59	8.50	1	6
Valter Engelmann	Buriti	0.89	0.75	0.50	0.80	0.50	0.50	0.67	0.59	6.70	3	20

Red = Management needs improvement; Green = Good management.

The IQP scores showed a wide amplitude, with the score of 4.8 being the lowest value and the score of 9.7 being the highest, indicating that it is an index capable of clearly differentiating the quality of the no-till system practiced by the farmers. The most frequent indicator of critical cases is CT, with 52%. This suggests that terracing issues should be prioritized by the CAB program in the project's micro-catchments. Then, the DR and PR indicators appear as critical in 32% of the cases, demonstrating that the diversity of crops in rotation and the persistence of the straw and stubble biomass generated by the no-till system also deserve attention for improvement. This quick analysis demonstrates the usefulness of indicators to guide the planning of extension actions aimed at mitigating critical levels and increasing the Quality of the no-till System [22].

Roloff et al. [22] statistically studied the results of the IQP model at farm scale (Table 9) and compared the scores with parameters of soil analyses from the assessed croplands. He concluded that there were good correlations between the index and soil fertility. While being of a preliminary nature, these results suggest that the IQP is a valid index from an output point of view. They also demonstrate that the IQP model can pinpoint practices that need to be targeted to improve the quality of a no-till system and hence its environmental services within the watershed.

7.2. Relationship between IQP and Soil Organic Matter

No-till CA systems are known to improve soil organic matter, which enhances soil health and functions, and crop productivity performance. As expected, the IQP showed a close relationship to soil organic matter of the top soil layer (0–10 cm depth), with an R^2 of 0.60 (n = 23, 2 farms were erased for not consistent values) (Figure 5). Thus, the index has a valuable ability to reflect soil organic matter differences, improvement, and conservation.

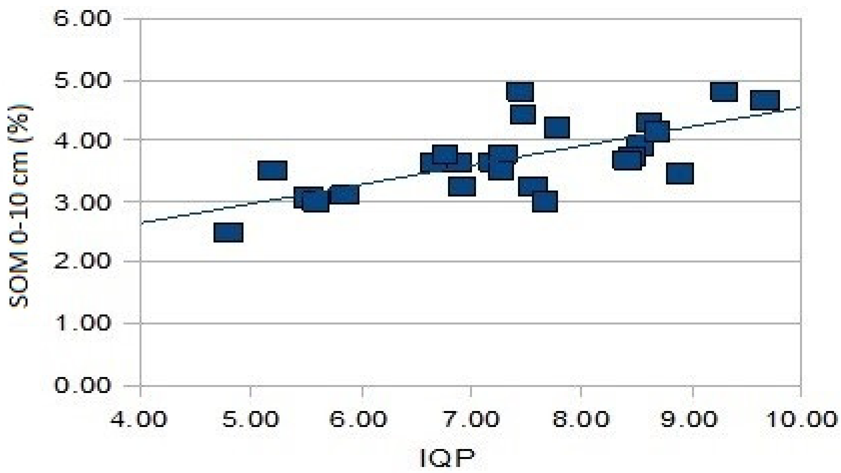

Figure 5. IQP and soil organic matter content [22].

Furthermore, Nunes [37], in analyzing correlations between IQP and soil parameters, concluded that soil organic matter contents agree with better quality of a no-till system assessed by the IQP, as well as with the adoption of the CA system by the farmer.

Martins et al. [38], within the scope of Embrapa's Living Soil Project, applied the IQP methodology to 19 producers, from 21 plots distributed in 12 micro-watersheds in five Brazilian states. They concluded that IQP is a good qualifying tool for management, a motivating tool for changes and adoption of sustainable agricultural practices and can also be used as a guide for policies to promote conservation programs, encouraging users to gradually establish the no-till CA System comprising the practical application of the recommended three interlinked principles.

7.3. Soil Erosion and Water Quality

Water quality is affected by sediment and agrochemical loads. Many studies in Brazil have shown that CA-based land use in the Paraná 3 watershed have resulted in drastically reduced soil erosion. In some cases, erosion is reduced to negligible levels [15,39–46]. This can be seen from the colour of water in the water courses, in the Paraná River, in the Itaipu reservoir, and in the water passing through the dam. Most studies, including longitudinal studies, show that water draining into the Itaipu reservoir is less polluted with agrochemicals, carries much less sediment, and has a greater transparency [15,46]. An extension of the working life of Itaipu dam, from the original 60 years to 350 years now [47], is a major result of this. However, studies also show that much needs to be done in terms of maintaining the various soil and water conservation practices to continue to keep water pollution from various sources to a minimum [48]. This is a key objective of IB, and their wide range of cross-sectoral programs.

The no-till system, or conservation agriculture quality assessment methodology, developed within the Cultivating Good Water Program makes farmers more autonomous in their decision-making through self-assessment based on field observations and indirect assessments, helping them to reduce inputs (especially fertilizers) and improve their productivity in terms of use efficiency and biological production and profit. This simultaneously contributes to reducing or minimizing runoff and soil surface erosion and the leaching of solids and pollutants such as nitrogen and phosphorus into waterways, thus reducing eutrophication that generates greenhouse gases emissions and larger drinking water treatment costs for urban populations. It is also important to note that the greater infiltration into the soil provided by a well-managed CA system contributes very significantly to the recharge of aquifers and to the regulated flow of good quality water in the Paraná 3 watershed rivers that supply water to the Itaipu dam.

7.4. Productivity and Economic Benefits

According to Telles et al. [16], some form of CA is practiced in 89% of the Paraná 3 watershed. Fourteen out of the 29 Paraná 3 watershed municipalities use CA in more than 91% of areas dedicated to temporary crops. These municipalities are mainly located in the central region of the watershed. The area dedicated to annual crops managed through CA ranges from 71–90% in 10 municipalities, from 51–70% in three, and from 38–50% in two. The quality of CA varies across different areas and there is also variation in the adoption of other conservation practices for land stabilization, such as contour bunding and terracing. However, as a result of the watershed-scale adoption of CA, the Paraná 3 watershed has become known for its high agricultural productivity with small-scale and large-scale farmers using modern, mechanized, intensive and highly technical systems. Small-scale farmers have access to affordable no-till seeding and spraying services. The watershed is also known for its equitable community-based rural and agricultural development which has benefitted participating farmers, small and large-scale, as well as the watershed's non-agricultural population.

Through the adoption of CA, crop yields have shown continued increases. Figures 6 and 7 show soybean and maize yields from 1996 to 2018. Since 1996, there have been approximate 40% increases in soybean yields and about 70% in maize yields. There has also been a 30–50% decrease in fertilizer use for both crops, as biological forms of nutrient pools increase in the soil as a result of more soil organic matter.

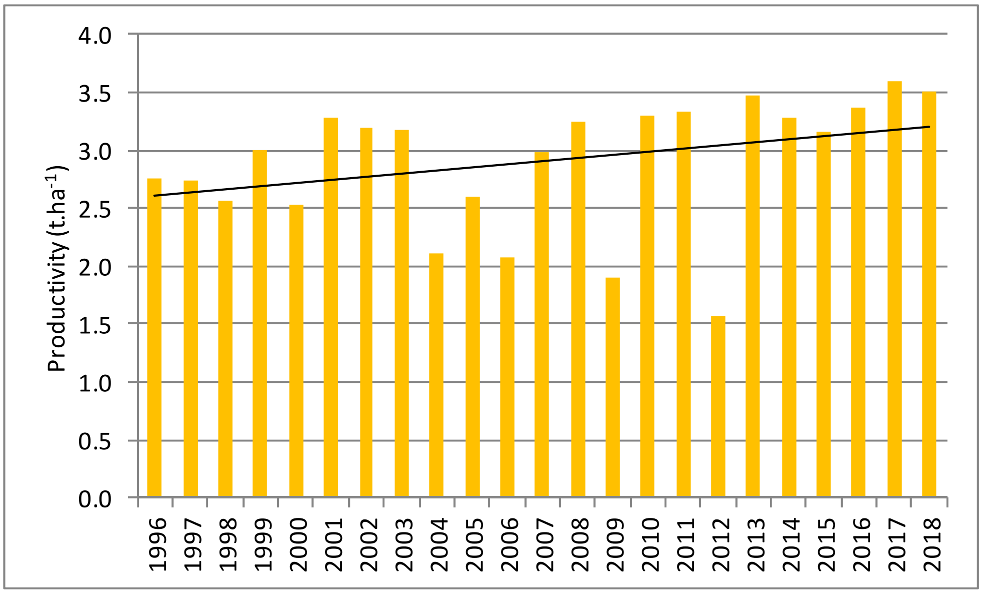

Figure 6. Mean soybean productivity in the Paraná 3 watershed, IBGE [49].

The economic impact of CA adoption and improving its performance benefitted small and large farms in the Paraná 3 watershed. It was shown that over a ten-year period, CA farmers were able to increase their gross margins and incomes, whereas non-CA farmers became loss-making operations as land degradation and erosion continued due to intensive tillage [38–45]. The adoption and improvement of CA systems was a grand scale, technological revolution in Brazil, including in the Paraná state. A break though was achieved by FEBRAPDP when it partnered with the seeding equipment industry and encouraged the manufacture of no-till seeders for all farm sizes, including smallholders using animal traction, at costs compatible with their realities.

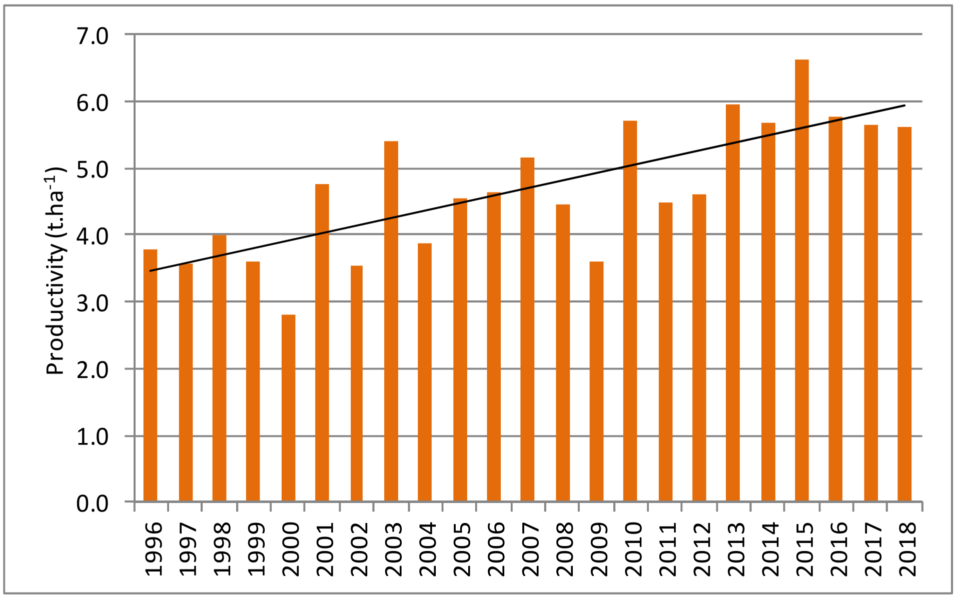

Figure 7. Mean maize productivity in the Paraná 3 watershed, IBGE [49].

7.5. Award for CAB Program

The CAB program was awarded by UN-Water "Water for Life" Best Practices Award in 2015. The award was established by UN-Water in 2011, marking the mid-term of the decade. The award aims to acknowledge and promote efforts to fulfill international commitments made on water and sanitation related issues by 2015, by recognizing outstanding best practices that can ensure sustainable long-term management of water resources and help achieve the water and sanitation targets of the Millennium Development Goals (MDG), Agenda 21 and the Johannesburg Plan of Implementation. CAB is a systemic program for watershed management and development based on civil society participation, where water is the backbone for a series of actions, with the objective to fight land degradation, poverty, and climate change. It represents a new way to substitute old habits with sustainable and participative management practices focused on those territories where natural resources are threatened by agricultural activities. It works with an awareness plan composed of 60 actions, which to date has enabled the following main achievements: recuperation of 200 micro-watersheds in the region, upgraded water quantity and quality, reduced soil erosion, improved life quality and social insertion of local people, reforestation of riversides, increased nature conservation and a participative water management promoting water stewardship and sustainable land management [50].

8. Conclusions

The IQP method presented in this article showed the benefit of supporting farmers in a state of transition to better conservation of soil and water resources and to mobilize greater productivity to raise income and quality of life. By building a system of indicators in a participatory manner, which responds to the principles of CA system, farmers can better assess the sustainability and efficiency of their production system considered in a holistic way. They can follow the evolution of IQP indicators over time in order to see their progress towards better performance. The tool is also a support for dialogue between local stakeholders on this subject by applying standardized and objective assessment and evaluation criteria. The application of the IQP model on farms in the Paraná 3 watershed has made it possible to develop production practices towards greater productivity, economic, social and ecological sustainability. The IQP tool opens up prospects for transferring the approach, with possible adaptations, to other areas in the world concerned with soil and water protection based on the practice of the alternate no-till CA system.

Author Contributions: All authors contributed to original draft preparation, and review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: This work was carried out with the technical support of the Coordination for the Improvement of Higher Education Personnel—Brazil (CAPES). Ivo Mello also expresses his gratitude for academic training and research support provided by the Professional Master's Program of the National Network in the Management and Regulation of Water Resources—ProfÁgua, CAPES/ANA Project AUXPE No. 2717/2015.

Conflicts of Interest: The authors declare no conflict of interest.

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