soil systems

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Review

Strategies and Public Policies for Soil and Water Conservation and Food Production in Brazil

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Abstract: There is an urgent demand to change our intensive crop production systems, replacing them with soil use and management systems that recover, preserve, or improve soil health and are environmentally sustainable, producing healthy and good-quality food. In this work, we compile and present strategies and public policies aimed toward soil and water conservation and food production in Brazil. The results presented may help Brazilian farmers adopt practices to recover, maintain, or improve soil health and politicians to create or modify public policies for healthy soil and food, without the necessity of increasing agricultural areas. Food insecurity was also addressed, with family farming playing an important role in food production and decreasing food insecurity. But these challenges need the combined efforts and engagement of the whole society.

Keywords: soil health; food insecurity; soil degradation; family farming; soil conservation practices; systemic perspective; multiple soil classes

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1. Introduction

Soil is a natural resource integrated within the environment; together with water, it is another resource of great importance to human survival. The inadequate use of these resources or their exploitation without the necessary care and attention may result in negative impacts such as soil compaction, soil erosion, and water pollution, which reflect negatively on the environment and human life.

Despite the vital importance of soil as a foundation for terrestrial life and the sustainability of humans, it has become increasingly threatened by excessive tillage, limited crop rotations, poor irrigation management, and contaminants [1]. Current crop production used in the intensive conventional system is not sustainable due to the high reliance on non-renewable resources and is likely to decline in the future when essential input becomes too expensive and/or unavailable [2].

There is an urgent demand to change our intensive crop production systems, replacing them with soil use and management systems that recover, preserve, or improve soil quality and are environmentally sustainable, producing healthy and good-quality food. It is worth highlighting the urgency of adopting measures to increase soil productivity for an area and recover degraded areas for food production, consequently reducing deforestation, which leads to soil and environmental degradation.

The data from Projeto MapBiomas [3] expose a loss of native vegetation from 1985 to 2021 in all Brazilian biomes (Figure 1) and a significant replacement of native vegetation for planted pastures (Figure 2). It is important to highlight that Figure 2 presents the planted pastures, but the total area occupied with livestock also includes 46 Mha of natural fields and 45 Mha of agriculture and livestock mosaics [4].

Despite the advance of livestock in the Brazilian biomes over the last few years, data from 2020 indicated that 47.7% of pastures were not degraded, while 38% had an intermediate level of degradation and 14.3% were severely degraded [4].

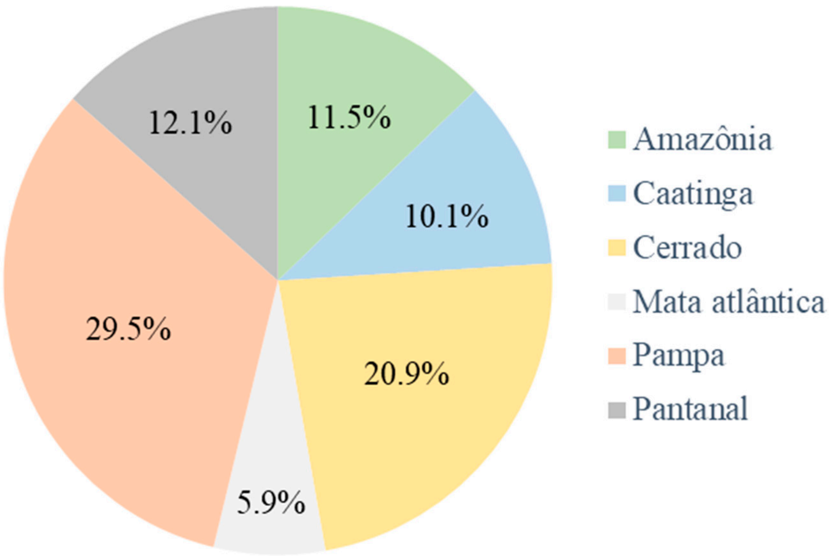

Figure 1. Loss of native vegetation from 1985 to 2021, according to Brazilian biomes. Source: data from Projeto MapBiomas [3].

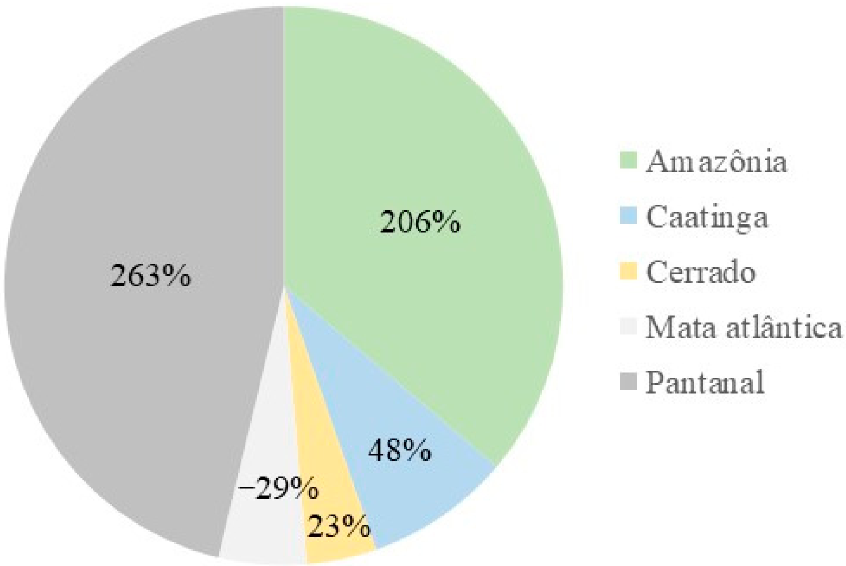

Figure 2. Evolution of planted pasture areas from 1985 to 2020, according to Brazilian biomes. Source: data from Projeto MapBiomas [4].

Brazil is a country with a significant area used for agriculture, and with climatic conditions and soil diversity that favor a variety of crops. Despite this, the data from PENSSAN [5] indicate that 55.2% of the Brazilian population has food insecurity, which represents 116.7 million people experiencing some level of food insecurity, 43.4 million who do not have enough food, and 19 million who are facing hunger, despite being the largest producers and exporters of soybean (50% share), coffee (33% share), orange juice (75% share), sugar (36% share), chicken meat (32% share and the third largest producer), and cow meat (24% share and the second largest producer) [6]. Food insecurity has increased significantly in Brazil over the years, with severe food insecurity at 1.9, 1.6, 7.3, and 9.9%, respectively, in the years 2014–2016, 2017–2019, 2019–2021, and 2020–2022, and 18.3, 20.6, 28.8, and 32.8% of people experiencing moderate to severe food insecurity for these same years; it predominantly occurs in women rather than in men [7]. In the year 2022, Brazil joined the hunger map, with the worst rates of food insecurity seen in the last few years.

Politicians, researchers, rural extension agents, professionals of different areas, farmers, and all people interested have the opportunity to face the challenge of recovering the degraded areas and soil health to produce food, having the advantage of the climate [8] and soil [9] diversity of Brazilian territory to produce a wide variety of food. In addition, it is important to ensure adequate food distribution so that the population has fair and equal access.

In that regard, Brazil has some public policies and programs regarding food access, such as Law nº 8080, from 19 September 1990 [10], regarding the conditions to promote, protect, and recover the health, the organization, and the functioning of the corresponding services; Law nº 11,947, from 16 June 2009 [11], regarding school feeding; and the most recent Decree nº 11,820, from 12 December 2023, that establishes the National Politician of Food Supply and order the National Plan of Food Supply [12], the National Politician of Feeding and Nutrition [13], the successful Program Zero Hunger created in 2003 [14] aiming to combat food insecurity by improving the income level of poor people, because according to the author, the hunger problem in Brazil is more associated with insufficient income than with a lack of supply or food scarcity, and the most recent Plan Brazil Without Hunger [15] aiming to promote food and nutritional security and combat hunger in Brazil. In 2006, the National System of Food and Nutritional Security [16] was created to ensure the human right to food. But it is important to contextualize that food policies can change over the years [17], especially considering the government and its priorities. And this is clear when comparing food insecurity in the period 2019–2022 and the years before.

To face all those challenges, it is essential to look at the natural resources in an integrated way and as dependent on each other, considering humans as an integral part of this environment, not only as being dependent on the natural resources but as agents of transformation. In this way, we are responsible for taking care of the environment and taking the necessary individual and collective actions to preserve it. And public policies play an important role in environmental preservation because they define limits and guidelines for the better use of natural resources. An example is Law nº 12,651 [18], which promotes the protection of native vegetation. It is necessary to better integrate soil ecology and agronomic crop production with human health, food/nutrition science, and genetics to enhance bacterial and fungal sequencing capabilities, metagenomics, and the subsequent analysis and interpretation [19].

Considering the abovementioned data, the objective of this work was to compile and present strategies and public policies aimed toward soil and water conservation and food production in Brazil.

2. Healthy Soil for Healthy Food and People

Considering the direct effects of soil or its constituents on human health, soil contains many infectious organisms that may enter the human body through ingestion, inhalation, or absorption, but it also provides organisms on which antibiotics are based, while indirect effects of soil arise from the quantity and quality of food that humans consume [20].

The World Health Organization [21] points out that soil, agriculture, nutrition, and food security are interconnected with health. The connection of soil with nutrient deficiencies in crops, food, and humans is generally not so conspicuous, and this is perplexing since the primary source of the nutrients that we all need to thrive are in soils. The nutrients that we find in animal foods come from plants or plant-based foods, which obtain their nutrients from soils; the nutritional quality of food is directly related to the quality and health of soils [22].

At this point, it is important to define soil health. Janzen et al. [23] define it as "the vitality of a soil in sustaining the socio-ecological functions of its enfolding land". Meanwhile, Friedrichsen et al. [24] reference that soil health assessments need to consider a holistic plurality of values as soil health and its effects on human well-being transform the food system to be equitable, just, healthy, and sustainable. Lehmann et al. [25] define soil health as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans, and connects agricultural and soil science to policy, stakeholder needs and sustainable supply chain management", and the definition of soil health according to the Intergovernmental Technical Panel on Soil [26] is "the ability of the soil to sustain the productivity, diversity, and environmental services of terrestrial ecosystems".

Karlen et al. [27] cite the challenges of food security and climate change and the need for studies focusing on soil and tillage based on developing sustainable agricultural practices and environmental protection. Analyzing the publications on soil health from 1999 to 2018, Liu et al. [28] identify that research is expanding beyond the knowledge of soil production, soil health indicators, and soil pollution, and involving the comprehension of the soil ecosystem. Meanwhile, Lehmann et al. [25] report that the focus has always been on crop production, but actually, soil health also includes the role of soil in water quality, climate change, and human health.

It is possible to verify the increase in the importance and position of soil health, actually including a holistic view, given the importance of the soil not only to food production but also as a source of food quality, health in people, and environmental services. And it is important to include the social and political role of soil.

Regarding soil as a source of nutrients, nitrogen (N), phosphorus (P), and potassium (K) are nutrients required in large amounts by plants (macronutrients), together with calcium (Ca), magnesium (Mg), and sulfur (S), while iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl) are required in lesser quantities (micronutrients), but all are essential nutrients for the nutrition of plants, and the solid soil phase is the main nutrient reservoir of essential nutrients that are taken up by plants only in mineral form from the soil solution [22]. While more than 22 mineral elements are required for humans, which can be obtained through an adequate diet [29], the diets of populations subsisting on cereals or inhabiting regions where soil mineral imbalances occur often lack Fe, Zn, Ca, Mg, Cu, I, or Se [29]. Nutrient-poor soils are unable to produce food with all of the nutrients required for a healthy person [30].

If the targeted nutrients are not available in the soil, even the biofortified crop cultivars will have low nutrient contents available, and this may adversely affect human and animal health [31]. Other ways to affect human health are soil contamination, either naturally or through anthropogenic activities, with chemical elements and substances that are in toxic amounts when ingested or inhaled [32]. The presence of toxic metals in fertilizers has been reported in the major food-producing countries, like the United States, China, and Brazil [33].

For any essential element, there is an optimal range of concentration in humans; falling below this optimal range results in deficiency, whereas concentrations above the optimal range create toxicity. The level of any essential element in humans can be deficient, adequate, or toxic depending on the concentrations of these elements in the soil and the degree of exposure [32]. There is a deficit of mineral micronutrients in global food systems, known as 'hidden hunger', especially in the global south [34]. The natural levels of zinc in plants, animals, and humans are related to zinc's level in the soil of agricultural areas. Growing plants with the important functions of introducing this micronutrient into the food chain, therefore by introducing zinc into the soil and/or leaf fertilizer, and those that are associated with cultivars that accumulate it in the grains may result in a decrease in the zinc deficit in the human organism [35]. The fertility in Brazilian soil is generally low, while the majority of agricultural crops cultivated in Brazil are highly nutrient-demanding, requiring procedures and techniques to improve yield without environmental impact [36].

The World Health Organization [21] exposes that poor diets with excessive fat, refined carbohydrate intake, and low fruit and vegetable intake cause obesity and contribute to a large proportion of non-communicable diseases in the World Health Organization European Region; globally, around 45% of deaths in children under 5 years of age are linked to undernutrition. Accelerating decreases in soil quality and biodiversity will affect access to food and its dietary diversity and nutritional value. Evidence also suggests that dietary diversity plays an important role in the gut microbiome, which influences metabolism and other health indices. Specifically, in Brazil, the diversity of the climate and soil makes it possible to produce a diversity of food, supporting dietary diversity and reinforcing the need to improve soil health to meet dietary demands. And this represents a chain, where healthy soil will attend to ecosystem services and produce a healthy environment for food and people, resulting in fewer illnesses and a smaller burden on the healthcare system (Figure 3).

Figure 3. The chain of benefits as a result of healthy soil.

Studies have shown that there are nutritional composition differences between plant foods cultivated in organic systems and conventional ones. Overall, organic plant foods contain higher concentrations of nutritionally desirable compounds (phenolics, other antioxidants, and/or mineral micronutrients) and lower concentrations of nutritionally undesirable chemicals (pesticide residues, cadmium, and/or Fusarium mycotoxins) [2]. To support this, a meta-analysis based on 343 peer-reviewed publications comparing organic and non-organic crops/crop-based foods verified the frequency of occurrences of pesticide residues to be four times higher in conventional crops, which also contained significantly higher concentrations of the toxic metal Cd [37]. Evidence has shown that many technologies (monoculture/shorter rotations, mineral N and P fertilizers, pesticides, and short-straw cereal varieties) available to farmers due to the green revolution have had negative effects on both crop health and the nutritional quality and/or safety of crops [2].

3. Factors Influencing Soil Degradation and the Need to Take Care of the Soil

Why do we need to take care of the soil? This question is simple to answer, but very encompassing because the soil is a representative and important natural resource that humans depend on to survive. Soil is the base of life; it sustains buildings, is the substrate for plants, is responsible for feeding humans and animals, maintains the water flow to recharge aquifers, holds water and oxygen for plants and organisms, creates employment and income, and also has a social function through the distribution of land to rural settlements, for example (Figure 4). In this section, we want to present the impacts of soil degradation and the need to take care of soil.

One third of the world's soil resources have been degraded, and within 60 years, the remaining topsoil could become unproductive if current rates of degradation continue [38]. In that regard, agriculture practices may harm the soil due to compaction, acidification, a loss of soil organic matter, and soil erosion, degrading the soil's physical properties, increasing nutrient loss, and reshaping fields, ultimately impacting productivity and environmental outcomes [1].

One of the negative impacts of inadequate soil use is compaction, which negatively influences soil structure in terms of properties such as bulk density, porosity, resistance of soil to penetration, and hydraulic conductivity [39,40], affecting nutrient uptake by plants, such as phosphorus and potassium, which are absorbed by plants through diffusion [41], and root growth, compromising crop yield [40,42–44]. Soil that is not compacted enables deeper root growth by searching for water and nutrients, while soil compaction limits root growth, hampering the aerial part of the plant and decreasing yield (Figure 5).

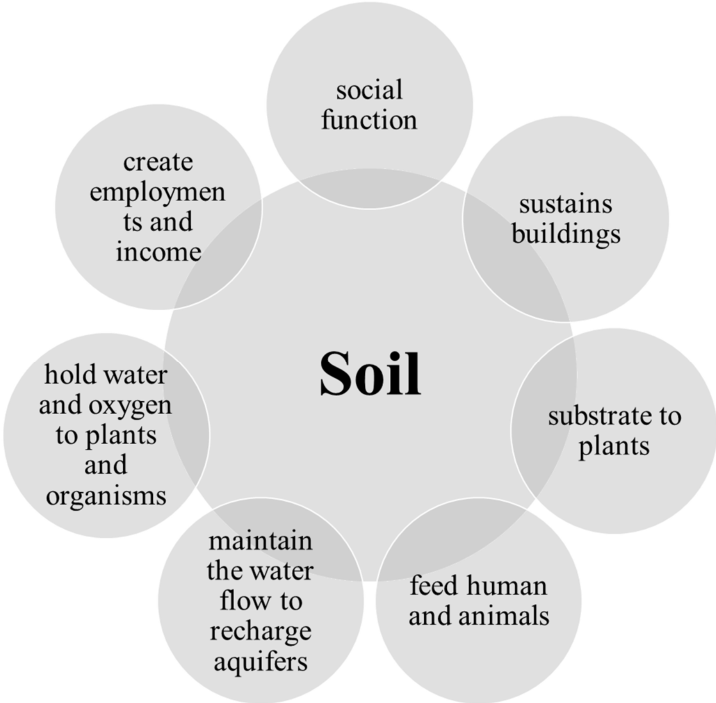

Figure 4. Some of soil's functions in sustaining life.

(**a**) (**b**)

Figure 5. Soybean root growing in soil not compacted (**a**) and compacted (**b**).

Soil porosity and hydraulic conductivity are ecological and environmental properties because they exchange gas with the atmosphere [45] and influence surface runoff and erosion [46], and soil compaction may negatively affect these ecological properties [39,42]. Furthermore, additional soil compaction causes economic losses based on yield decreases [40,47]. Strategies to reduce soil compaction and ameliorate compacted soils to maximize crop yield and develop crops with roots that penetrate the compacted soil layer to access water and nutrients are necessary [48].

Economic losses from soil compaction are not only associated with crop yield (on-site costs), but they are also associated with an increased incidence of flooding (off-site costs), which is estimated to be of the order of magnitude of several hundred M€ yr^{-1} in Sweden, for example [49].

Soil erosion and compaction are the two most important agents of soil degradation and are responsible for decreased soil health. The soil formation rate is lower than the soil erosion rate from agricultural fields, which is estimated to be currently from 10 to 20 times (no tillage) to more than 100 times (conventional tillage) higher, while the current levels of global warming are associated with moderate risks from increased soil erosion [50].

Runoff and soil erosion are usually favored by (i) the location on hill slopes and disposition of rows along the slope, which makes runoff and erosion stronger [51]; (ii) the maintenance of bare soil between rows by mechanical or chemical weeding [52–54]; and (iii) intense machinery traffic along fixed paths, which promotes soil compaction and reduces soil water-holding capacity and water infiltration [55].

In bare soil under avocado (*Persea americana* Mill) hillside orchards, higher sediment losses and herbicide residues in water runoff were verified [53], which means an off-site impact of erosion is able to compromise the environment and human health. While the soil runoff in a new peach orchard is basically composed of the topsoil of the ridges, generally enriched with organic matter and nutrients, increasing mulching decreases the soil runoff [56].

In agricultural areas, the soil surface has organic matter, nutrients, seeds, fertilizers, and agrochemicals, and depending on soil runoff intensity, these materials may be carried down in the relief and may pollute and degrade soil and rivers, decrease the soil's capacity to yield healthy plants, and increase costs of production due to increased input of fertilizers and interventions to reduce soil erosion [56–59]. Some studies in Brazil have shown that agricultural areas are the largest contributors of sediments to the rivers [60,61].

The cost of soil erosion in vineyard fields in Spain represented 6 and 26.1% of the annual intakes and 2.4 and 1.2% of the annual income from the sale of the grapes, which corresponded to soil erosion exportation of 14.9 kg ha^{-1} of N and 11.5 kg ha^{-1} of total P [62]. Meanwhile, in soil with the perennial crops of banana or banana–coffee, the cumulative cost of replacement of NPK losses was USD 16,663, 4404, and 442 ha^{-1} $year^{-1}$, corresponding to, respectively, 38.5, 6.6, and 0.87 Mg ha^{-1} $year^{-1}$ of soil loss [63]. Onesimus et al. [63] also observed that the total cost of replacing nutrients was higher (USD 15,451 ha^{-1} $year^{-1}$) in areas without conservation practices (terraces) compared to areas with terraces, equaling USD 6058 ha^{-1} $year^{-1}$.

By increasing straw mulching, the available nutrients P, K, Ca, and Mg decreased in the soil runoff by inter-rill erosion in a new peach orchard, and the cost to replace these nutrients via mineral fertilizer was USD 75.4 per hectare, considering the larger losses for no mulching, and USD 2.70 per hectare for 8 Mg ha^{-1} of oat straw mulching [56]. The cost to replace the available P, K, Ca, Mg, and S with mineral fertilizer was estimated at USD 0.75 per hectare in the least-eroded soil under no tillage and USD 1.88 per hectare in the most-eroded soil under conventional tillage, but the real cost of soil erosion could be larger when considering other costs such as fuel, fertilizer transportation, land depreciation, and environmental impacts [59].

Analyzing the costs of soil erosion is important, but it is difficult and complex because it involves direct and indirect questions, which may be difficult to quantify. For example, some arguments say that the economic impacts of soil erosion belong to society and that there is a need to implement policies to encourage the adoption of soil conservation practices. Nevertheless, Alfsen et al. [64] posed the following question relative to the cost of soil erosion in Nicaragua: "If there is excessive soil erosion, why do the affected farmers not engage more heavily in soil conservation?". These authors also pointed out the slow process of soil degradation, resulting in small annual changes that are hard to verify when crop growth varies considerably due to management, disease, and rainfall. According to the authors, technological improvements, such as fertilizer and pesticide inputs, may hide the impact of soil degradation.

Soil erosion is a source of environmental, social, and economic issues, and can be considered a major setback for food security and a serious problem for sustainable development [65]. As observed, the cost of soil erosion due to a loss of nutrients is documented in the literature, but how great is the cost to the environment, soil, and human health due to soil erosion?

In areas containing annual crops, high concentrations of nutrients and predominantly silt and clay were verified in the soil runoff, which has a strong relation with particle size due to cation exchange capacity [59]. This sediment runoff to the rivers may contaminate the water resources and the aquatic biota [66–69], which could be consumed by people [70,71], or the water contaminated with pesticides may be used for crop irrigation [72] or distributed to residences for human consumption, as observed by Panis et al. [73] studying 127 grain-producing municipalities in Parana State, Brazil, which revealed contamination of drinking water and that contamination may increase the risk of cancer. In the Brazilian Amazon, pesticides were detected in aquatic ecosystems and sediments near a large zone of soybean production in the Santarém region [74], in the surface and ground waters, in drainage sediments in the indigenous lands surrounded by oil palm monoculture [75], and in aquatic and terrestrial ecosystems in the Brazilian Pampa [76].

Soil and water are of vital importance to humans; they are integrated with each other and the environment. In this way, their conscious use aiming for a reduced negative impact is necessary as part of a sustainable environment. Either by soil compaction or erosion, we can see that they cause economic losses due to crop yield decreases and fertilizer losses, for example, but soil degradation, water contamination, and environmental impacts are also observed. That is why we should take care of soil health and engage all of society in this task.

4. Strategies and Public Policies for Soil and Water Conservation and Food Production

Practices aimed toward soil and water conservation are available, but sometimes, they are not adopted or it is necessary to adopt a set of practices to effectively recover, maintain, or improve the soil.

Although conservation agricultural practices, such as reduced tillage, have been adopted, it was verified that most of the sediment deposited in 32 lakes in the intensively agricultural region of the Midwestern United States was from the last 50 years and reflected agricultural intensification in that region rather than land clearance or the predominance of agricultural lands. Heathcote et al. [77] suggested that traditional soil conservation programs have not decelerated downstream losses in the face of intensive agricultural practices, reinforcing the necessity of new approaches to mitigate erosion and water degradation.

Strategies involving soil restoration based on the management of drought stress, soil infertility, and the deficiency of microelements can minimize the adverse effects of soil degradation on human health and well-being, and with the adoption of proven management options, global soil resources are adequate to meet the food and nutritional needs of the present and future population [78].

Based on the literature, we present in Table 1 some strategies that contribute to soil and water conservation.

Table 1. Strategies that contribute to soil and water conservation.

Strategies	Source
Agroecology or organic farming	[2,37,79,80]
No-tillage systems	[40,79,81,82]
Cover crops or mulching	[56,82–88]
Cropping system diversification	[81,87,89,90]
Keyline arrangement	[91,92]
Terracing such as dry-stone wall or earth bank terraces	[93–97]
Fertilization according to the soil analyses	[98]
Organic fertilizers	[79,99]
Increase soil organic matter	[39,55,100,101]
Avoid soil compaction	[40,102–104]
Avoid the use of pesticides	[37,105]
Consider the capacity of use and agricultural aptitude of land	[106]
Maintain the areas of permanent preservation and riparian vegetation	[107]

Under no-tillage conditions (Figure 6), due to a lack of soil mobilization, a more stable and porous structure can be formed, and newly formed pores and the rearrangement of soil particles can be preserved if operations are carried out with machines with low ground pressure [108]. Furthermore, the highest soil runoff rate was observed in a farm under conventional tillage conditions, while farms using no-tillage systems in the long term had the lowest rates [59].

(**a**) (**b**) (**c**) (**d**)

Figure 6. Peach orchard with spontaneous vegetation (**a**) and oat (*Avena sativa*) sown as cover crop in inter-rows (**b**); soybean under no-tillage conditions (**c**); agroecology system with corn (*Zea mays*), coffee (*Coffea arabica*), and banana (*Musa* spp.) (**d**).

Mulching or cover crops protect the soil against rainfall dropping directly onto the soil, reducing or eliminating soil displacement by splashing, increasing water infiltration, and reducing ponding and improving the ability to breakdown sediment transport [109–114] (Figure 6). Furthermore, with mulching increments, the available nutrients P, K, Ca, and Mg decreased in the soil runoff in a new peach orchard [56]. Other practices used together with straw mulching in peach orchards, such as the disposal of branches from the yearly pruning on the inter-rows, harvesting manually, and opting for using a compact tractor, contribute to avoiding soil compaction and probably soil erosion [115].

Measurements from paired farms across the United States indicated that regenerative farms that combined no tillage, cover crops, and diverse rotations produced crops with higher soil organic matter levels, soil health scores, and levels of certain vitamins, minerals, and phytochemicals compared with areas under conventional (synthetically fertilized and herbicide-treated) practices, and the study suggested that soil health has an underappreciated influence on nutrient density, particularly for phytochemicals which are not conventionally considered nutrients but are nonetheless relevant to chronic disease prevention [82].

Only 36.1% of Brazilian farmers do not adopt at least one conservation practice (Table 2), meaning it is necessary to increase the adoption of more than one practice and encourage the integration of complementary practices; this may be achieved through rural extension and by applying the findings from the research to the farms, working together with the farmers, and adopting the necessary perspective that soil and water conservation practices mean investment in the soil, environment, and healthy food and people.

Table 2. Conservation practices adopted by farmers in Brazil. Source: data from IBGE [116].

Practices	* Absolute Number	%
Level planting	480,428	7.8
Crop rotation	946,607	15.3
Fallow or soil resting	699,180	11.3
Protection and/or conservation of slopes	204,246	3.3
Recovery of riparia forest	122,507	2.0
Reforestation to protect river nascent	116,962	1.9
Stabilization of gully	39,629	0.6
Forest management	88,730	1.4
Other	1,245,991	20.2
None	2,224,000	36.1

* The same farm may have adopted different practices.

Of a total of 5,073,324 Brazilian farms, 64,690 farms, which represent 1%, practice organic farming, while 66% of the farmers do not use pesticides [116], which is an optimistic percentage considering the risk of pesticides to the environment [66–69,105] and to the farmers [117]. On the other hand, the practice of organic farming is low, despite the notion that organic farming or agroecology is good for farmers and consumers by facilitating healthy soil, food, and people.

In a review, Jat et al. [105] recognize that pesticides reduce the losses caused by pests and increase crops yield, but they describe the incorrect application of synthetic chemical fertilizers and pesticides as contaminating soil and water, as well as groundwater by leaching, while the use of persistent chemical pesticides negatively affects soil ecosystem services provided by microfauna and changes the soil properties, making an appeal for the rational use of the pesticides necessary. The microbial activity and bioavailability of the pesticide are the most important agents of degradation of these chemical molecules in the remediation of contaminated soils [118].

While one of our proposed strategies in this work is fertilization according to the soil analyses or the use of organic fertilizers, we see that 51.8% of the farmers generally do not make fertilization, while 11.6% make organic fertilization (Table 3). Soil fertilization, according to the recommendations in handbooks such as the "*Handbook of fertilizing and liming to Rio Grande do Sul and Santa Catarina States*" [98], is important to help the soil reach its higher potential to yield crops and avoid nutrient imbalance in the soil. For example, in many Indian soils, the continuous addition of micronutrient-free NPK fertilizers without adequate soil testing and indiscriminate use of irrigation water resulted in micronutrient and secondary nutrient deficiencies, creating nutrient imbalances in many agricultural fields [31].

Table 3. Fertilization practices adopted by farmers in Brazil. Source: data from IBGE [116].

Fertilization Practices	Absolute Number	%
Made fertilization	2,144,693	42.3
Made chemical fertilization	1,015,429	20.0
Made organic fertilization	590,834	11.6
Made chemical and organic fertilization	538,430	10.6
Did not make fertilization	290,2873	57.2
Generally does not make fertilization	2,626,577	51.8
Generally makes fertilization	276,296	5.4

Strategies to avoid additional compaction and degradation of the soil structure should consider the soil moisture when there are machinery traffic and animals trampling into the areas [103] and its load-bearing capacity [103,104]. Preventing and mitigating soil compaction is one of the strategies necessary to implement sustainable soil management to recover degraded soils and improve soil health, providing food and clean water, maintaining biodiversity, ensuring carbon sequestration, and increasing resilience to climate change [119].

The intensive use of the soil, without considering its capacity or aptitude for use and without using practices of soil and water conservation, can lead to negative impacts on the soil and the environment, and these practices should be implemented at the level of watersheds, considering their magnitude and importance in local, regional, and global processes [106].

Beyond the cited strategies, agroecology or organic farming systems are practices that aim to balance soil and food health and the environment. It is important to work from a systemic perspective to recover, maintain, or improve soil health, aiming for the integrated management of soil–water and plants through management practices that may directly or indirectly influence or address the demands related simultaneously to the physical, chemical, biological, and morphological soil properties.

From the systemic perspective, there is a better understanding of the interactions between different soil properties and the processes of soil health degradation, making it possible to search for better management strategies for soil, water, and plants and contributing to the building of more sustainable agroecosystems.

The practices that promote soil health include conservative agricultural practices such as balanced fertilization, crop rotation, organic matter management, integrated pest and disease management, and regular soil monitoring, which lead to protecting the soil from erosion, enhancing its quality, preserving its structure, increasing its water and nutrient retention capacity, promoting microbial biodiversity, and reducing reliance on chemical pesticides [120].

Despite the already well-known soil and water conservation practices, policies for a healthy soil, water, and food should be established nationally, but especially at a regional and local scale, considering land use, climate, soil characteristics, topography, and other regional and local specificities, and promoting the use of conservation practices.

In that regard, although sustainable agricultural practices have been promoted and adopted around the world, their benefits might be site-specific and cannot be generalized [84] because the magnitude of those effects on soil health and crop yield depends on the adopted cropping system, soil type, weather, topography, and other inherent factors [81,87].

We compiled in Table 4 some Brazilian public policies that contribute to soil and water conservation. Despite having policies since 1964, and programs at the national level, that contribute to soil conservation, some states also have their own policies aiming to promote soil health. At the national level, we can see relevant programs to contribute to soil and water conservation, such as the ABC Plan, PronaSolos, and the National Program for Watersheds and Soil Conservation in Agriculture.

Table 4. Public policies that contribute to soil and water conservation in Brazil.

Public Policies	Subject	Source
Law n° 4504, 30 November 1964	Provides the land statute and adopts other provisions	https://www.planalto.gov.br/ccivil_03/leis/l4504.htm (accessed on 23 February 2023)
Law n° 6225, 14 July 1975	Provides the discrimination, by the Ministry of Agriculture, of regions based on the mandatory execution of soil protection and erosion combatting plans and adopts other provisions	https://www.planalto.gov.br/ccivil_03/leis/l6225.htm (accessed on 23 February 2023)

Table 4. *Cont.*

Public Policies	Subject	Source
Law n° 6938, 31 August 1981	Establishes the National Environmental Policy, its purposes, and formulation mechanisms, and adopts other provisions	https://www.planalto.gov.br/ccivil_03/leis/l6938.htm (accessed on 23 February 2023)
Decree n° 94,076, 5 March 1987	Establishes the National Program for Watersheds and adopts other provisions	https://www.planalto.gov.br/ccivil_03/decreto/1980-1989/1985-1987/d94076.htm#:~:text=DECRETO%20No%2094.076,%20DE,Hidrogr%C3%A1ficas,%20e%20d%C3%A1%20outras%20provid%C3%AAncias (accessed on 23 February 2023)
Constitution of the Federative Republic of Brazil, 1988	Constitution of the Federative Republic of Brazil	https://www.planalto.gov.br/ccivil_03/constituicao/constituicao.htm (accessed on 23 February 2023)
Law n° 8171, 17 January 1991	Provides information about the agricultural policy	https://www.planalto.gov.br/ccivil_03/leis/l8171.htm (accessed on 23 February 2023)
Law nº 10,831, 23 December 2003	Provides organic agriculture policies and adopts other provisions	https://www.planalto.gov.br/ccivil_03/leis/2003/l10.831.htm (accessed on 23 February 2023)
Resolution nº 420, 28 December 2009	Provides guiding criteria and values for soil quality regarding the presence of chemical substances and establishes guidelines for the environmental management of areas contaminated by these substances as a result of anthropogenic activities	https://www.legisweb.com.br/legislacao/?id=111046 (accessed on 23 February 2023)
Law n° 12,389, 3 March 2011	Provides the establishment of the national agricultural limestone day	http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2011/lei/L12389.htm#:~:text=LEI%20N%C2%BA%2012.389,%20DE%203,Art (accessed on 23 February 2023)
Law nº 12,651, 25 May 2012	Provides guidelines for the protection of native vegetation	https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm (accessed on 23 February 2023)
Decree n° 7794, 20 August 2012	Establishes the national policy on agroecology and organic production	https://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/decreto/d7794.htm#:~:text=DECRETO%20N%C2%BA%207.794,%20DE%2020,vista%20o%20disposto%20no%20art (accessed on 23 February 2023)
Decree n° 9414, 19 June 2018	Establishes the national program for the survey and interpretation of soils in Brazil	https://www.planalto.gov.br/ccivil_03/_ato2015-2018/2018/decreto/d9414.htm (accessed on 23 February 2023)
National Program for the Survey and Interpretation of Soils in Brazil (PronaSolos)	Investigation, documentation, inventory, and interpretation of data of Brazilian soils	http://pronasolos.agenciazetta.ufla.br/ (accessed on 23 February 2023)
ABC Plan—Low Carbon Emission Agriculture	Responsible for the organization and planning of actions to be carried out for the adoption of sustainable production technologies, selected with the objective of responding to commitments to reduce greenhouse gas emissions in the agricultural sector	https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/plano-abc/plano-abc-agricultura-de-baixa-emissao-de-carbono (accessed on 23 February 2023)
National Program for Watersheds and Soil Conservation in Agriculture	Seeks to promote development in an integrated and sustainable way; with the rational use of natural resources, food production and the generation of jobs and income in rural areas are increased	https://www.gov.br/agricultura/pt-br/assuntos/sustentabilidade/plano-abc/programas-e-orientacoes (accessed on 23 February 2023)
Law n° 6115, 23 November 1992 (Mato Grosso state)	Provides guidelines for the conservation and preservation of soil resources and adopts other provisions	https://leisestaduais.com.br/mt/lei-ordinaria-n-6115-1992-mato-grosso-dispoe-sobre-conservacao-e-preservacao-do-recurso-solo-e-adota-outras-providencias (accessed on 23 February 2023)

Table 4. *Cont.*

Public Policies	Subject	Source
Law n° 12,596, 30 July 1997 (Minas Gerais state)	Provides guidelines for the occupation, use, management, and conservation of agricultural soil	https://agenciapeixevivo.org.br/wp-content/uploads/2010/02/images_arquivos_legislacaoambiental_AGRICULTURA_lei-estadual-n-12.596-1997.pdf (accessed on 23 February 2023)
Law n° 6171, 4 July 1988 (São Paulo state)	Provides guidelines for the use, conservation, and preservation of agricultural soil	https://www.defesa.agricultura.sp.gov.br/legislacoes/lei-n-6171-de-04-07-1988,321.html (accessed on 23 February 2023)
São Paulo state program of use, conservation, and preservation of agricultural soil (São Paulo state)	Inspection of the use, conservation, and preservation of agricultural soil, aiming to monitor agricultural areas in the São Paulo state with the aim of minimizing existing erosion processes	https://www.defesa.agricultura.sp.gov.br/www/programas/?/conservacao-e-preservacao-do-solo/programa-estadual-de-uso-conservacao-e-preservacao-do-solo-agricola/&cod=28 (accessed on 23 February 2023)
Law n° 8014, 14 December 1984 (Paraná state)	Establishes the preservation of agricultural soil and adopts other measures	https://leisestaduais.com.br/pr/lei-ordinaria-n-8014-1984-parana-dispoe-sobre-a-preservacao-do-solo-agricola-e-adota-outras-providencias (accessed on 23 February 2023)
Resolution n° 172, 03 September 2010 (Paraná state)	Establishes criteria for allocating terraces in the no-tillage system, according to technical guidelines from the Instituto Agronômico do Paraná-IAPAR	https://www.legisweb.com.br/legislacao/?id=144503 (accessed on 23 February 2023)
Decree n° 4966, 29 August 2016 (Paraná state)	Establishes the integrated soil and water conservation program in Paraná state and takes other measures	https://www.legisweb.com.br/legislacao/?id=327957#:~:text=Institui%20o%20Programa%20Integrado%20de,que%20lhe%20confere%20o%20art (accessed on 23 February 2023)
Law n° 9474, 20 December 1991 (Rio Grande do Sul state)	Establishes the preservation of agricultural soil and adopts other measures	https://ww3.al.rs.gov.br/filerepository/repLegis/arquivos/09.474.pdf (accessed on 23 February 2023)
Law n° 11,194, 13 July 1998 (Rio Grande do Sul state)	Establishes the Agricultural Green Seal in the Rio Grande do Sul state and adopts other measures	https://ww3.al.rs.gov.br/filerepository/repLegis/arquivos/11.194.pdf (accessed on 23 February 2023)
Law n° 11,520, 3 August 2000 (Rio Grande do Sul state)	Establishes the state environmental code of the Rio Grande do Sul state and adopts other measures	https://www.sema.rs.gov.br/upload/arquivos/201611/28093051-codigo-estadual-do-meio-ambiente.pdf (accessed on 23 February 2023)
Decree n° 52,751, 4 December 2015 (Rio Grande do Sul state)	Establish the soil and water conservation policy in the Rio Grande do Sul state	https://www.soloeagua.rs.gov.br/upload/arquivos/201805/03090934-decreto-politica-estadual-solo-e-agua-dec-52-751-de-04-de-dezembro-de-2015.pdf (accessed on 23 February 2023)
State program of soil and water conservation (Rio Grande do Sul state)	Provides guidelines to conserve the soil and water for better crop production	https://www.soloeagua.rs.gov.br/inicial (accessed on 23 February 2023)

Table 5 presents some suggestions for public policies necessary for the effective use of soil and water conservation practices and for food production. It is also important to consider site-specific characteristics (state, city, regional, and others).

The use of pesticides in agriculture is a potential risk for soil and water contamination; farmers and agrochemical producers should pay taxes to repair the damage to the environment and farmers who adopt agriculture practices free of agrochemicals, such as agroecology and organic farming, should be rewarded. If we want healthy people, food and water free of contaminants should be one of the most important resources for this. But nowadays, we pay more for food free of agrochemicals, while this food should be accessible to everyone.

Table 5. Public policies necessary for soil and water conservation and food production in Brazil.

Public Policies Necessary for Soil and Water Conservation and Food Production
Whoever contaminates should pay and whoever preserves should have economic benefits
Enforce the environmental cost on the agricultural user of agrochemicals
Agrochemical industries should pay for environmental and human health damage
Whoever produces food free of agrochemicals should have an economic benefit, while the commodities should be taxed
Ensure access for all people and at an accessible cost to food free of agrochemicals
Offer incentives to farmers that protect or improve soil health
Offer payment for environmental services associated with soil health
Offer incentives to adopt agroecology or organic farming and diversification of crops, instead monocrop practices
Offer incentives to plant food (legumes, vegetables, fruits, grains, and others) instead commodities
Use unproductive land in rural settlements to produce food
Recover degraded land to produce food
Ensure fair and equal access to healthy food
Develop strategies, courses, and incentives for food reuse
Develop strategies to reduce food loss during transport and storage
Develop programs encouraging the use of soil and water conservation practices at the watershed level
Provide incentives to the younger generation of farmers to continue producing food

A review of more than 100 studies found that although factors such as country, region, age, and gender may have different influences, in general, water pollution has a huge impact on human health, being the cause of many diseases, mainly diarrhea, skin diseases, cancer, and various childhood diseases [121]. The authors point out the need to adopt corresponding water management policies to reduce the harm caused by water pollution on human health; among them, they cite training farmers to avoid the overuse of agricultural chemicals that contaminate drinking water, and preventing and controlling source pollution from the production, consumption, and transportation of water.

In a review of studies conducted in Brazil considering the presence of pesticides in water and food, Palma and Laurencetti [122] verified the presence of pesticides in surface and subsurface water in several cities, and in fruits, vegetables, and grains. Meanwhile Mello et al. [123] highlight the need to protect the water due to land use and land cover, such as deforestation, agriculture expansion, and urban sprawl in Brazil, to be able to supply water of high quality in the long term. The pesticide laws and regulations in Brazil need to be revised, taking into account the criteria used in countries where the use of pesticides has been reduced [124].

To support healthy diets for all, nutritious food needs to be accessible and affordable [21]. In this sense, the FAO [125] point out the reasons why organic food is more expensive than conventional food: organic food supply is limited compared to demand; production costs for organic food are typically higher because of greater labor inputs per unit of output and because a greater diversity of enterprises means economies of scale cannot be achieved; post-harvest handling of relatively small quantities of organic food results in higher costs because of the mandatory segregation of organic and conventional produce, especially for processing and transportation; marketing and the distribution chain for organic products are relatively inefficient and costs are higher because of the relatively small volumes produced. They complement this by saying that "prices of organic foods include not only the cost of the food production itself, but also a range of other factors that are not captured in the price of conventional food", such as environmental enhancement and protection (and avoidance of future expenses to mitigate pollution); higher standards for animal welfare; the avoidance of health risks to farmers due to inappropriate handling of pesticides (and avoidance of future medical expenses); rural development by generating additional farming employment and assuring a fair and sufficient income to producers.

The Indian government has launched key development programs to support farmers and related stakeholders, such as the soil health card mission to strengthen irrigation, traditional agriculture, crop insurance, and soil testing [31].

The concentrations of a range of antioxidants, such as polyphenolics, were found to be substantially higher in organic crops/crop-based foods than conventional crops, and the frequency of occurrences of pesticide residues in conventional crops, which also contained significantly higher concentrations of the toxic metal Cd, was four times higher in conventional crops [37]. Conventional crops consistently have higher pesticide levels, and organic crops have higher phytochemical levels, particularly antioxidants and anti-inflammatory compounds [80]. Our politicians' suggestion agrees with these findings and reinforces the need for a sustainable use of soil free of agrochemicals. The investment in agroecology or organic farming systems means lower expenses for farmers and consumers' health.

Organic food consumers have a lower risk of childhood allergies, adult overweight/obesity, and non-Hodgkin lymphoma (but not for total cancer), although the scarcity or lack of prospective studies and the lack of evidence do not contribute to determining whether organic food plays a causal role in these observations [126]. And the fact that consumers who prefer organic food have healthier dietary patterns overall, including a higher consumption of fruit, vegetables, whole grains, and legumes and a lower consumption of meat, leads to some methodological difficulties in separating the potential effect of organic food preference from the potential effect of other associated lifestyle factors [126].

The many pollutants that contaminate soil (plastic, heavy metals, overfertilization, pesticides, and toxic agents) increase the risk of cardiovascular disease and other non-communicable diseases through shared pathophysiological pathways centered on oxidative stress and inflammation, leading to a dysregulation of circadian rhythms and causing cardiovascular, neurodegenerative, and metabolic diseases [127].

We cannot link soil and human health without including the different farming systems (for example, organic, agroecology, and conventional) because part of the soil reflects the farming system adopted. In that regard, Montgomery and Biklé [80] highlight the different definitions of what constitutes a nutrient: the conventional definition of dietary constituents necessary for growth and survival, or a broader one that also encompasses compounds beneficial for the maintenance of health and the prevention of chronic diseases.

In this line of discussion, soil health, represented by soil edaphic factors like moisture, pH, and temperature, plays an important role in the management of plant diseases because healthy soils maintain the pathogenic microbiota populations below the economic injury levels, which means that it is possible to manage many soil-borne diseases by improving the soil health [128]. The same authors cite some practices to keep the pathogenic populations at low levels and also add beneficial nutrients like nitrogen, phosphorus, and potassium to the soil, such as cover crops, crop rotations, mulching, suppressive soil, good-quality compost, and healthy sanitary practices, providing systemic resistance to the crops, reducing disease incidence, and minimizing crop yield loss.

Unsustainable food systems characterized by monocrops with an excess of agrochemicals, mass livestock production, and deforestation have led to elevated greenhouse gas emissions and a loss of biodiversity, but reducing environmental footprints linked to food systems may be achieved by reverting to more sustainable diets that meet nutrition requirements while safeguarding the environment, such as dietary diversification, fortification, biofortification, and the inclusion of alternative protein sources (e.g., edible insects) [129].

The deforestation of Brazilian biomes (Figure 1), especially the Amazônia, with the justification of food production is not consistent. While 77% of agriculture farms in Brazil are family farms, distributed across 23% of agricultural areas in the country [116], that produce the largest amount of food that feeds Brazilians, the majority of the areas belong to a minority of farmers, producers generally of commodities. Agriculture and pasture areas occupied 31.15% (265 Mha) of the Brazilian territory in the year 2021, and of this value, the pasture and soybean areas represented, respectively, 17.77% and 5.05% [3].

Recovering degraded soil pastures for food production is a way to recover soil health and reduce the hunger of 55.2% of the Brazilian population with some food insecurity [5], and it is necessary to consider, in this effort to recover soil health and reduce food insecurity, the families waiting for the agrarian reform to have their land to produce food, since the rural settlements may have a great contribution in this way. The 23% of agricultural areas of family farming represent 80.9 Mha [116], while the 38% of pastures with intermediate levels of degradation and 14.3% of severe degradation in the year 2020 represent, respectively, 58.8 Mha and 22.1 Mha [4], which is the same total area (80.9 Mha) used in the family-based production; this means that food production could be doubled and that we could feed people if we recovered soil health and if the areas of degraded pastures were converted to food production areas. Furthermore, the conversion of degraded pasture areas to food production areas represents employment opportunity, since according to the IBGE [116], the 80.9 Mha of family farming production areas occupy 67% (10.1 million people) of all people that work with agriculture and livestock in Brazil.

Climate change, air and soil pollution, and species extinction represent an existential threat to the sustainability of societies; these forms of environmental degradation are ultimately the consequences of short-term economic thinking and greed that have no respect for natural systems and no concern either for other people today or for future generations [127].

The government needs to understand that soil and water conservation strategies mean healthy food and people, and fewer expenses due to diseases or health problems, in addition to an equilibrated environment. Approaching people about the importance of soil for healthy food and people is an important stage in partnering with people to demand the necessary policies and their application. In this sense, after reviewing more than 50 soil citizen science initiatives, Pino et al. [130] found 3 main trends that citizen soil initiatives tend to follow: linking soil to human health (e.g., lead, healthy soil for food, and antibiotics), future-proofing and education, and soil health (degradation) and productivity (agriculture). It is necessary to effectively communicate soil and human health connections to society, as people cannot act on information they do not have [19].

Considering everything that has been exposed, our proposal of public policies follows a sequence of connected events: the degraded land should be converted to family farming for food production, especially agroecology or organic farming, including offering incentives for soil and water conservation practices at the watershed level, and this conversion will create employment opportunities in the food production chain, which means that people will be able to access food and other well-being products. Naturally, food produced via agroecology or organic food are more expensive, but the subsidies from agrochemical industries and users could result in low-cost food free of agrochemicals for consumers, which means healthy food and people. The increment in food production needs to be linked to access in order to decrease food insecurity (Figure 7).

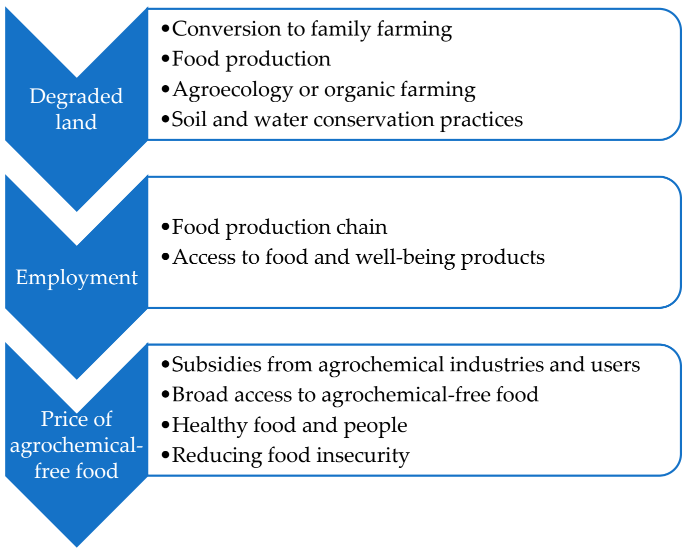

Figure 7. Sequence of connected events due to proposed public policies for soil and water conservation and food production.

5. Summary and Outlook

In this review work, we present some strategies and policies to contribute to soil and water conservation and healthy food production in Brazil, and we present possible ways to reduce food insecurity. More than 50% of the Brazilian population suffers from food insecurity, while we are the largest producer and exporter of a variety of food products. On the other hand, it is not acceptable to deforest Brazilian biomes with the justification of producing food because we have 80.9 Mha of degraded pastures that could be recovered and converted to food production areas. This area used for pastures represents the same area used for family farming that produces food for the Brazilian population.

We have the opportunity to face the challenge to recover the degraded areas and soil health to produce food, and the climate and soil diversity of Brazilian territory are advantages in producing a wide variety of food. However, it is important that adequate distribution of food occurs so that the population has fair and equal access.

High food and water quality mean healthy people and fewer expenses due to diseases. Making people aware of the importance of soil to produce healthy food and maintain the health of people is a vital stage in partnering with all of society to demand the necessary policies and their application.

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