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Agriculture in the Cerrado: a sleeping giant rose up

Abstract

Cerrado is a savanna biome, the second in extension among Brazilian ecosystems. The soils of the Cerrado are among the oldest on Earth. Weathering effects resulted in impoverished, acid soils in the Cerrado. Until the inauguration of Brasília (the capital of Brazil) in central Brazil, Cerrado was regarded as useless for agricultural exploitation. Research and implementation of techniques of soil fertilization, plant and animal genetics, breeding, and farming technology turned the Cerrado the main Brazilian area for food production. Notable gains in overall production and productivity of several crops were obtained. Over four decades, grain production in Brazil increased 6-fold, whereas the cultivated area increased 1.6-fold. Brazil became the third world's food producer and the second top exporter of food products. On the other hand, much of the original extension of the Cerrado domain was replaced by farming fields. In consequence, Cerrado is presently the most threatened Brazilian biome, chiefly due to losses and fragmentation of natural habitats. A balance between farming and environmental protection of the Cerrado is needed, aiming a sustainable food production, by means of a harmonic convivence of farming and environment preservation.

Keywords: soil science, food science, fertilization, farming technology, cerrado, biome preservation

Volume 11 Issue 2 - 2023

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Received: September 12, 2023 | **Published:** September 25, 2023

Introduction

Brazil is a large country, with latitudes ranging from equatorial to nearly temperate, and longitudes spreading over 80% of the widest part of South America. In consequence, in Brazil there are distinct climatic characteristics, ranging from very humid to semi-arid, and from tropical to nearly temperate. This and other factors determine the existence of distinct biomes in Brazil: a) Amazonian forest; b) Palm Tree Forest; b) Caatinga, an exclusive Brazilian biome, characterized by dry forests in the northeast region; c)Atlantic and interior rain forests; d) Pantanal, a periodically flooded area in the central-east region; d) Chaco, a dry forest biome; e) Pampas, grass fields in the south of the country; g) *Araucaria* Forests, with predominance of trees of *Araucaria angustifolia* (Araucariaceae); h) Cerrado, a tropical savanna biome, in the southeast and the central parts of the country; 1) Altitudinal Fields (Campos Rupestres), savanna biomes at altitudes above 1000 m, mostly with sand and rocky soils, located in the Cerrado domain (Figure 1). On coastal regions from the south up to the extreme north of Brazil, there are mangroves, where fresh river waters meet salt sea water.[1] The Cerrado is the second largest biome in the Brazilian territory, second only to Amazonia. It spreads over 2.04 million km^2 (204 million ha), corresponding to 22% of the Brazilian area, and extends into Bolivia and Paraguay. The mean temperature in the Cerrado is 22^o C, and the mean rain precipitation is 1,500 mm, distributed over two well defined annual periods: a dry season, with lower temperatures (April-September), and a wet season in the warmer period (October-March). Several physiognomies of Cerrado are recognized: a) Cerradão: a dry forest or a dense bushy vegetation; b) Campo Sujo: a savanna with many trees and shrubs; c) Cerrado *sensu stricto*: a savanna with a continuous layer of herbs, and few interspersed trees and shrubs; d) Campo Limpo: a savanna vegetation, containing mostly grasses and herb plants, with rare interspersed shrubs.[2] The typical trees and shrubs of the Cerrado have thick and tortuous stems, covered by a thick layer of cork, and thick, sclerophyllous leaves,[3] a condition that became known as oligotrophic scleromorphism.[4]

Not only has a dry season contributed to the low frequency of trees in the Cerrado. Fires occurring chiefly in dry months may be a necessary factor to maintain the savanna physiognomy in many areas of the Cerrado domain. Otherwise, with time the vegetation loses its shrubby and herbaceous typical representatives and the ecosystem evolves to a dry forest (Cerradão).[5] Studies beginning in the early 1940s at the University of São Paulo (USP) by Felix Rawitscher, Mario Guimarães Ferri and Mercedes Rachid, under the intellectual influence of Theodosius Dobzhansky (at the time working at the University of São Paulo), revealed that woody plants of the Cerrado, even in the mid of the dry season, had no symptoms of water deficiency. In fact, there is abundant water in the deep layers of the Cerrado soil. This water is captured by deep and wide underground systems of stems and roots of Cerrado trees. It has been said that the Cerrado is an "upside-down forest", with trees possessing underground systems larger than their canopies.[6] These and posterior studies revealed that the sclerophylly and low frequency of woody species of the Cerrado is chiefly the result of a chronic low availability of soil mineral nutrients, combined with a high acidity and toxic levels of aluminum.[7,8] The 1940s investigations by the USP researchers, linking soil chemistry with the peculiar characteristics of the vegetation of the Cerrado, stand as the beginning of the ecological studies in Brazil.[9,10]

Figure 1 Distribution of Brazilian biomes. Map with biome limits based on htpps://br.pinterest.com/pin/821484788254686886.

The nutritional deficiency of the soils of Cerrado derives from its antiquity: the Cerrado domain in the Brazilian Plateau is home to some of the oldest soils on Earth,[8] dating to the Tertiary. In this way, the weathering agents (climate, rain and wind) have had much time to lixiviate the soil layers, deploying them from nutrients essential to plant growth, preserving, however, cations of aluminum, a toxic element to plants. The soil of most areas of Cerrado are latosols, with lower contents of relevant nutrients for plant growth, and high contents of aluminum.[11,12] Prior to the 1970's, agricultural activities were virtually impossible in cerrado areas. They were mostly restricted to the cultivation of grasses to feed cows and goats. Several typical woody species of Cerrado are evolutionary adapted to unfavorable characteristics of the Cerrado soils, including aluminum accumulation. Examples of species in this category are *Miconia ferruginata* (Melastomataceae), *Palicourea rigida* (Rubiaceae), and *Qualea grandiflora* (Vochysiaceae).[13]

The findings by Rawitscher and collaborators influenced a generation of botanists, soil scientists, and agronomists in Brazil.[14] If, on the one hand, the soils of Cerrado are crucial limiting factors for agriculture implementation, on the other hand, the Cerrado's favorable climate, topography and open vegetation favor land occupation, mechanization and large-scale agriculture production.[7,15] Another factor that favored advances toward farming in the Cerrado was the absence, at the time, of laws aiming the protection of the biome. In fact, in the 1950's, virtually no voices by authorities, environmentalists and society were raised against the project and then the construction of Brasilia, the new capital of Brazil (inaugurated in April 1960). Brasilia is in central Brazil, within the very heart of the distribution of the Cerrado domain. Distinct from the exuberant Amazonia and Atlantic Rain Forests, the Cerrado vegetation, with its dry and aggressive aspect, its tortuous trees with coarse-looking stems, was scorned by the population, with reflexes in the environmental Brazilian legislation. The vast areas of Cerrado were seen just as useless lands, suitable at best for low-productive pastures. Two barriers needed to be overcome toward the occupation of Cerrado for agriculture and livestock production: a) construction of roads interlinking long distantly locations in central Brazil; b) developments in soil science. The installation of the central government of Brazil in Brasília stimulated the rapid development of roads and the growth of towns in central Brazil. In turn, this achievement fostered studies in soil science aiming for improvements in the chemical characteristics of Cerrado soils.

The "conquest" of the Cerrado

Incentives to increment human settlements in the central region of Brazil started prior to the Second World War, during the campaign "March to the West", as announced by the President Getúlio Vargas (1937-1945). In 1957, the geographer Speridião Faissol (head of the Center-West Section of the Brazilian Institute of Statistics and Geography) warned that the time had come to stop agriculture in lands of the Atlantic Forest, because very little was then remaining from the initial extension of the ecosystem. In his opinion, Brazil had two options toward maintenance and increase of agricultural production: a) rejuvenate the devastated forest areas, victims of the slash-and-burn agriculture that prevailed since the initial colonization of Brazil in the Atlantic Forest; b) introduction of agriculture in the Cerrado. Both options were challenging, and both involved the implement of fertilization techniques.[15] The second option imposed additional difficulties, because the central part of Brazil was still poorly inhabited, with few and long distant small towns. The construction of Brasília during the government of the President Juscelino Kubitschek (1957-1960) stimulated the development of central Brazil, within a campaign proclaimed as the "New March to the West". Studies aiming the agricultural occupation of the Cerrado was then started and stimulated by official incentives.

Research in this regard was conducted initially by the Ibec Research Institute (later recognized as IRI Research Institute). Devoted initially to recover lands wasted by inadequate practices of coffee cultivation, the institute shifted its attention to the soils of the Cerrado. The task necessarily aimed to bring fertility to the soils. Several aims toward the correction of the chemical characteristics of the Cerrado soil had to be achieved, such as removal of the aluminum toxicity using calcareous dolomite, provision of calcium and magnesium, as well as correction of the availability of other nutrients.[15] Progresses achieved by IRI stimulated further studies and several Brazilian institutions added efforts aiming at the agricultural occupation of the Cerrado. The most relevant among them was Embrapa (Brazilian Enterprise of Agricultural Research) and its main unit: the Cerrado *Agricultural Research Center* (CPAC), in the municipality of Planaltina.[11] The institution was founded in 1973, at a time when Brazil regularly imported wheat, beans, soybean, and beef, among other food products. In parallel with advancements in soil science, programs for breeding crop species adapted to new habitats were developed.

A notable success in this regard was the spread of soybean plantations. When first introduced in Brazil, soybean was cultivated in the south of Brazil, with a temperate-subtropical climate, similar to the region of origin of the crop. Nowadays, it is cultivated in nearly all Brazilian latitudes. Starting in the 1990s, mechanization brought new impetus to the productivity of nearly all crops cultivated in the Cerrado. Official incentives for the migration of farmers from the south to central and central-west Brazil represented key efforts toward the agricultural development in the Cerrado. The construction of roads, railroads and ports assisted the transport of farming products in central and western Brazil. The population of the previously existing towns in the region increased, and new towns appeared, stimulated by the rapidly growing farming. Eventually, not only food production achieved successive increments, but also the productivity of most crops increased gradually. Scientific achievements by Embrapa and other institutions in the period 1977-2017 enabled grain production in Brazil to increase from 40 million to 240 million metric tons (6-fold), whereas the area cultivated increased from 37 million ha to 61 million ha (1.6-fold;[16] Figure 2). The higher the efficiency of the processes of food production, the lower the rate of invasion of natural areas by agriculture, and also the lower is the attack on the Cerrado biome. This is relevant in the present context of massive losses of biodiversity, environmental contamination and global warming. Not only soil science was crucial for the successful agricultural exploitation of the Cerrado. Breeding programs of varieties of plants and animals were developed, and increasing productivity was achieved. Advanced technological implements are in course in Brazilian farming, such as the use of drones. With 20 liter capacity, drones are used for several purposes, such as the application of fertilizers and pulverization of pesticides and herbicides. They enable a minimization of the amounts of fertilizers and agricultural defensives, with economic and environmental gains. Drones bearing special cameras are used to monitor the health conditions of crop plants. The combination of soil fertilization, genetic improvements, pest control, cultivation management, and modern advanced technology, combined with favorable climate conditions all year round, have enabled unprecedent attainments of grain harvests three times a year. This has been possible with corn, common beans and soybean.

Citation: Salatino A, Faria Salatino ML. Agriculture in the Cerrado: a sleeping giant rose up. *MOJ Food Process Technols*. 2023;11(2):111–114.
DOI: 10.15406/mojfpt.2023.11.00288

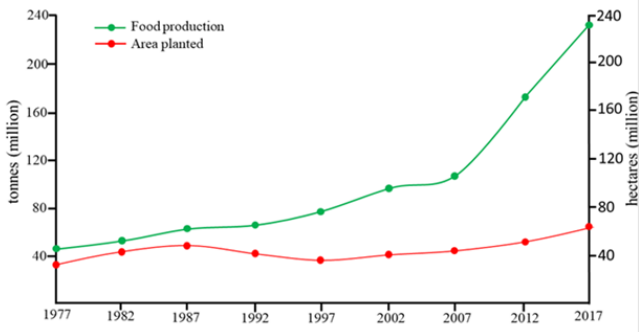

Figure 2 Evolution of food production and area cultivated by farming in the cerrado domain. Based on Embrapa.[16]

Statistical data released in 2022 place Brazil as the third world's largest food producer. China leads the ranking, India coming next. Converting to American dollars, the value of the Brazilian contribution is close to $ 240 billion. From this total, agriculture contributed with US$ 164 billion and livestock with US$ 76 billion.[17] The increase in the production of Brazilian farming in the last decades is remarkable. Over the past two decades, the average annual growth of Brazilian farming was eight percent. In this period, the agricultural output doubled, and livestock production increased threefold.[18] In 2020, the contribution of Brazilian farming to the country's exportation was 48%. In fact, Brazil is not only among the top food producers; it is also the second top exporter of agricultural products.[19] Most relevant foods in Brazilian farming are produced partly or entirely in the Cerrado, which represents 44% of the Brazilian agricultural area and produces 40% of Brazilian beef.[20]

Main products of Brazilian farming

Celebrating its 50th anniversary, Embrapa released a publication,[21] listing 50 foods produced by Brazilian farming. The publication provides information about the geographical location of cultivation, and technological improvements for each product, including soil fertilization, breeding of plant and animal varieties, as well as techniques of poultry and cattle ranching. Brazil has a long tradition as the world's largest coffee producer. However, the country is also a leader in the production of several other food plants native to the country, such as açai, Brazilian nuts, cashew nuts, guarana and passion fruit, as well as of non-native food products, such as orange and soybean (Table 1). On the other hand, the country does not lead the production of some native plant foods, such as cassava and pineapple (Table 1). The largest areas cultivated in Brazilian farming are dedicated to the production of foods largely consumed worldwide, either for human nutrition or animal feed. These are the cases of beans (2.6 million ha), beef (150 million ha), corn (19.5 million ha), rice (1.8 million ha) and soybean (38.8 million ha) (Table 1).

Relevance of the "conquest" of cerrado to the world's food production

Given the size and abundance of natural resources, a saying was current in the country until not long ago: *Brazil is a "sleeping giant", waiting for the right time to rise up and join the powerful economies of the world*. However far from realization this prophecy may be, Brazil indeed is home of a giant – the Cerrado domain -, which remained dormant over four and half centuries, since the arrival and occupation of the Americas by the Europeans. However, in the second half of the last century, scientific research and agricultural implementations led to the rise of the giant. The outcome is that Brazil now integrates the top world centers of food production. In other words, the agricultural conquest of the Cerrado may be likened to a hypothetical discovery of a new continent, with fertile lands, amenable climate and topography, and an area larger than the combined territories of Portugal, Spain, France, Swiss, Italy, Germany, Austria, Netherlands and Belgium. The rise and growth of farming in the Cerrado represented a relevant push to the huge increments of food production over the last century, following the invention of the Haber-Bosch process, which triggered the explosion of the world human population from 2 billion people in 1927 to the present 8 billion.[22,23]

Table 1 List of food products from Brazilian farming, respective position among top world producers, and area cultivated. The data corresponds to statistics of 2022. Foods with superscript asterisks are produced in cerrado areas. Based on Embrapa.[21]

Food product	Production (10^6 tons)	Area cultivated (10^3 ha)	World position
Açai	1.7	280	1
Avocado*	0.31	18	7
Banana*	6.8	453	4
Beans*	2.9	2,600	2
Beef *	9.75	150,000	2
Black pepper	0.12	38	4
Brazilian nut	0.33	-	1
Cashew nut	0.12	400	1
Cassava*	18.1	1,206	5
Chicken meat*	13.78	-	2
Coffee*	2.99	1,836	1
Corn*	116.0	19,500	3
Guarana	0.002	10,000	1
Guava*	0.54	23,000	7
Lemon*	1.5	58	5
Mango fruit*	1.5	76.1	6
Milk*	36	-	3
Orange*	16.2	578	1
Papaya*	1.26	50.3	3
Passion fruit	0.68	44.8	1
Pineapple*	2.3	64	4
Pork*	4.4	-	4
Rice*	11.2	1,800	10
Sorghum*	2.4	810	9
Soybean*	128.3	38,800	1
Tomato*	3.7	52.1	9

Environmental drawbacks

Among Brazilian biomes, the savanna ecosystems, including Cerrado, Pampas and Chaco, have deserved little care in public laws aiming at protection and preservation.[24] With modern techniques of soil fertilization, the open vegetation of these biomes is easily adapted to mechanized farming. Regarding Cerrado, only 46% of its natural vegetation persists, and not more than 20% remain untouched.[25] Because there are 1,140 species endemic to the Cerrado, a historically unprecedent mass extinction of Cerrado plant species is predicted to occur 30 years from now, if the current expansion of agriculture over this ecosystem persists.[26] Several animal species of the Cerrado are seriously endangered, including the giant armadillo (*Priodontes maximus*), the giant anteater (*Myrmecophaga tridactyla*), and the mane wolf (*Chrysocyon brachyurus*). Populations of these and other animals of the Cerrado are rapidly dwindling, not only because of

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losses and fragmentation of natural habitats but also due to collision of animals with trucks and other vehicles. In the period 2017-2021, the death of 12,000 anteaters on roads of the state of Mato Grosso do Sul was reported. In addition to efforts aiming further increase of productivity, other measures have been recommended for the protection and preservation of the Cerrado biome, such as the recovery of degraded areas previously used by agriculture and cattle ranching and protection by laws of vulnerable areas.[26,27]

Conclusion

The world population is still escalating and will remain so for the next decades. In consequence, the pressure for increasing amounts of food tends to prevail. In consequence, it is expected increases in the Brazilian contribution among the world leaders of food production. On the other hand, bearing in mind the environmental damages resulting from farming activities, the society and authorities in Brazil, as well as the influential farming corporations operating in the Cerrado, need to look at this biome with increasing care, toward the conservation of the little proportion of its natural areas still untouched. Science and technology are expected to advance further toward increases in productivity and minimization of environmental damages.

Acknowledgments

"AS is fellow researcher of CNPq (Conselho Nacional do Desenvolvimento Científico e Tecnológico, Brazil)" and corresponding grant for this Research is 303896/2019-1.

Conflicts of interest

The authors declare that there are no conflicts of interests.

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