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Agroenvironmental modeling and the digital transformation of agriculture

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Introduction

Agriculture is an activity with significant returns and risks. Therefore, production processes and businesses are increasingly benefiting from the availability and use of information. Technical, economic, social, and environmental dimensions are of interest to all agribusiness segments, which seek reliable indicators for operations and business. Financing, inputs, sales and insurance contracts, certifications and regulatory processes come to depend on the development of intelligent systems and information at reasonable costs. These become essential for competitiveness and sustainability from a viewpoint of strengthening the value chains in agriculture.

It is undeniable, for example, that the upheavals resulting from climatic instability, sanitary events, and fluctuations in markets or business environments stand out due to their impacts on agriculture, and the related data and information must be investigated in an interdisciplinary manner. A study supported by the World Bank indicates that Brazil loses more than R$ 11 billion annually due to risks that could be minimized (Arias et al., 2015). In many regions, more than 60% of the variability and risk of agricultural production is caused by climatic effects. Farmers exert little or no control over natural phenomena such as drought, frost, heat waves, windstorms, or hail (Rossetti, 1998), and to bypass such occurrences, agricultural producers depend on information derived from more complex analytical processes.

It is essential to understand and quantify the climate risks of different ecoregions[1] in order to reduce risks of exposure and ensure greater agroecosystem resilience[2] in Brazil. This task is complex, given the continental dimension of the country, the diversity of agricultural crops, production systems, the supply of natural resources, soil conditions, relief and climate. It requires specialized knowledge about the functioning of agroecosystems and the correct allocation of competences and resources, especially from Embrapa, considering its mission, dimension, and capillarity. Science advances the understanding of these complex biophysical and economic systems with the intensive use of data associated to robust analytical systems. As such, the formulation of policies, the creation of incentives, and regulation of economic activities progressively incorporated these advances and consequently came to depend on new information processes. Measures of risks and returns, as well as productive, economic, social, and environmental impacts have become an essential aspect of the innovation that Embrapa promotes in digital agriculture, also called Agriculture 4.0.

Dealing with this complexity requires the ability to process a large set of data and information in order to generate knowledge and support decision-making that is more informed and, consequently, more accurate.

Therefore, a large investment in information technology is necessary in order to guarantee the collection of basic and primary data, using field and remote sensors; storing, organizing, accessing, and interoperating multiple databasesas. Lastly, but key to the entire process is the adaptation and development of powerful processing tools for analyzing large data volumes. Thus, information and knowledge are generated and disseminated in an appropriate and understandable format for various audiences. The advancements in information and communication technologies (ICT) can contribute to developing knowledge, public policies, and investments in a highly technified agriculture backed by scientific knowledge, regardless of scale.

Considering this scenario, Embrapa Digital Agriculture invests in solutions by the development and application of agroenvironmental models. The Research Group on Agroenvironmental Modeling was established, and professionals with interdisciplinary skills have contributed to the development of research, processes, products, and services related to understanding and quantifying soil-plant-animal-atmosphere interactions. Another strategic dimension of the Unit's performance is to foster synergy and networking with other Embrapa Units, universities, national, and international research institutions. Agroenvironment modeling no only generates spatially explicit data and information that supports the stability and increase in agricultural productivity, but also decreases the use of natural resources, helping to achieve the Sustainable Development Goals (SDGs) for 2030 (United Nations, 2015) – especially in SDG 02, Zero Hunger; in SDG 12, Responsible Consumption and Production; and in SDG 13, Climate Action.

This chapter presents a brief history of agro-environmental modeling and its importance as an essential element in the digital transformation of agriculture, especially with regard to rural planning and strategic/managerial decision-making in the public and private sectors. Some of the generated knowledge and products are summarized here, which highlight the direct contributions of Embrapa Digital Agriculture. Also noteworthy is the support that the Unit offers to the challenges and risks posed by historical variability and climate change, as well as understanding the synergies between production and ecosystem services.

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[1] Resilience, for agriculture, can be understood as the capacity of production systems to coexist with variability and risks, whether through the best selection of planting times, cultivars and the use of technologies to combat adversities (irrigation, use of pesticides etc.) or financial mechanisms to absorb shocks caused by adverse effects.

[2] Ecoregions are geographic units with similar physical and biological characteristics, whose boundaries are defined based on abiotic characteristics (altitude, relief, soil, geology, precipitation, flood cycle, tidal effects) and biotic (groups of plants and animals present).

The evolution of agroenvironmental modelling

Modeling of agricultural systems began to flourish in the mid-twentieth century, with the contributions of linear programming and economic modeling of agricultural systems as important milestones. At that time, the models explored the components of the agricultural system and their interactions in a more limited manner. From the 1960s onwards, many models were developed with a focus on forecasting and evaluating agricultural system performance in response to changes in their components and interactions (Jones et al., 2017).

In the 1980s and 1990s, modeling of agricultural systems started to be used progressively so as to expand our knowledge on fundamental aspects of the functioning of the soil-plant-animal-atmosphere system. It enabled to simulate variations in the state of the system, along with its components and their interactions in different spatiotemporal scales. This evolution allowed to incorporate physical processes (such as the balance of radiation, absorption by vegetation, and soil water movement), biophysical (such as photosynthesis and plant growth processes), biogeochemical (such as the soil carbon cycle) within a single numerical simulation model. At the same time, the development of numerical models by agrometeorology community had grown significantly, with the emergence of various software that included models that simulate the development and growth of agricultural crops. Based on these analyses, the models began to provide important elements to support the prediction of potential responses of the agricultural system to changes in the conditions of the environment, the production system and the management employed. Therefore, agroenvironmental modeling stands out as a tool to assess the responses of agricultural productivity to climatic conditions using empirical statistical models and models based on biophysical and socioeconomic processes, which simulate agricultural productivity and its interactions with the environment and management practices (Jones et al., 2017). The models used utilize mathematical formulations to represent the functioning of natural systems, be it simulating the growth of a plant in specific meteorological conditions, the need for food supplementation for cattle or another process to be evaluated.

The expanded knowledge brought about by modeling on the multiple facets of agricultural systems and their components has percolated more extensively into decision-making on rural properties and with decision makers in the political sphere. Today these models are now widely used in precision agriculture, irrigation management, soil fertility management, plant breeding, monitoring and forecasting of yield for crop management, agricultural insurance, impact assessment and subsequent adaptation to climate change., quantification of carbon sequestration in the soil, environmental impacts in land cover and land use changes, forecast of agricultural crop production, and disease risk assessments.

Agroenvironmental modeling products to support decision-making

Several technologies and products that make use of agro-environmental modeling applied to rural planning have been developed, directly or indirectly, by the Agroenvironmental Modeling Research Group, with the main lines of action presented below. These works can be grouped into four central areas: i) obtaining, organizing, storing and distributing basic data for agroenvironmental modeling; ii) quantification and analysis of climate risks and resilience of agricultural systems; iii) products that support territorial planning; and iv) integration of socio-economic analysis in agro-environmental modeling. Although these components are presented separately in order to be evidenced and specified, they complement each other, and at various times merge during analysis, modeling, and simulation development. This generation of knowledge and products are applied to rural planning in an integrated approach.

Databases for agricultural and environmental research

One of the prerequisites for using models is the collection, storage, use, and distribution of agrometeorological data. These must be suitable for their specific purpose with the appropriate spatial and temporal coverage, as well as having a known quality. Climatic data are essential for agro-environmental modeling. Thus, tools are developed for the acquisition, storage, processing, and availability of agrometeorological data for Brazil.

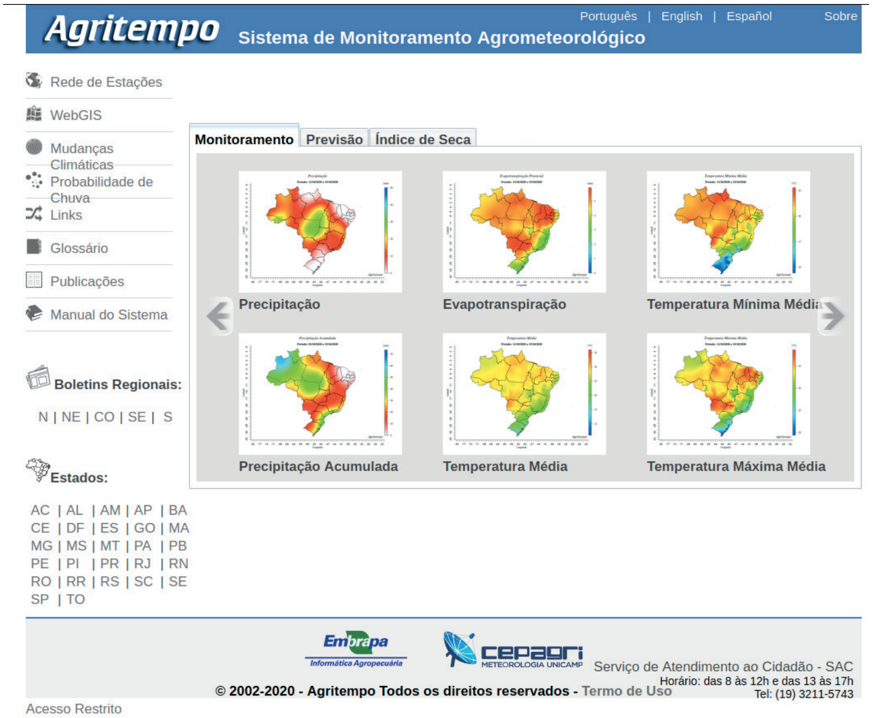
Agritempo

Agritempo[3], currently available on the portal and the Agritempo mobile and Agritempo GIS mobile applications has been offering free agrometeorological data that supports agricultural activities in rural properties, reducing risks related to climate and weather while also supporting public policies and allowing online actions for agrometeorological monitoring.

The main innovation offered by the system refers to the automation of tasks, enabled using ICT, in which the entire process of receiving data, incorporating it into the database, and building maps occurs automatically through the system without human intervention. This provides greater speed and accuracy, in addition to offering better quality to the database itself as the system automatically performs tests on the collected variables (Alencar et al., 2016).

Agritempo mobilizes a collaborative network with 40 institutions, involving the exchange of meteorological data, research in agrometheorology, generation of new technologies such as system modules, functionalities, and availability of information, such as studies and scientific publications. The system organizes and manages a set of more than 1,600 meteorological stations, a number that is constantly expanding. It also contains a database of at least ten years of satellite images that can be used to support research in agrometeorology.

In 2019 alone, the Agritempo portal (Figure 1) had 180,950 hits.



Serviço de Atendimento ao Cidadão - SAC
Horário: das 8 às 12h e das 13 às 17h
Tel: (19) 3211-5743

© 2002-2020 - Agritempo Todos os direitos reservados - Termo de Uso

Figure 1. Interface of the Agritempo system – version 2.0.

Source: Agritempo (2020).

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[3] Available at: http://www.agritempo.br

The Agritempo mobile and Agritempo GIS mobile applications recorded more than 10,000 installations, showing the demand and transfer of information contained in these systems.

Conprees

Currently, Embrapa Digital Agriculture has meteorological data integration and remote sensing systems from various sources. However, the low density of meteorological stations in vast regions of the country, in addition to inherent flaws in the operation and maintenance of existing stations, results in the lack of reliable data for many producing regions. More recently, CONPREES, an acronym for Consistent, Completed, and Spatialized meteorological data, will enter the testing and operation phase in 2020. This system uses a much larger number of data sources ranging from public and private meteorological stations and from different meteorological and remote sensing models. Thus, it is possible to develop a database with sufficient resolution and accuracy to monitor the occurrence of adverse events and agrometeorological accidents.

The integration of agrometeorological monitoring systems and remote sensing vegetation cover, such as System for Temporal Analysis of Vegetation (SATVeg) (detailed in chapter 4), will provide information on plant biomass that will allow for more effective monitoring of the areas. While systematic agrometeorological monitoring allows identifying unfavorable conditions (low temperatures, dry spells, water deficit, etc.), vegetation indices obtained from satellite images can indicate conditions related to management, such as planting time, planted area and vegetative vigor. In addition, vegetation indices synthesize the vigor of vegetation during the development process of an agricultural crop. As such, they also reflect the agrometeorological conditions in a cultivated area when analyzed through the harvest period.

Risk assessments and climate resilience evaluation

Climate is the main environmental factor associated with agricultural productivity variability. Climatic risks have the potential to cause significant or total losses to production, divided into two groups: i) extreme event (low and high temperatures, very intense rain, strong winds, among others); ii) cumulative event (prolonged droughts, temperatures limiting growth for long periods, etc.).

The adoption of good agricultural management practices is considered one of the most viable means for adding resilience to the production system. This occurs mainly by reducing exposure to climate risks, but it is also possible to reduce current productivity gaps. In this context of serving rural and agricultural planning, agroenvironmental modeling has been used both in the history of meteorological phenomena and in developing the productivity of agricultural crops. This risk assessment focus and promotion of climate resilience is leading to the simulation of future agricultural scenarios derived from climate change. As such, the use of modeling can guide both research priority and development themes or practices to be adopted and intensified in production systems. The guiding base for this development is the greater risk and vulnerability, or a pronounced reduction in adaptive capacity of a particular crop.

Agricultural Climate Risk Zoning

The Agricultural Climate Risk Zoning (ZARC), governed by the National Program of Presidential Decree No. 9,841/2019 is one of the most important examples of the agroenvironmental modeling application aimed at generating value with broad social, economic, and environmental benefits. It is an agrometeorological product that delimits regions and planting times according to the probabilities of production loss caused by adverse weather events. These studies are based on a broad knowledge base, agronomic, and meteorological data, as well as modeling techniques combined with large-scale processing systems. This allows for the generation and analysis of different scenarios per crop, enabling an assessment of climate impacts associated with the hydro-physical characteristics of the soil, crop cycles, planting dates, and crop sensitivity to climate effects at different plant stages, among others (Santos; Martins, 2016). The results translate into risk levels per ten days of planting for each municipality.

The objective of ZARC is to provide information for the management of climatic risks on rural properties, as well as for public managers (Ministry of Agriculture and Livestock – MAPA), Central Bank of Brazil – BACEN, National Monetary Council – CMN). Additional to this is the decision-making support in the Federal Government's insurance programs, such as the Agricultural Activity Guarantee Program (PROAGRO) and the Rural Insurance Premium Subsidy Program (PSR). This information is used to avoid excessive losses with compensation in areas or times of high agricultural risk, as well as to evaluate solutions for production systems less susceptible to climatic adversities. In order to be entitled to PROAGRO or PSR, and thus have access to Rural Credit, the producer must observe the ZARC recommendations. In addition, several financial agents in the private sector condition the granting of rural credit to the ZARC indicators.

Embrapa Digital Agriculture houses the processing cloud infrastructure, with large servers dedicated to ZARC. They use a workflow management system to automate the pre-processing (storage and processing of data used by agrometeorological models), processing (execution of simulations) and post-processing steps (probability calculations, results visualization and processing the final results), ending with its delivery to the Agricultural Policy Secretariat (SPA-MAPA).

The generated results are stored in a database, available to different teams in Brazil through Micura (Figure 2). This system enables the visualization and analysis of the ZARC results, allowing the technical teams to carry out validations and to investigate better ways to parameterize the models. After verification by the teams of each analyzed agricultural crop, the results are presented to the broad public at validation meetings in several states in Brazil, through Micura, with the participation of rural producers, technicians, agronomists, researchers from different institutions, public managers, financing and insurance agents, and cooperatives. If the results are not approved, the team identifies and proposes the necessary adjustments. New scenarios are then processed and presented, until results that are more coherent with the reality in the field are obtained.

The results are sent to MAPA to determine the recommended planting windows for more than 44 agricultural crops. These recommendations are the basis of insurance programs tied to the Federal Government, such as the PROAGRO, the Family Farming Agricultural Activity Guarantee Program (PROAGRO MAIS) and the PSR.

Plantio Certo (Sure Sowing)

As these are tools aimed for academic use, the results of the models often lack adequate interpretation. Thus, in order to facilitate access to ZARC indications, the Plantio Certo (Sure Sowing) mobile application was developed. It is available at Embrapa's app store[4]. With it, farmers, bank agents and people linked to rural insurance are able to consult the planting periods recommended by ZARC for different agricultural

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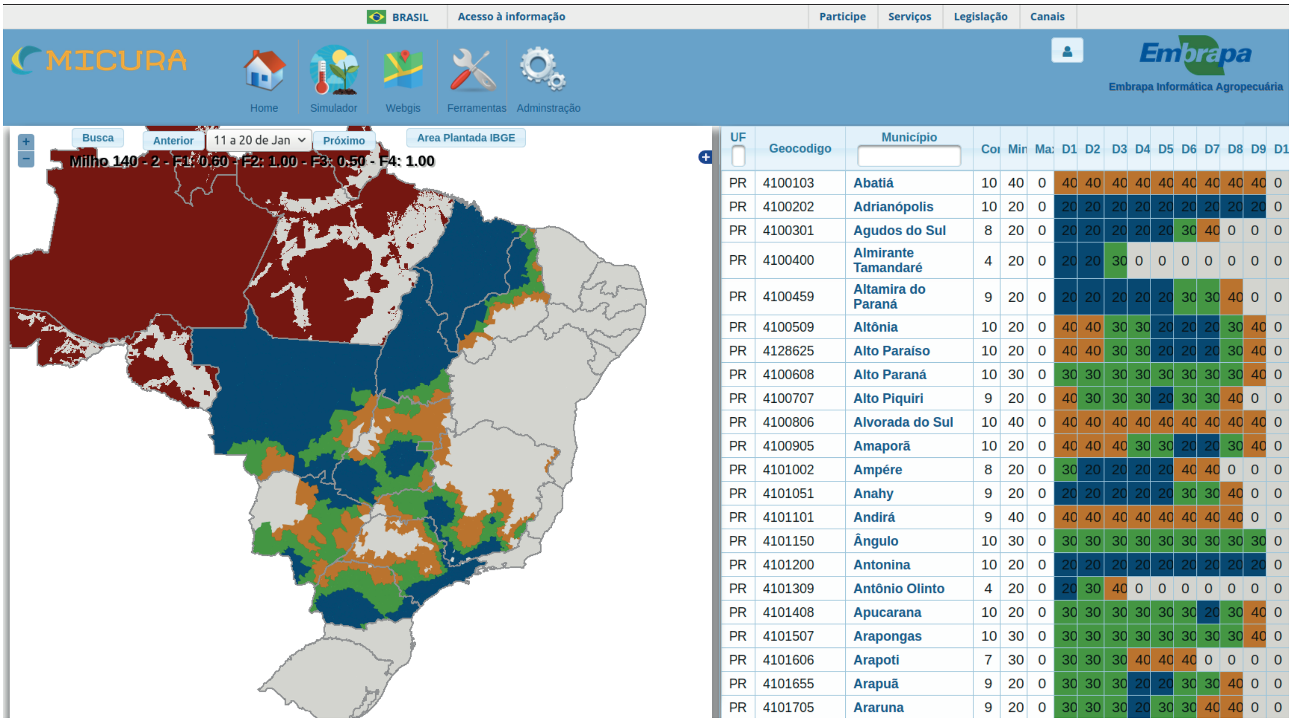
[4] Available at: www.embrapa. br/applications



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UF	Geocodigo	Município	Co	Mir	Ma	D1	D2	D3	D4	D5	D6	D7	D8	D9	D1
PR	4100103	Abatiá	10	40	0	40	40	40	40	40	40	40	40	40	0
PR	4100202	Adrianópolis	10	20	0	20	20	20	20	20	20	20	20	20	0
PR	4100301	Agudos do Sul	8	20	0	20	20	20	20	20	30	40	0	0	0
PR	4100400	Almirante Tamandaré	4	20	0	20	20	30	0	0	0	0	0	0	0
PR	4100459	Altamira do Paraná	9	20	0	20	20	20	20	20	30	30	40	0	0
PR	4100509	Altônia	10	20	0	40	40	30	30	20	20	20	30	40	0
PR	4128625	Alto Paraíso	10	20	0	40	40	30	30	20	20	20	30	40	0
PR	4100608	Alto Paraná	10	30	0	30	30	30	30	30	30	30	30	40	0
PR	4100707	Alto Piquiri	9	20	0	40	30	30	30	20	30	30	40	0	0
PR	4100806	Alvorada do Sul	10	40	0	40	40	40	40	40	40	40	40	40	0
PR	4100905	Amaporã	10	20	0	40	40	40	30	30	20	20	30	40	0
PR	4101002	Ampére	8	20	0	30	20	20	20	20	40	40	0	0	0
PR	4101051	Anahy	9	20	0	20	20	20	20	20	30	30	40	0	0
PR	4101101	Andirá	9	40	0	40	40	40	40	40	40	40	40	0	0
PR	4101150	Ângulo	10	30	0	30	30	30	30	30	30	30	30	30	0
PR	4101200	Antonina	10	20	0	20	20	20	20	20	20	20	20	20	0
PR	4101309	Antônio Olinto	4	20	0	20	30	40	0	0	0	0	0	0	0
PR	4101408	Apucarana	10	20	0	30	30	30	30	30	30	20	30	40	0
PR	4101507	Arapongas	10	30	0	30	30	30	30	30	30	30	30	40	0
PR	4101606	Arapoti	7	30	0	30	30	30	40	40	40	0	0	0	0
PR	4101655	Arapuã	9	20	0	30	30	30	20	20	30	30	40	0	0
PR	4101705	Araruna	9	20	0	30	30	30	20	30	30	40	40	0	0

Figure 2. Vizualization of scenarios in the ZARC on the Micura system.

Source: Micura (2020).

crops in all Brazilian municipalities in a simplified way (Figure 3). The application also allows climate monitoring from the informed sowing date, returning information to the user on soil water storage, accumulated precipitation, number of days without rain, as well as minimum and maximum temperatures.

Secretaria de Política Agrícola
Ministério da Agricultura, Pecuária e Abastecimento

RIO VERDE/GO
ALGODÃO HERBÁCEO
Safra: 2020/2021

Legenda:
risco até: 20% 30% 40% sem indicação

Ciclo da planta: 1 (precoce), 2 (médio), 3 (tardio)

Solo: 1 (arenoso), 2 (textura média), 3 (argiloso)

RIO VERDE/GO
data base: 1/12/2019 (-30 dias)

armazenamento de água no solo: média no decêndio

Legenda: armazenamento de água no solo (%)

🟥 < 10	50 -| 60
10 -| 20	60 -| 70
20 -| 30	70 -| 80
30 -| 40	80 -| 90
40 -| 50	90 -|100

O número dentro do círculo indica a fase fenológica estimada: (1) semeadura e estabelecimento, (2) vegetativo, (3) floração e formação da produção e (4) maturação

Figure 3. Interface of the Plantio Certo application. The example shows recommendations for cotton planting time in the municipality of Rio Verde, Goiás state, and agrometeorological monitoring of conditions at the location.

Source: Embrapa (2020).

Support for agricultural planning and monitoring

The availability of data from sensors located in the field or from remote platforms, along with time series obtained throughout the season and accessible as soon as they are collected, provides opportunities to monitor crops in real time and improve their management. This can be done directly from raw data or from derived indices such as rainfall measurements or vegetation indices (e.g., SATVeg, described in Chapter 4), or from more complex model results that make use of such data. The use of modeling can be done directly as the data are fed as input parameters in the models (e.g., temperature and precipitation data in a water balance model). This can also be done in the form of data assimilation, in that the results of a model are corrected throughout its execution, as new field observations are incorporated.

Helping in the planning of agricultural activities and monitoring field conditions are of interest to both producers and managers in various sectors, such as agricultural insurance, retail, processing industry, government agencies, among others. Embrapa has been working in this area with tools such as Agritempo and the Plantio Certo mobile application, SATVeg, Invernada, WebAgritec, in addition to other technologies under development.

Invernada

Invernada[5] is a support system for planning the production of beef cattle. It incorporates a database of climate and nutritional composition of pastures and supplementary foods. It also has dynamic models of pasture growth as a function of climate and soil water content, and able to estimate the seasonal distribution of forage production. In addition, it takes into account the selectivity of grazing animals, the growth of animals, and whether or not nutritional demands are met. Invernada incorporates algorithms for formulating diets with several optimization alternatives which are used in different aspects of decision-making, from pasture performance to animal management, and nutrition strategies. Additionally, it allows analyzing and comparing different management scenarios.

WebAgritec

WebAgritec makes several systems developed at Embrapa Agricultural Informatics available in the form of a website or a set of Application Programing Interface (APIs). APIs provide a set of functions and procedures that allow other software applications, internal or third-party, to access resources, data, and functionalities. The system is entirely developed by Embrapa Agricultural Informatics (detailed in chapter 12). The main modules available to users are: agricultural zoning, weather forecasting, crop selection, fertilizer and liming recommendation, identification of plant diseases, estimation of achievable productivity for soybean, corn, rice, bean and wheat, in addition to ancillary support with videos and recommendations. The productivity module uses meteorological data from the current crop as input into specific calibrated models. Thus, WebAgritec's main objective is to support rural extension services in Brazil, being used by institutions such as technical assistance and rural extension companies EMATER-GO and EMATER-MG. In addition, considering the functions of penalizing productivity, the system has been used by the National Supply Company (CONAB-MAPA) to assist in crop forecasting.

Climate change impact assessments and agricultural adaptation based on agroenvironmental models

By incorporating future climate projections into agro-environmental models it is possible to assess the impact of climate change on agricultural crops. These are obtained from projected scenarios using climate models, for example, these projections can be applied to ZARC models in order to assess whether a given crop will have more or less low-risk areas.

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[5] Available at: www.invernada.cnptia.embrapa.br

Current and projected impacts for the coming decades are generally derived from trends observed in the present, which can be, for example, derived from observed climate series. These projections are extremely important for rural producers and for the territorial planning of production. On the other hand, projections of the impacts of climate change in the long term are extremely important for defining public policies, foreseeing trends and for the planning of adaptation and mitigation actions.

Adaptation generally seeks to reduce exposure to projected risks or increase the resilience capacity of production systems. The main objective of mitigation is adopting agricultural practices and crops that reduce emissions or increase carbon sequestration in agricultural systems. In agriculture, as a rule, good agricultural practices that promote resilience also have the co-benefit of mitigating climate change, either by emissions reduction and/or the improvement of the carbon balance in the agricultural system. In this context, Embrapa Agricultural Informatics has made a great contribution, through its leadership in Embrapa's Climate Change Portfolio, in the preparation of data and the execution of simulations. The results obtained have been used as the basis for important public policies, such as the definition of the strategic lines of the ABC Plan and the National Adaptation Plan – Agriculture Sector.

Climatic projections

In order to assess the impact of climate change on agriculture, the first step is to process and analyze climate projections. These are carried out by the Intergovernmental Panel on Climate Change (IPCC) at the global level and by the Brazilian Panel on Climate Change (PBMC) in the national context.

The processing and treatment of climate projections is a complex task that demands high processing and data storage capacity. Currently, the climate scenarios provided by the IPCC are in their sixth version. The Embrapa Agricultural Informatics team has traditionally made these data available for studies on the impacts of climate change. This step involves not only data processing, but also analyses and distribution to be used in agro-environment models. Figure 4 shows, as an example, the expected changes to the water balance, considering the results of climate projections for 76 different climate models.

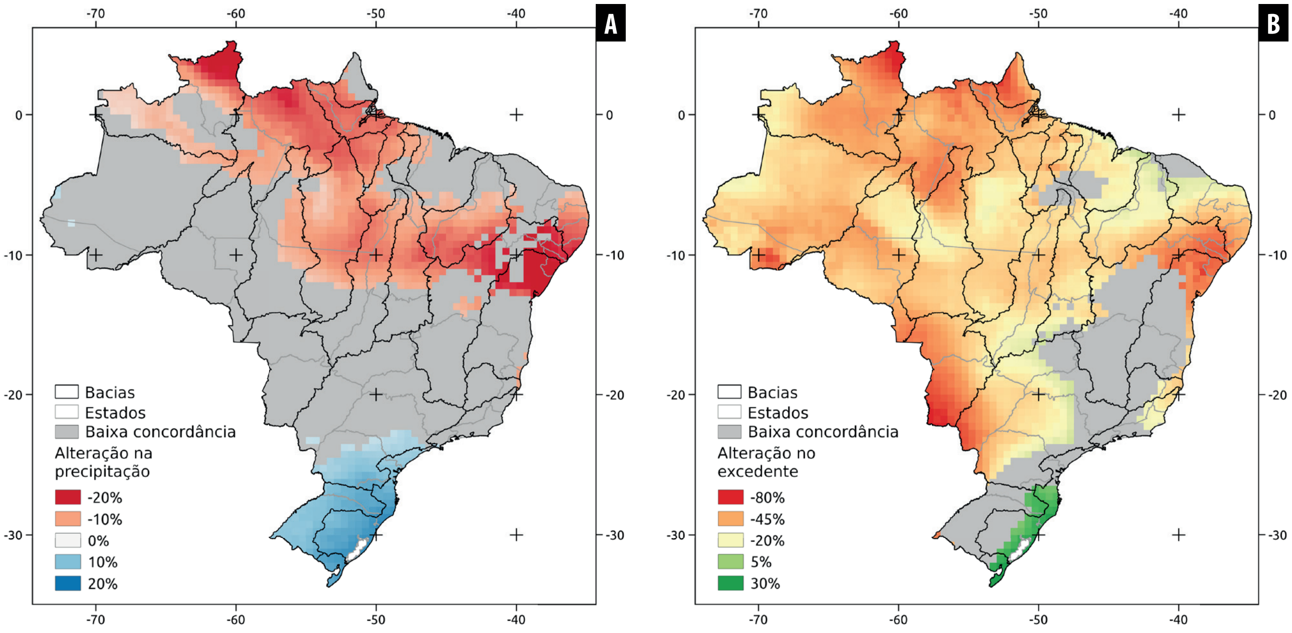

Figure 4. Change in annual precipitation (A) and water surplus (B), medians from 76 global climate model projections. Gray areas indicate less than 2/3 of agreement between the models.

Agricultural impacts

Several studies in Brazil elucidate that the materialization of climate change scenarios will severely impact Brazilian agriculture (Assad et al., 2016). Unlike high latitude regions, tropical regions, exporters of agricultural commodities are likely to experience more severe impacts of climate change on crop yields (Stevanović et al., 2016). The increase in global average temperatures could increase the occurrence of thermal and water stresses and, as a consequence, decrease productivity (Zhao et al., 2017). It is estimated that climate change is already reducing global agricultural production by 1 to 5% per decade over the past 30 years, and that it will continue to pose challenges in the coming decades (Challinor et al., 2014).

Embrapa Agricultural Informatics has actively contributed to the understanding, quantification, and proposal of adaptation measures against climate change. As an example Embrapa led the development of SCenAgri, which has already been used as a modeling basis in some studies on the subject (Assad; Pinto, 2008).

Simulation of future agricultural scenarios

The Agricultural Scenario Simulator (SCenAgri) is a system created to provide high-performance computing to support researchers working with climate change impacts on Brazilian agriculture. The system was developed based on the Bipzon model (Assad, 1986), which allows the simulation of future agricultural scenarios using data from different regionalized climate projection models. Its database includes more than 3,000 rainfall stations with daily data for at least 30 years, and is prepared to simulate climate risks for 20 annual and perennial crops. Several models of future climate projections are also incorporated into the simulator and made available by the Coupled Model Intercomparison Project Phases 5 and 6 (CMIP5 and CMIP6).

Territorial planning and land use

When considering rural planning, it is essential to understand aspects of the territory and its biophysical and human interrelationships. The integration and articulation between different territory scales and actors is complex and sensitive, requiring a series of preliminary considerations with implications at the local, municipal, and regional levels. It must be taken into account that rural planning has advanced beyond agricultural planning and needs to integrate elements from different disciplinary domains. For example, consider not just soil conservation, irrigation, and drainage, but the allocation of water resources and integrated watershed management, involving urban and rural populations. The existence of conflicting interests must also be recognized, as well as developing processes to deal with them.

Considering this scenario, it is essential to obtain social, economic, and environmental data, as well as additional information to support decision-making on land use at different territory scales. Studies and application of territorially based models allow to better understand the processes of expansion, retraction, transition, conversion, and agricultural intensification. These can support public policies associated with climate change and sustainable rural development in Brazil (Bolfe et al., 2016).

By combining agro-environmental modeling in a Geographic Information System (GIS) environment with the use of geographic data and remote sensing, it is possible to support territorial planning based on more complex spatial analyses, integrating information on soil, climate, vegetation, agriculture, water and socioeconomic resources. As an example, we can highlight the generation of models and simulations associated with the potential of land use, the analyses and projections on agricultural dynamics, agro-ecological and ecological-economic zoning, risk assessments and climate resilience.

As in most of the products and tools presented in this chapter, this spatial and temporal information supports managerial decision-making in public policies and private actions in the rural planning of properties, micro-watersheds, municipalities, states or biomes. Therefore, they benefit greater productive diversification and a more sustainable use of natural resourses in rural areas.

Agroideal

The Agroideal system, available at agroideal.org, developed by The Nature Conservancy (TNC), in partnership with Embrapa Agricultural Informatics and commercial companies in the agricultural sector, represents an example of the application of agri-environmental models in the decision-making of territorial occupation. Agroideal brings together information on logistics (location of storage silos), socioeconomic (occurrence of land conflicts), and environmental legislation (location of conservation units) with information on crop growth models (attainable productivity of soy). As such, decision makers can assess their operating strategy, identifying risks and opportunities in different regions of Brazil. The estimate of attainable soybean productivity (Figure 5) was only possible due to the organization of a large climatic database covering the entire territory along with a database of physical and water characteristics of Brazilian soils. These were then used in an agricultural crop growth model.

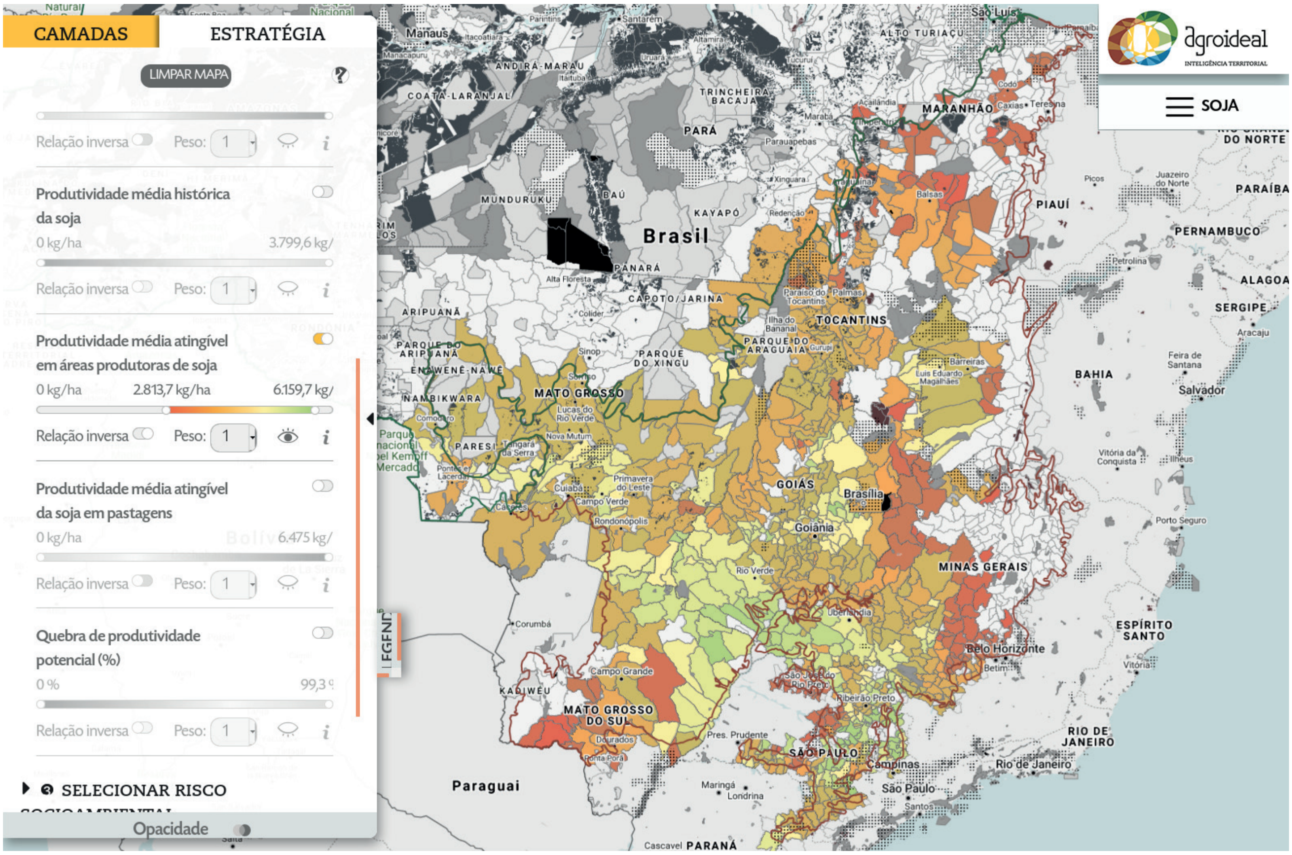

Figure 5. Potential soy productivity average in municipalities within the Cerrado biome (limited to productivity above 3,000 kg ha^{-1}).

Source: Agroideal (2020).

DINACER

Agricultural Dynamics in the Cerrado (DINACER) is another example of a database and information to support public and private decision-making in agricultural development on geospatial land use bases (Bolfe et al., 2020). This biome has strategic importance for the country's interests regarding food security, environmentally sustainable agriculture, and the preservation of biodiversity. DINACER, is carried out in collaboration with the National Institute for Space Research (INPE) and the Institute for Applied Economic Research (IPEA). They analyzed edaphoclimatic and vegetational aspects, public policies, research, innovations, technical assistance, agricultural dynamics, productivity, climate change, projections on the potential for expansion, and agricultural diversification of the biome. The analyses considered, whenever possible, the period corresponding to the past four decades up to 20-year projections. One of the analyses assessed the potential for expansion of agriculture in areas occupied by cultivated pastures (Figure 6). They identified that 44.5 million hectares of pastures present climatic and relief characteristics similar to the areas currently occupied by annual rainfed agriculture (Victoria et al., 2020).

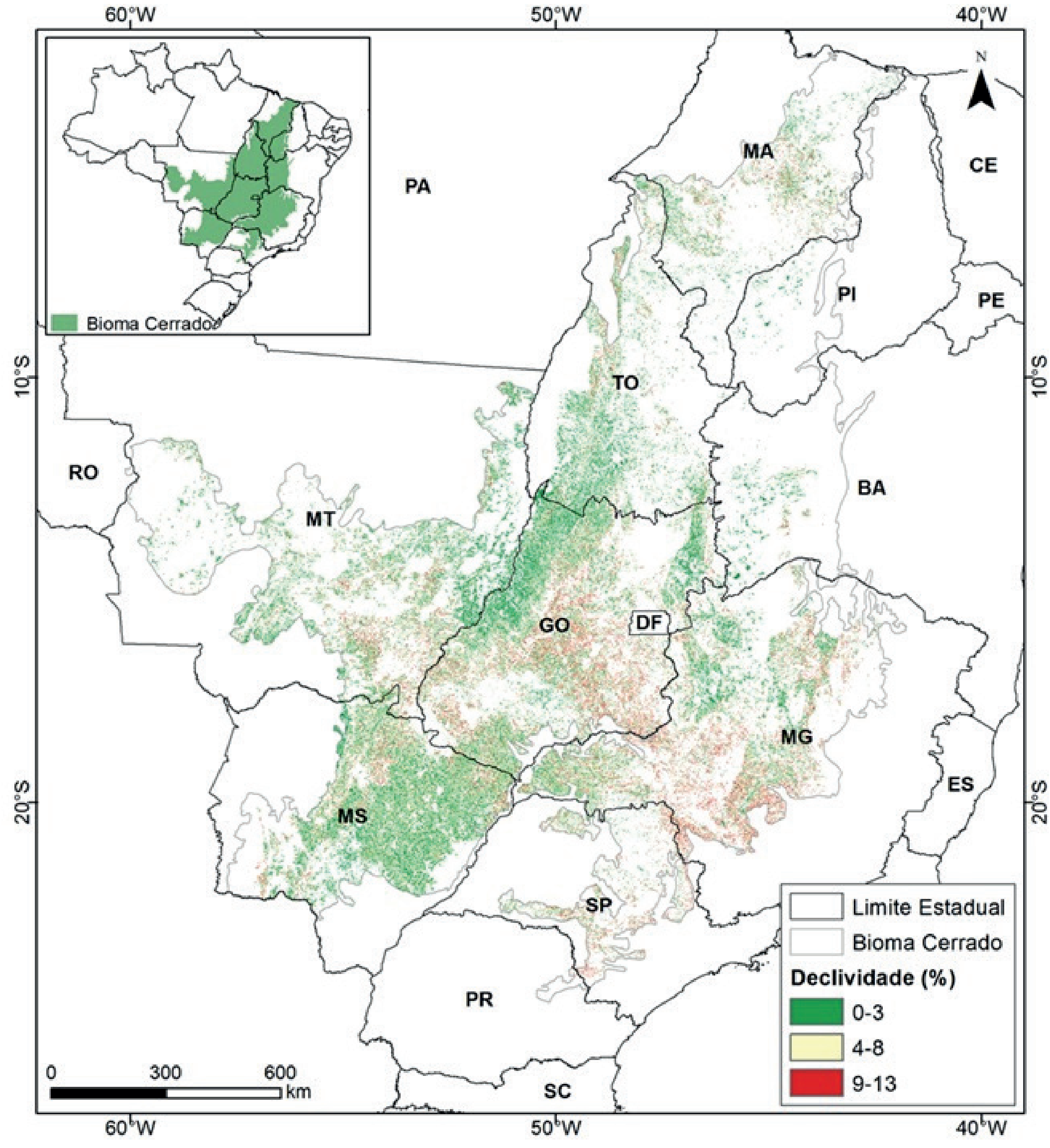

Figure 6. Pastures areas in the Cerrado biome with potential for annual agriculture according to water balance and broken down into slope ranges.

Source: Victoria et al. (2020).

Applications of agroenvironmental models for the conservation of ecosystem services

Agroenvironmental models are a powerful tool in the planning of a technified and digital agriculture based on robust knowledge about the functioning of agroecosystems. They consider other aspects in the relationship between agriculture and its means of production. These go beyond the generation of food, fibers and energy and analyze other benefits, such as the impacts of agricultural systems on the maintenance of water regulation (through the assessment of the water footprint), climate regulation, and other ecosystem services enjoyed by society.

Ecosystem services are the benefits directly and indirectly appropriated by man from the functioning of healthy ecosystems. Their importance for the economic system and for the well-being of future generations is increasingly recognized, as they provide essential goods (such as food) and services (such as the assimilation of waste).

According to Costanza et al. (1997), examples of ecosystem services, among many others, consist of: the carbon and nutrient cycle, the water cycle, soil formation, erosion control, climate regulation, conservation and evolution of biodiversity, the concentration of minerals, the dispersion or assimilation of contaminants, and the various usable forms of energy. The authors estimated the annual value of global flow from 17 services in 16 types of ecosystems. The results show that planet Earth's natural capital would annually yield an estimated average flow of US$ 33 trillion per year, about 1.8 times the gross world product at the time (US$ 18 trillion), at 1994 prices.

The Millennium Ecosystem Assessment (2005), conducted between 2001 and 2005, provided scientific bases for the sustainable management of ecosystems, allowing the continuous provision of the services they generate. This work demonstrates the recognition, by the international community, of the need and urgency of innovative measures to protect ecosystems, measuring their preservation for economic development (Andrade; Fasiaben, 2009).

Despite the importance of ecosystem services, these are currently not considered in economic transactions, as they are considered "free" or "gifts" from nature. The fact that they are not priced like other goods or services means that there are no incentives for their preservation, leading to overexploitation and often to total loss (Andrade; Fasiaben, 2009). However, such services and the stocks of natural capital that produce them are critical to supporting life on Earth. They contribute to human well-being, and therefore represent part of the planet's total economic value.

As natural capital and ecosystem services become more overexploited and scarcer, their value is expected to increase. Thus, studies related to its conservation are fully justified, in order to guarantee the provision of ecosystem services and support the formulation of policies that move in this direction. In this regard, agro-environmental modeling provides tools to support decision-making by public and private agents.

WebAmbiente

WebAmbiente[6] is an interactive system intended to facilitate the storage and search for information on technological solutions. These are involved in the use, recovery, and restoration of environments in legal reserves and areas for permanent preservation in all six biomes. The system was developed

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[6] Available at: www.webambiente.gov.bz

by Embrapa and the Secretariat for Extractivism and Sustainable Rural Development of the Ministry of the Environment (MMA), in cooperation with specialists from partner institutions. It provides technical assistance and rural extension (ATER) multiplying agents with an information set aimed at environmental recovery, in particular a detailed database on native species, as well as articles, videos and a glossary that addresses various topics and techniques. These range from seed collection to seedling production, planting, and strategies for ecological restoration. The system provides the user with a friendly tool that helps generate a report containing suggestions for native species (Figure 7), recomposition strategies and good practices to be adopted based on the characterization of the rural property in terms of biome, above-soil vegetation and risk conditions. WebAmbiente, aligned with the National System of Rural Environmental Registry (SICAR), expands the integration with the Brazilian Forest Service (SFB), and one of its main functions is to support the implementation of the new Forest Code, by encouraging the use of the Rural Environmental Registry (CAR).

Acrocomia aculeata **(Jacq) Lodd. ex Mart.**

Espécie:	*Acrocomia aculeata* (Jacq) Lodd. ex Mart.
Nome Popular:	Bocaiuva, Macaúba, Coco-babão, Coco-babosa, Coco-macaúba, Coqueiro-de-espinho, Macajuba, Macaibeira, Palmeira-macaúva, Coquinho
Sinonímia:	*Cocos aculeata* Jacq.
Família:	Arecaceae
Bioma:	Amazônia, Cerrado, Pantanal
Formação Vegetal:	Campestre, Florestal, Savânica
Fitofisionomias:	Campo não Inundável, Cerrado Típico, Cerradão, Chaco, Mata Ciliar, Mata Ripária, Mata Seca, Mata Seca (decídua), Mata Semidecídua, Mata de Galeria, Palmeiral, Savana, Terra Firme
Presença nos estados:	BA, CE, DF, ES, GO, MA, MG, MS, MT, PA, PE, PI, PR, RJ, RO, RR, SP, TO
Período de coleta de sementes:	Cerrado - ago-fev ; Pantanal - ago-dez; Amazônia - set-jan

Figure 7. Native plants catalog from WebAmbiente.

Source: WebAmbiente (2020).

Hydric resources

Even though Brazil being considered a country with great availability of water resources, there are regional differences and variations throughout the year that render the study of hydrological regimes as very important. Human actions, such as changes in land use and coverage, and fluctuations in weather patterns can affect the availability of water resources, altering the natural flow in watercourses. These changes can affect the flow both in small basins (Bosch; Hewlett, 1982) and in large areas (Costa et al., 2003). The same applies to different agricultural systems and crops, with different characteristics of rain and soilwater interception. Such changes can modify the total flow rate of rainfall, generally increasing the portion drained into water bodies by anthropogenic changes (Lima et al., 2014).

Thus, biophysical models coupled with hydrological models enable evaluating human impacts or climate change on water resources. Such models vary in their degree of complexity and can be applied in the most different scales and situations. As an example, the integration of the results of the water balance with economic models of general equilibrium can be mentioned. These allow evaluating the effects of irrigation expansion on the water demand in relation to the water supply (Ferrarini et al., 2020).

Integration of socio-economic analysis in agro-environmental modeling

Projects conducted in partnership with other company units[7] and with the Brazilian Institute of Geography and Statistics (IBGE) improved the image of Brazilian agricultural production. Data from the IBGE Agricultural Census served as a basis to differentiate the types of beef and sugarcane production systems in use by producers throughout the country. Based on these works, the most representative types of production systems were chosen to be studied in depth. The project team held meetings with producers, technicians, and other agents linked to regional agriculture where they expanded the description of the technical and economic behavior of these products on rural properties. The information collected also allowed to associate the different forms of production with environmental impacts, such as the calculation of greenhouse gas emissions.

The obtained results were incorporated into mathematical models of land use – which explain how this activity's expansion takes place – which were the basis for the construction of Life Cycle Inventories (LCI), which resulted in studies of sugar cane Life Cycle Assessment (LCA) and derivatives of livestock production. Such works contribute to improving the environmental performance of products, enabling the reduction of environmental and socioeconomic impacts. The generated technical coefficients contributed to the results of several Embrapa projects with different partners[8], in addition to collaborating with the National Biofuel Policy (RenovaBio).

As a result, there is more reliable information on environmental performance of Brazilian agricultural products. This information was inserted by Embrapa in the most important international LCI databank, ecoinvent, through LCI AgroBR, which made available more than 400 LCIs of Brazilian agricultural products. Such actions help increase the competitiveness of agricultural products in the international market and promote the sustainability of Brazilian agriculture.

The characterization of sugarcane production systems was adopted by the National Bank for Economic and Social Development (BNDES) in the context of financing Flex Plants and by RenovaBio. The tool for accounting for the biofuels' carbon footprint was RenovaCalc, one of the pillars of RenovaBio, which was developed by Embrapa and partners. This policy strongly contributes to the adoption of a more sustainable model for the production of bioenergy and biofuels and to the reduction of greenhouse gas (GHG) emissions from the transport sector, contributing to reaching the national goals assumed in the Paris Agreement, as well as for national energy security.

Another aspect of the team's work makes use of models that integrate the biological and economic dimensions, with different degrees of complexity and regional outlines to assess the effects of intensification strategies on sustainability. More recently, more complex economic models have been developed to investigate the potential impacts of supply shocks, like productivity gains, and demand shocks, such as an increase in population, per capita income, changes in the Brazilian and global agriculture, equilibrium prices, and land use dynamics.

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[7] Siscana Project, Socioeconomic Action Plan: Embrapa Environment, Embrapa Western Agriculture, Embrapa Coastal Tablelands; Economics Component of the PECUS Network Project: Embrapa Beef Cattle, Embrapa Dairy Cattle, Embrapa Eastern Amazon, Embrapa Pantanal, Embrapa Southeastern Livestock, Embrapa Southern Livestock, Embrapa Forestry and Embrapa Swine & Poultry.

[8] Among such projects, the following stand out: "Assessment of the Life Cycle of sugarcane and derivatives produced in the Center-South of Brazil, based on data, factors, and models adapted to national conditions" (LCI-cane, Embrapa); "Ethanol production through the integration of off-season corn to sugarcane mills: environmental-economic assessment and policy suggestions" (BNDES) – Available et: https://web.bndes.gov.br/bib/jspui/handle/1408/2496; "Life Cycle Inventories of Brazilian Agricultural Products: a contribution to the ecoinvent database" (ICVAgroBR, SECO, Switzerland).

Therefore, the capacity to investigate future expansion, competitiveness and sustainability scenarios for Brazilian agriculture is increased, as well as the potential impacts of some of the public policies of sectoral interest.

Applications for quantification and mitigation strategies for GHG emissions

Despite being affected by climate change, agriculture can contribute to reducing GHG emissions and mitigating the impacts of climate change. This is because the mitigation actions proposed for the sector also serve as adaptation modes, that is, by promoting greater carbon sequestration, they also result in lower nutrient losses in agroecosystems and improved physical structure and soil water availability, for example. Such actions also promote better productivity rates and better use of natural resources. Mitigating emissions result in more favorable GHG balances, helping the transition to low-emission agricultural production.

In defining the technologies contained in the Low Carbon Agriculture Plan (ABC Plan), estimates of the carbon balance were based on the difference between emissions and sequestration in production systems. These were based on data derived from experiments carried out by Embrapa and the use of simplified models for calculating how this balance could be more favorable with the adoption of good practices or technologies encouraged by the Plan. The comparison worked with the differences in relation to what is traditionally done in the management of agricultural, livestock and forestry systems. In technical jargon, the improvement of the balance in relation to what is usually done, *i.e.,* from business as usual, is called additionality. When focusing on ensuring sustainability in agriculture in all its aspects, only adaptive technologies and practices were considered. These, on top to being additional, bring greater efficiency, diversification, and profitability to the agricultural producer, along with the co-benefit of reducing emissions.

More complex studies on the carbon balance in agricultural, livestock, and forest systems, including integrated systems, were carried out by the Fluxus, Pecus, and Saltus projects, respectively. These enabled the improvement of carbon balance models in Brazilian production systems, knowledge about GHG emissions from these systems, and application in the national inventory of gases for the agricultural sector. This is part of the national communication to the UN and contains a national balance of how much is emitted in the sector.

As a way of monitoring the effectiveness of the ABC Plan and its actions, the Multi-institutional Platform for Monitoring the Reductions of Greenhouse Gas Emissions in Agriculture was created. The ABC Platform uses models based on georeferenced data and GHG emission parameters from different production systems in order to estimate emission reductions during the first ten years of the ABC Plan. This will enable the compliance assessment for the goals established for each different technology. Another tool that contributes in this regard are the GHG balance estimation protocols (GHG Protocol), internationally accepted as the best practices for the quantification of corporate, project, or product GHG emissions. These protocols offer specific technical guidelines for the national agricultural sector, constituting tools that measure and manage agricultural emissions, especially in the private sector, such as the program implemented by WRI Brazil[9].

The GHG Protocol has been used in the Carbono Araguaia project, hosted by the Liga do Araguaia[10]. The tool was adapted to the national context based on tropical agriculture and livestock parameters,

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[9] Available at: https://wribrasil.org.br/pt/o-que-fazemos/projetos/ghg-protocolo-agropecuario

[10] Available at: http://www.ligadoaraguaia.com.br/projetos-da-liga

it was developed by Embrapa and Unicamp, and allows monitoring the GHG emission reductions from the adoption of intensification practices in 24 livestock farms in the region. These farms have a total 89,000 hectares of pastures.

For the biofuels chain, modeling contributes significantly by the development of RenovaCalc[11] in partnership with Embrapa Environment. RenovaCalc is a biofuels carbon footprint calculator, in other words, it measures the intensity of GHG emissions in the life cycle of biofuels. It generates the necessary estimates for the carbon market related to ethanol, biodiesel, and biomethane.

Another good practical example of this agro-environmental modeling derivation is the effort to estimate, monitor, better communicate, and highlight good practices in the meat sector in accordance with IPCC recommendations with Brazilian and international socio-environmental legislation. This involves the development of standards for voluntary certification of livestock products, the Certified Low Carbon Livestock Platform, led by Embrapa Beef Cattle de Corte and with the significant participation of researchers from Embrapa Agricultural Informatics. It is aligned with the ABC Plan, as is encourages and values the use of livestock systems in a more favorable carbon balance, such as ILP, ILPF, silvopastoral and intensified pasture systems. The following protocols are considered: Carbon Neutral (CCN) or Carbon Neutral Brazilian Beef (CNBB), Low Carbon Beef (CBC) or Low Carbon Brazilian Beef (LCBB), Native Carbon (CN), Low Carbon Calf (Bezerro-CN) and Neutral Carbon Leather (Couro-CN). The protocol developed by Embrapa allows partners to use their respective concept brands – or "environmental seals" – in their activities. This certification will allow consumers to recognize farmers' efforts to promote sustainable, low-GHG farming systems in an integrated landscape approach. Another important point is the dissociation of deforestation and the differentiation of meat sustainably produced in Brazil, which improves international acceptance in the international market, where the country is highly competitive.

Another important initiative to support the formulation of Brazilian public policies to mitigate GHG emissions was the development of the model Economic Analysis of Greenhouse Gases for Livestock Emissions (EAGGLE). It is a detailed optimization model that economically evaluates pasture recovery and GHG mitigation strategies in beef cattle production systems (De Oliveira Silva et al., 2017). It was developed in partnership between Embrapa, the State University of Campinas (UNICAMP), and the University of Edinburgh. The model explores complex scenarios focused on sustainable use of the production area by increasing productivity and the diversity of techniques and products. In the most technical jargon, sustainable intensification of animal production. Furthermore, it allows analyzing the optimization of the adoption rate in the main practices on animal performance efficiency (pasture supplementation, confinement) and pasture (direct and indirect restoration, irrigation), in order to mitigate emissions and save land. It was used by the Brazilian government to develop national policies aimed at emission mitigation actions, particularly in the submission of the Nationally Determined Contribution (NDC) (De Oliveira Silva et al., 2018), a document that records the main commitments of Brazil's contributions to the Paris climate agreement. Additionally, it allows for the consequential analysis on the intensification of meat production in Brazil (De Oliveira Silva et al., 2016).

All these initiatives have been carried out with the strong collaboration of the Agro-environmental Modeling Research Group and also the presidency of Embrapa's Climate Change Portfolio, under the responsibility of Embrapa Agricultural Informatics. They represent Embrapa's contribution to meeting the various demands of society with regard to the climate change and agriculture interface, using simulation tools to envision and positively influence trends for agriculture in the future climate.

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[11] Available at: http://www.anp.gov.br/producao-de-biocombustiveis/renovabio/renovacalc

Final considerations

Models and simulators that can accurately and precisely depict the responses of agroecosystems demand quantity and quality data for their calibration, validation, and model fusion. In this "big data era", data derived from experimental stations are critical for the development of models and simulators, and must be complemented by massive data collection in the field. Obviously, this greater data collection capacity must be accompanied by compatible transfer capacity (IoT, cloud computing) and storage (Big Data). And with data in adequate quantity and quality, algorithms and analysis tools can be improved and/or developed, tested, validated. These can then be made available as part of the decision-making process within agricultural establishments from the production chains and in the formulation of public policies.

One of the great challenges of the digital age is the efficient integration of data, information, and knowledge into models and algorithms. This continuous incorporation of new knowledge into mathematical models and algorithms for data assimilation, decision analysis and optimization, and the integrated use of multi-source and multi-temporal spatial data through agro-environmental modeling are essential to promote competitiveness and the sustainable development of Brazilian agriculture. It is necessary to intensify public-private partnerships in order to enable massive data collection, in space and time, and faster research advances to assimilate these measures, generating analyses, products and services that can be used by rural producers and decision makers in the public and private spheres.

Producers will increasingly demand efficiency and sustainability, given the increase in production costs and the demands not only of agricultural products, but also of environmental and ecosystem services associated with them. Companies and service providers should be more interconnected with innovation ecosystems via research institutes, universities and rural extension. Consumer markets, national and international, tend to increasingly demand food, fiber and energy with certifications that guarantee sustainable production, in addition to quality. Therefore, digital technological solutions that integrate a wide knowledge spectrum will be essential to guide the various actors in Brazilian agribusiness.

As exemplified throughout this chapter, Embrapa Agricultural Informatics has been engaged in the direct development and support for new technologies, and also in making this technology accessible. This is a toolset capable of bringing innovation to all of society and the potential users of digital agriculture in the very near future.

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