ISSN 1517-5685 / e-ISSN 2966-2486

Comunicado Técnico 90

Rio de Janeiro, RJ / Agosto, 2026

OBJETIVOS DE DESENVOLVIMENTO SUSTENTÁVEL

Harmonized protocol for assessing soil ecosystem services in intensive agriculture areas in Argentina and Brazil

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Introduction

Population and economic growth increase the demand for goods and services produced by ecosystems such as food, water, fibre and energy (Fu et al., 2015). Projections show that feeding a global population of 9.1 billion people in 2050 would require an increase in food production by about 70% between 2005 and 2050. Agricultural production in developing countries, such as in South America, is expected to almost double (FAO, 2009). This fact brings the risk of increasing pressures on natural systems if greater efficiency and sustainability are not achieved in production methods (Barral et al., 2020).

In recent decades, socio-environmental problems have been increasingly addressed through the perspective of Ecosystem Services (ES), defined as "the benefits that humans obtain from ecosystems" (Millennium Ecosystem Assessment, 2003). Global agendas have expanded the discussion of the potential of agriculture to generate not only food but also contribute to several other ES provisions for society. In this context, the concept of sustainable intensification (SI) arises, which is defined as a system where agricultural yields are increased without adverse environmental impact and expansion of agriculture to new areas (Pretty; Bharucha, 2014). Figure 1 illustrates the relationship between ecosystem functions and services and their implications for human well-being.

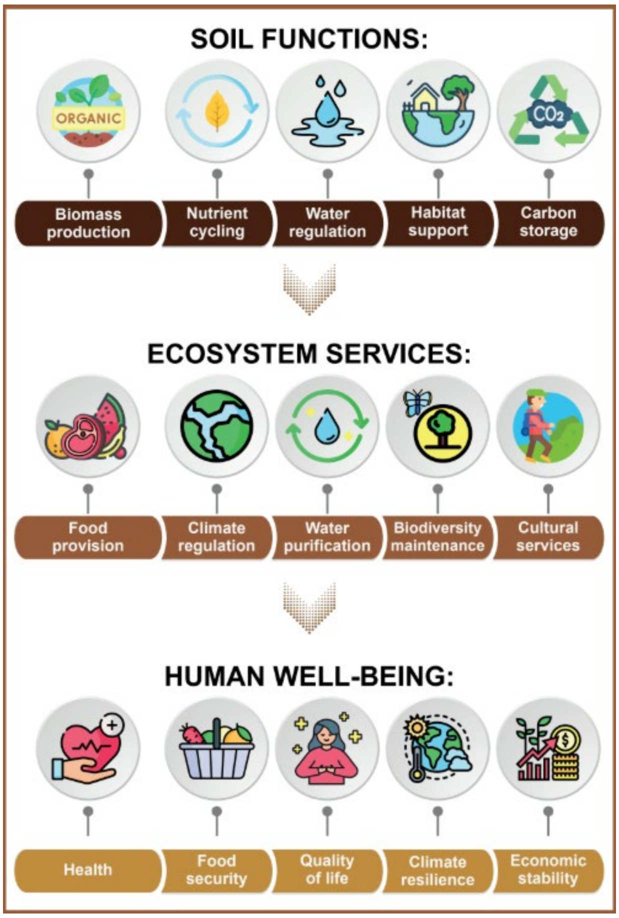


Figure 1. Illustration of the relationship between soil functions, ecosystem services, and human well-being.
Source: Adapted from Millennium Ecosystem Assessment (2003).

Embrapa Solos

Soil is the basis for developing agriculture and providing multiple ES. It depends on environmental characteristics, but above all on agricultural management. Soil Ecosystem Services (SES) can be understood as flows of natural capital stocks in soil which are beneficial to humans and can be classified into regulation, provision, and cultural (Dominati et al., 2010). In this work, the following SES are highlighted: food provision, water regulation, erosion control, carbon storage, and soil biodiversity maintenance.

Soil fertility forms the foundation of agricultural productivity, underpinning the provision of food, fibre, and other ecosystem goods. Key soil processes, including nutrient cycling, microbial activity, and structural integrity, are essential determinants of plant health and crop yield. In addition, soil plays a fundamental role in the hydrological cycle by regulating the infiltration, storage, and redistribution of water, thereby ensuring its availability for agricultural, ecological, and domestic uses (Bronick; Lal, 2005).

Soils also function as a major global carbon sink, storing significant quantities of organic carbon. The depletion of soil organic carbon (SOC) reserves contributes to elevated atmospheric CO_2 concentrations. Conversely, the adoption of soil conservation and carbon storage management practices can mitigate climate change by reducing the net flux of CO_2 to the atmosphere, and simultaneously offer co-benefits for food security, water quality, agro-industrial productivity, and broader environmental sustainability (Lal, 2004).

Furthermore, well-structured soils enhance water infiltration and reduce surface runoff, thereby minimizing erosion and lowering the risk of flooding. Effective erosion control is critical to maintaining soil fertility and preventing sedimentation in aquatic systems. Soil also provides habitat for a diverse array of organisms, playing a crucial role in the maintenance of soil biodiversity. Soil biota significantly influences fundamental soil properties, including hydrological regulation, gaseous exchange, and aeration, which are vital for primary productivity, nutrient cycling, and decomposing organic residues and waste materials (Brussaard, 1997).

Despite the growing interest in the role of soil and recognition of its functions in providing ES, it is still under-evaluated, and little considered in policy decisions, particularly in tropical countries (Hewitt et al., 2015; Adhikari; Hartemink, 2016; Prado et al., 2016; Rodrigues et al., 2021). One of the key challenges is identifying and standardizing comprehensive indicators (EJP Soil, 2026).

Thus, this publication presents a set of SES, indicators and assessment methods at the local (farm) scale, which were selected and validated by a team of experts on the subject and with experience from Brazil and Argentina. The classification of ecosystem services adopted was that of the Millennium Ecosystem Assessment (2003). The aim was to standardize and facilitate their application, also taking into account their low cost and ease of application. The methods are generally similar among Brazil and Argentina, however they are presented separately where differences occur. This publication contributes to the following Sustainable Development Goals (SDGs): 6 — Clean Water and Sanitation, 11 — Sustainable Cities and Communities, and 12 — Responsible Consumption and Production.

Protocol for assessing soil ecosystem services

Figure 2 presents all the evaluation methods of the indicators in an integrated manner, composing the tool for assessing soil ecosystem services in intensive agriculture areas in Argentina and Brazil.

This figure illustrates the indicators selected to quantify SES. To determine these indicators four virtual workshops were conducted during the first year of the project with the participation of all involved countries. Each workshop focused on a specific ecosystem service, which researchers presented the methodologies employed to quantify the indicators representing each SES considering the edaphoclimatic conditions of each country.

The participants agreed adopt a common measurement protocol in instances where identical or harmonized approaches were feasible. Conversely, it was agreed that alternative protocols could be employed when methodological differences were required due to intrinsic soil characteristics, pre-established national protocols, or available analytical instruments, provided that the resulting data remained comparable across countries.

The importance of including an assessment of soil structural stability was discussed during these workshops, as this indicator is directly or indirectly related to all SES. Consequently, it was agreed to include field-based protocols for assessing soil structure to meet the necessary criteria for a suitable indicator (simplicity, cost-effectiveness, and sensitivity). All indicators selected to represent the SES are explained in detail in the following section.

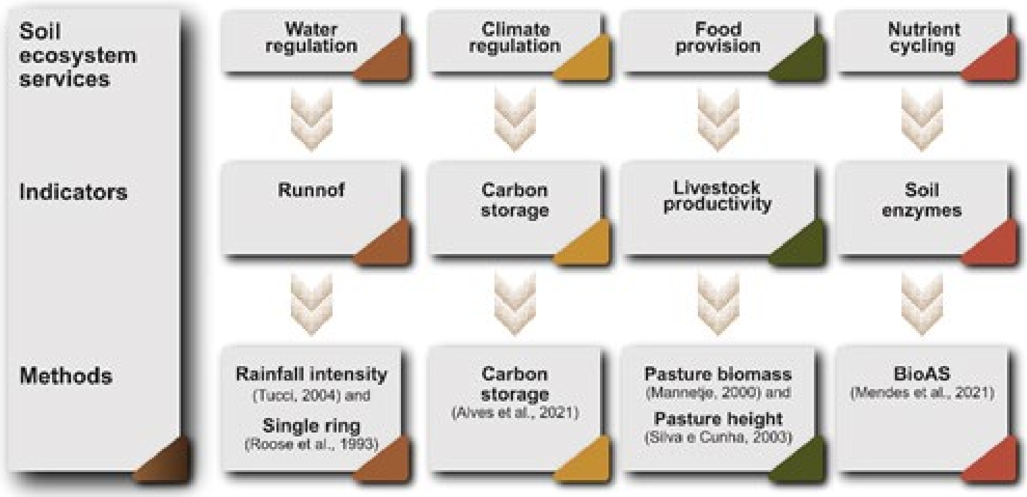


Figure 2. Tool for assessing soil ecosystem services in intensive agriculture areas in South America.

Details of the soil ecosystem service indicators and methods

Water regulation SES

The "water regulation service" was agreed to be represented by an estimate of surface runoff, calculated as rainfall intensity minus water infiltration into the soil, as it is closely to soil functions such as water-holding capacity, water movement through the soil, soil structure, soil pore system, and the presence of compactation layers. The rate of water entry into the soil profile determines the volume of surface runoff. The protocol selected to assess soil water infiltration was the single ring method adapted to local conditions of the study regions, as well as the estimation of rainfall intensity, as detailed below.

Brazil

Measurements were taken at three points spaced 20 m apart, in homogeneous plots of up to 2 ha, in each land-use system, with two replication per point. A single ring (15 cm in height × 10 cm in diameter) (Figure 3A) was inserted 2 cm into the soil. A 510 mL water layer (equivalent to a standard mineral water bottle) was applied, and the time required for complete infiltration was recorded. A second application of the same volume was then performed, and the infiltration time was recorded at one-centimetre intervals until the full volume was absorbed. After this step, a pit was excavated with a shovel to remove the soil beneath the ring, exposing a vertical face at the infiltration site to visualize the wetting front. The wetting

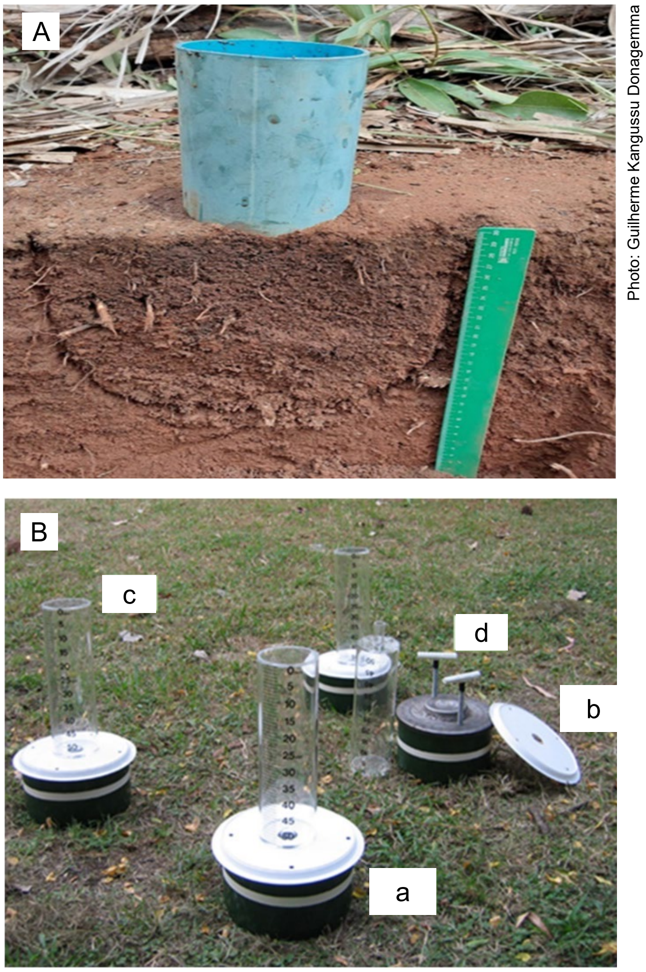


Figure 3. Illustration of methods to evaluate indicators of SES Water Regulation. A) Simple pvc ring of 100 mm, 15 cm x 10 cm; B) Simple ring equipment (developed by Soil Institute, INTA, Argentina) composed of metal ring or cylinder (a), support disc (b), a graduated or Mariotte bottle (c) and steel plate (d).

front was photographed, and its maximum depth and width were determined using software. Infiltration rates were then corrected based on these measurements according to Roose et al. (1993).

Soil samples were subsequently collected to determine soil water content. One sample was taken from the centre of the ring, corresponding to the infiltration site, and another from an adjacent area without water application. Soil water content was determined using the gravimetric method (Teixeira et al., 2017). After calculating the basic infiltration rate, the mean value of the two replication was obtained, followed by calculation of the average across the three sampling points.

Soil erosion depends on several factors such as land slope, climatic conditions and parameters inherent to the soil genetics such as soil texture, soil profile and horizon depths, soil structure, and others related to soil management such as soil coverage, among others. These parameters related to soil can be represented by the water entering into the soil by "Water infiltration" (description included in section *Water regulation SES*). However, the climate conditions of each region are additionally key factors for soil erosion estimation. Rainfall intensity is considered as the main climate factor related to soil erosion.

Figure 4 summarizes the impact of rainfall and soil parameters on soil water erosion. Nonetheless, it is important to consider that not all water enters the soil profile during heavy rainfall, resulting in surface runoff. The rain intensity and the rate at which water enters the profile determines the amount of runoff, which can be used to detect the risk of erosion during flooding or very heavy rainfall.

The erosion control service was estimated by calculating the difference between the maximum 1-hour rainfall intensity (Im) and soil water infiltration. The maximum 1-hour rainfall intensity with a return period of one year was determined using the methodology proposed by Tucci (2004), based on the INMET Database, and the geographic coordinates of each land-use system. Mean values were first calculated from the evaluation points within each land-use system and then averaged across the three sampling points. Erosion control was obtained by subtracting the infiltration value from the maximum 1-hour rainfall intensity. Results are expressed in mm h^{-1}, with optional conversion to cm h^{-1}. Positive values indicate the occurrence of surface runoff and consequently erosion, suggesting that the management practices adopted are not effective for erosion control and may require improvement. Negative values indicate that the land-use systems and their management practices are effective in controlling erosion.

Argentina

The Soil Institute of the National Institute of Agricultural Technology (INTA) in Argentina developed a simple ring apparatus to perform and standardize soil infiltration measurements. These devices are of simple construction and consist of the following components: a metal cylinder measuring 21 cm in diameter, 12 cm in height, and 4.1 mm in thickness (Figure 3B-a); a plastic support disc with a diameter slightly larger than the metal cylinder and a rim that allows it to

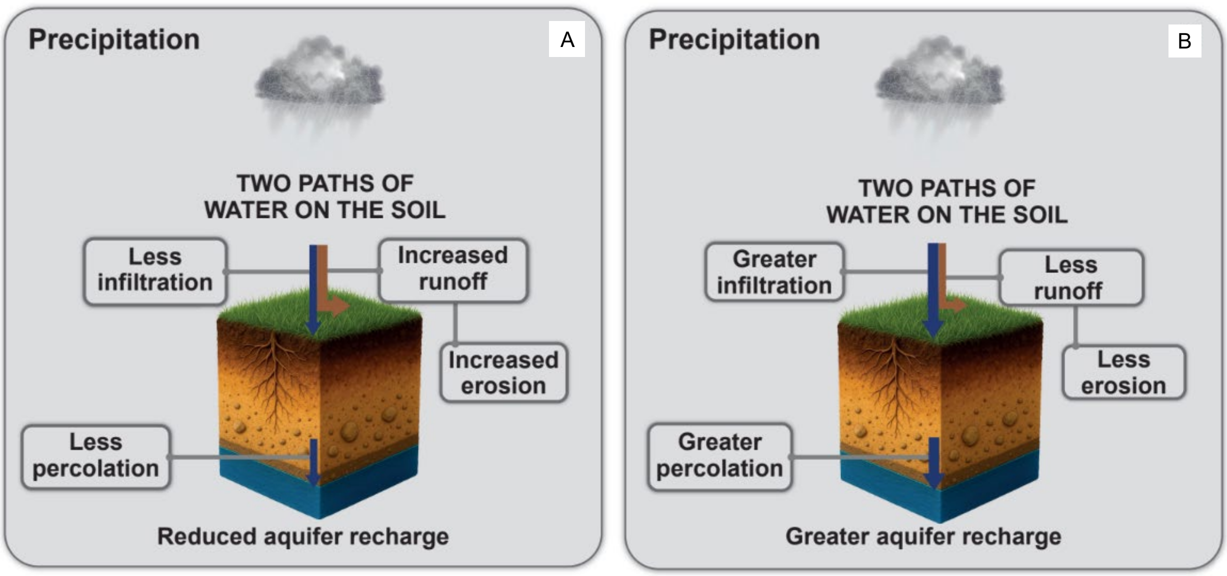


Figure 4. Diagram of the paths that water can follow in the case of: A) lower infiltration capacity of the soil and B) greater infiltration, at the same rain intensity.
Source: Adapted from Escobar Betancourt (2021).

fit over the cylinder (Figure 3B-b), featuring a central perforation that allows the bottle to be inserted upside down; a graduated or Mariotte bottle made in transparent acrylic with a scale printed in mm of water depth (Figure 3B-c); and a solid steel plate which allows the infiltrometer to be embedded evenly in the soil (Figure 3B-d), avoiding cracks that could cause errors in the readings. Infiltration tests are characterized by frequency, repetitions, and measurement time, parameters described below. The number of replicates primarily depends on the size of the experimental units or farmer´s field and the spatial heterogeneity within the area being evaluated. The protocol is commonly applied in relatively homogeneous areas, often larger than 10 ha; however, additional replicates should be included when soil, vegetation, topography, or management conditions are spatially variable. A minimum of four replicates per treatment is recommended and is generally considered adequate for relatively homogeneous areas between 10 and 50 ha. Additional replicates should be included when evaluating larger areas or when substantial variability in soil properties, vegetation, topography, or management practices is present. It is also important to select a uniform site for measurements, avoiding areas affected by vehicle traffic, animal trampling, or concentrated water flow.

For measurements, cylinders are driven into the ground using the steel plate, placing it on the infiltrometer and then tapping it with a hammer up to the mark indicated on the cylinder, leaving it buried 5 cm deep. This mark is a wide line and must be driven all the way to the bottom of said line, allowing a uniform water load to be generated inside the infiltrometer. Once all the infiltrometers are in place, the plastic support discs are placed in position. Using a stopwatch and in an order that will be followed throughout the test, the graduated bottles are inverted onto each support to begin the test. The first reading is taken after 5 minutes, recording all the information on a spreadsheet. The readings on each bottle must be taken in the order in which they were placed. Readings are repeated every 5 minutes or according to a pre-established time. It is vitally important to achieve the basic, final, or stabilized infiltration to complete an infiltration test. In this regard, three consecutive similar measures should be recorded (the rate of water entry into the soil is constant) and the basic infiltration or infiltration rate in mm h^{-1} calculated. As a general rule, this time is set at 1 hour, although stabilized infiltration is not easily achieved in some very sandy soils with more than 80% sand, which requires extending the reading time. It is advisable to sample the initial moisture content of the soil profile at the beginning of each infiltration test. This will enable better interpretation of the results.

Climate regulation SES

Carbon storage in soil plays a major role in climate change mitigation, and also in climate regulation. Moreover, soil organic carbon is widely known as a key indicator of soil health due to the multiple soil functions in which it is involved. Soil organic carbon is central for water retention, nutrient availability, microbial activity, pollutant retention and reduction, and improvements in soil structure stability which is a key factor to decrease the risk by water and wind erosion, among others benefits for resilience of the agricultural systems and human well-being (Figure 1).

This protocol summarizes the steps for site selection, soil sampling, and the calculations required to obtain soil carbon storage. The protocol presented by Alves (2021) has been used as a reference.

For site selection it is important to consider that soil sampling can be performed in long-term experiments (with plots and experimental designs) or in field production situations, where it is important to consult with producers about the management of the study area and its usage history. Satellite images over the years are excellent tools for reconstructing the history of the selected plots. The existence of an undisturbed area representing the original condition is also highly desirable and valuable for these studies. Evaluating uniformity between areas in terms of soil type, horizon thickness, density below 40 cm, and horizon texture are very important for determining the homogeneity of the sites to be compared.

Next, test pits in each sampling unit to be studied are opened (Figure 5A), the number of which will be decided based on the degree of areal heterogeneity. Three test pits are generally considered sufficient for relatively homogeneous sampling units, which are often larger than 10 ha. However, the number of test pits should be increased in areas with greater spatial heterogeneity to adequately capture soil variability. Then, soil samples are taken from the pits at a depth of at least 0–10, 10–20, 20–30 cm, as this is the minimum sampling depth indicated by the Intergovernmental Panel on Climate Change (IPCC). It is desirable to continue sampling to a greater depth if possible, including the 30–50, 50–70, 70–100 cm strata (Figure 5B), or until the water table or other impediment is encountered.

Deformed soil samples are taken from three walls of the pit and are composed into a single sample by depth. Four other sampling points within a radius of 5 to 10 m around the pits should be included, but only using the auger at 0–10, 10–20 and 20–30 cm, where the most significant changes are expected.

Other undisturbed samples that require preservation of the natural soil structure are also obtained using metal rings with known internal volume (volumetric cylinder, Figure 5C), to determine the soil bulk density (SBD) (Burke et al., 1986) by the following equation:

SBD (g cm-3 = Mg m-3) = dry soil mass/ cylinder volume

Disturbed soil samples for carbon content determination were collected using an auger, while undisturbed samples for soil bulk density were taken using volumetric cylinders, both at the bottom soil depth (Figure 5D).

After collecting and identifying the samples, soil must be air-dried and sieved through a 2-mm mesh. Sieved samples are analyzed for texture and C content. It is essential that all samples be analyzed using the dry oxidation method by automatic total C analysis equipment to accurately determine total soil C and for methodological consistency. The samples must be finely ground to facilitate and increase the quality of the analysis, which is achieved using a roller mill, according to the requirements of the analytical equipment.

The different management practices adopted within each sampling situation can result in differences in soil bulk densities. However, comparisons between treatment areas under study within a given experimental site should be based on the same soil mass of the reference treatment profile; this means the entire comparison is made with respect to the same soil mass. This procedure assumes that compaction resulting from mechanical operations most significantly affects the surface layers of the soil profile. Thus, the C contents in the soil profiles are calculated to adjust to the soil profile of the reference system by subtracting the total C contents accumulated in the extra soil mass at this depth from the deepest layer (70–100 cm). The soil profile selected as the reference will be the soil profile with the lowest total soil mass among the compared soil profiles. This correction was

Photos: Romina Romaniuk (a and b); João Henrique Zonta (c and d).

Figure 5. Illustration of methods to evaluate climate regulation SES indicators. A) Pit at 1 m soil depth; B) Depths delimited within the pit for soil sampling, the red arrows indicate that samples must be taken from three sides of the pit; C) Soil bulk density measurement by simple metallic ring at the first soil layer; D) Auger used to collect disturbed samples, and volumetric cylinders to collect undisturbed samples at the bottom soil depth.

calculated mathematically and expressed through the following equation (Sisti et al., 2004):

$$C_s = \sum_{i=1}^{n-1} C_{Ti} + \left[M_{Ti} - \left(\sum_{i=1}^{n} M_{Ti} - \sum_{i=1}^{n} M_{Si} \right) \right] C_{Tn}$$

in which:

Cs is the accumulation (stock) of C (Mg C ha^{-1}) in the soil at a depth where the soil mass is the same as that observed in the soil profile used as a reference;

$\sum_{i=1}^{n-1} C_{Ti}$ is the sum of the total C content (Mg ha^{-1}) from layer 1 (surface) to layer 'n^{-1}' (penultimate) in the soil profile under treatment;

$\sum_{i=1}^{n} M_{Si}$ is the sum of the soil mass (Mg ha^{-1}) from layer 1 (surface) to bed 'n' (last layer) in the reference soil profile;

$\sum_{i=1}^{n} M_{Ti}$ is the sum of the soil mass (Mg ha^{-1}) from layer 1 (surface) to layer 'n' (last layer) of the treatment profile; and M_{Tn} and C_{Tn} are respectively the soil mass and C concentration in the last layer of the soil profile under the system under evaluation.

The soil carbon stock in Brazil was assessed by following the same approach previously described, with minor adaptations detailed below. Three pits were excavated to a depth of 1 m, spaced 20 m apart for plots of up to 2 ha. Soil bulk density samples were collected using a 100 cm^3 volumetric ring (Figure 5C) (Teixeira et al., 2017), along with samples for determining elemental carbon content using an elemental carbon analyser. Sampling depths were: 0–5, 5–10, 10–20, 20–30, 30–40, 40–60, 60–80, and 80–100 cm, collected from two pit walls: the central wall and the right-hand wall (Figure 5D). For carbon analysis, a composite sample was prepared from the two walls, resulting in one sample per depth per pit. Carbon stock calculations were performed in the same manner as described previously.

Food provision SES

"Food provision service" represents the capability of each productive system to provide a determined food product to society. Livestock production play a crucial role in satisfying this basic human need while also impacting ecosystem health and overall well-being.

Thus, the productivity of grasses in livestock systems was selected to represent this ecosystem service based on pasture biomass. The protocols used were as follows: the quadrat method for pasture biomass assessment (Mannetje, 2000), using a 0.25 m^2 quadrat (Figure 6A) at five sampling points, in homogeneous plots of up to 2 ha, according to the scheme presented in Figure 6B; and an alternative method for estimating biomass based on pasture height, proposed by Donagemma et al. (2025), in which pasture height is measured using the ruler method (Silva; Cunha, 2003) with a PVC tube ruler (Figure 6C), at 50 sampling points, using a rope marked every 10 m, in homogeneous plots of up to 2 ha, following Donagemma et al. (2025). An equation with high accuracy using the biomass and height data was subsequently selected to estimate pasture biomass as a function of height (i.e. with a high R^2 value). It should be noted that this equation is valid for the forage species used in this study for the same soil type, and for the season in which the measurements were taken. A new equation must be developed if any of these factors change.

Nutrient cycling SES

The nutrient cycling service was assessed using BioAs approach, which is primarily based on the analysis of the enzymes β-glucosidase and arylsulfatase (Mendes et al., 2021), specifically carbon and sulfur cycling. Composite samples were collected, each composed of eight simple samples taken with a Dutch auger at a depth of 0–10 cm (Figure 7A to D), in circles around the three pits, totalling three composite samples in each land use system, in areas up to 2 ha. Air-dried fine soil was subsequently prepared from these samples (Teixeira et al., 2017). In turn, β-glucosidase and arylsulfatase activities in the air-dried fine soil were determined according to Tabatabai (1994).

Complementary SES indicator: Soil Structural Quality Index

Finally, the Soil Structural Quality Index (SSQI) is obtained from a rapid diagnosis of soil structure, was selected as a complementary indicator, as it is related to all evaluated ecosystem services.

Brazil

The proposed method for determining the quality of soil structure in Brazil was the Rapid Diagnosis of Soil Structure (RDSE), which consists of a shovel test to assess the surface soil structure based on visual characteristics (Ralisch et al., 2017). A soil block measuring 25 × 20 × 10 cm (Figure 7A) was collected in an area up to 2 ha, using a straight shovel with the soil in a friable state. The block was placed in a tray, and aggregates were gently manually separated, without applying excessive force, until the smallest aggregate size was reached (Figure 7B). Aggregate size was

Photos: Roberson Machado Pimentel (a and c); Claudio Lucas Capeche (d).

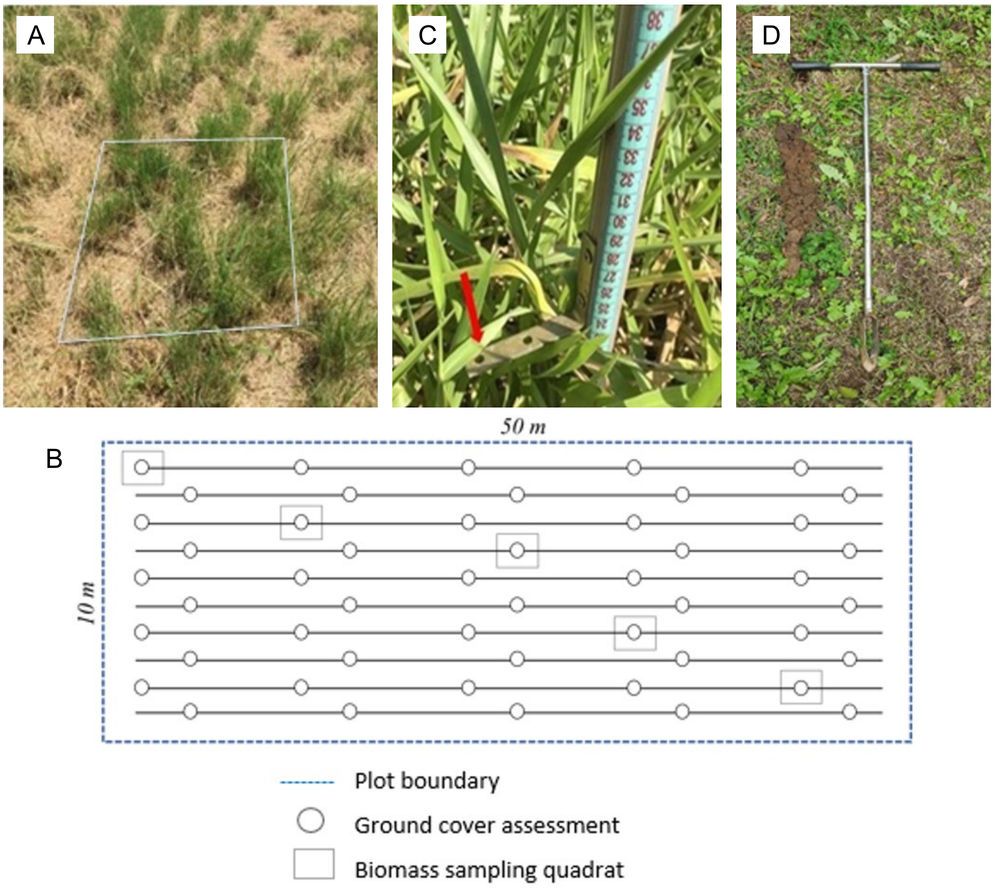


Figure 6. Illustration of methods to evaluate the indicators of food provision and nutrient cycling soil ecosystem services. A) Positioning of the metal quadrat for biomass measurement (0.25 m²); B) Scheme for pasture biomass assessment; C) PVC ruler for measuring pasture height; and D) Dutch auger (10 cm).

Source: Donagemma et al. (2025).

Photos: João Henrique Zonta.

Figure 7. Illustration of RDSE methodology protocol for soil structural quality evaluation in Brazil. A) Soil block for RDSE collected with a flat shovel; B) Aggregates prepared for the evaluation of structural quality, showing the two layers where the assessment of the structural quality of the layer is conducted.

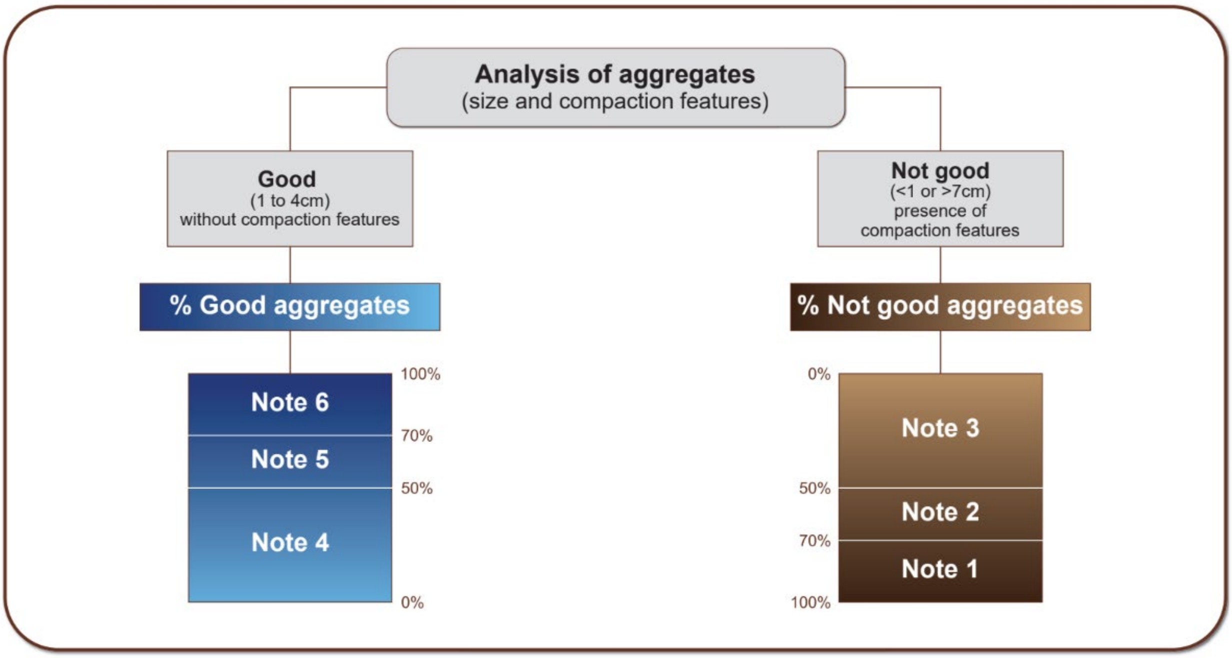


Figure 8. Scheme for aggregate classification for each layer.

Source: Adapted from Ralisch et al. (2017).

then assessed, and a visual evaluation was performed to determine quality (Figure 8). Aggregates were classified as high quality if they were porous and easily penetrated by roots, or low quality if they exhibited compaction, hindering root penetration and causing lateralization. Aggregates between 1 and 4 cm were considered high quality, whereas aggregates smaller than 1 cm were classified as low quality due to fragmentation and loss of original shape. Aggregates larger than 7 cm showing signs of compaction were also considered of low quality.

An aggregate classification scheme (Figure 8) following Ralisch et al. (2017) was used to determine the structural quality of each layer. Finally, a weighted average of structural quality values from the two layers was calculated to obtain the Soil Structure Quality Index for each land-use system.

High-quality aggregates generally range from 1 to 4 cm in size, exhibiting good porosity with roots growing through them. They do not show compaction features such as planar faces and slickensides, nor do they exhibit roots growing laterally. Furthermore, biological activity is often observed, indicated by the presence of earthworms and biopores (pores formed by biological activity) (Figure 9). Conversely, poor-quality aggregates are smaller than 1 cm or pulverized, typically resulting from the breakdown of larger aggregates due to anthropogenic practices, such as plowing and harrowing. In the larger poor-quality aggregates, low porosity, planar faces, and slickensides are noticeable (Figure 10).

Argentina

Due to the particular soil management (No till systems) and texture classes to be assessed in Argentina, it was decided to use a protocol developed for these conditions called the “Field guide for visual evaluation of structural quality” (Peralta et al., 2019). This protocol includes a description of how to select homogeneous areas, a field evaluation of soil moisture and texture, and the detailed explanation to perform the “Burst testing” and the “Laminar structure evaluation”.

The “Burst test” enables analysing the current surface stability condition by quantifying the proportions of aggregates of different sizes observed after the mechanical rupture of the first 20 cm of soil by dropping an undisturbed soil sample (20 cm deep x 20 cm long x 15 cm wide) from a height of 1.5 meters into a plastic recipient (Figure 11A). The structural types are expected to break along their natural cracks, planes of weakness, and fissures into smaller units (soil aggregates < 5 cm, 5–10 cm, and >10 cm) (Figure 11B). Then each soil aggregate size fraction is weighed (Figure 11C) to calculate the percentage of the total as follows:

$$Soil\ aggregates\ by\ size(\%) = \frac{weight\ of\ soil\ aggregates\ by\ size\ *}{Total\ weight\ **}$$

* corresponding to each size fraction (<5 cm, 5–10 cm, >10 cm)

** sum of all size fractions weights

Photos: Alba Leonor da Silva Martins.

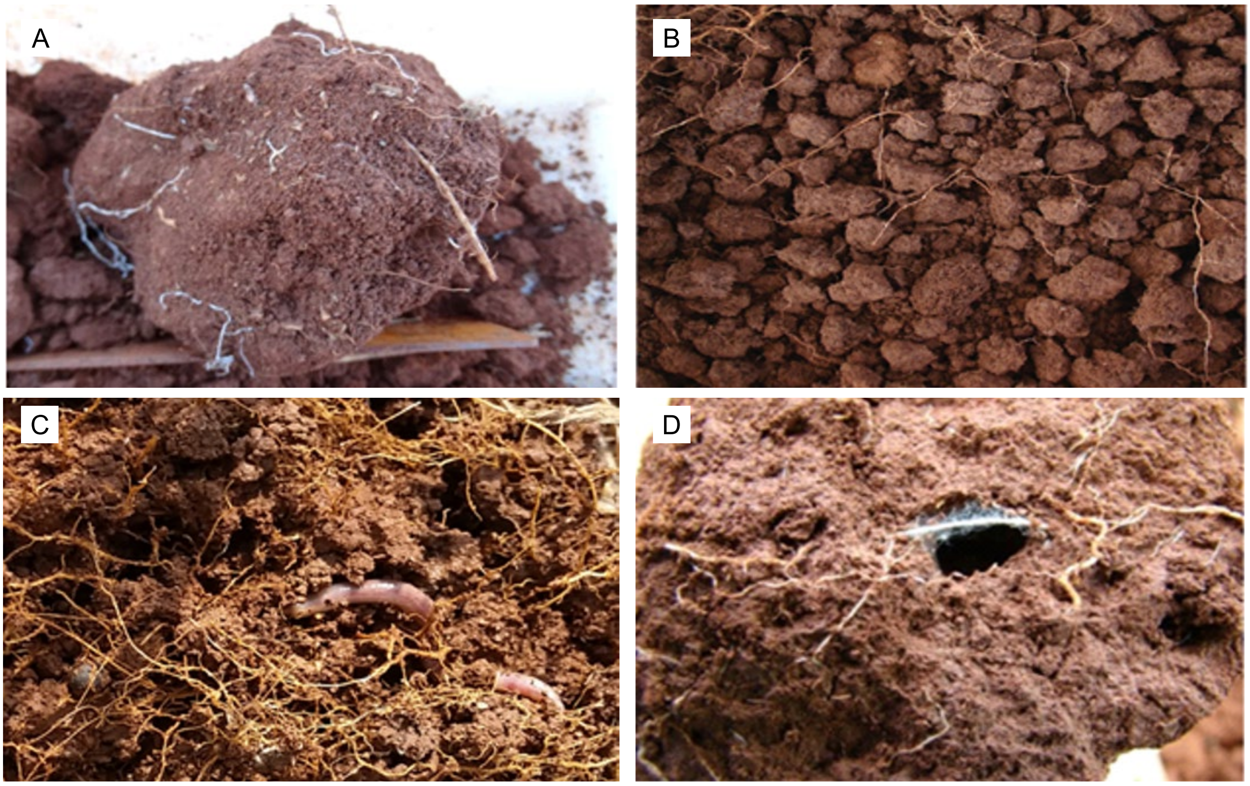


Figure 9. High-quality aggregates. A) Aggregate showing porosity and a root growing normally through it without impedance. B) High-quality aggregates without planar faces or slickensides, displaying roots growing vertically. C) Aggregates showing earthworm biological activity. D) Aggregates with biological activity evidenced by biopores (pores formed by biological activity), highlighting two biopores of approximately 1–2 cm.

Photos: Alba Leonor da Silva Martins.

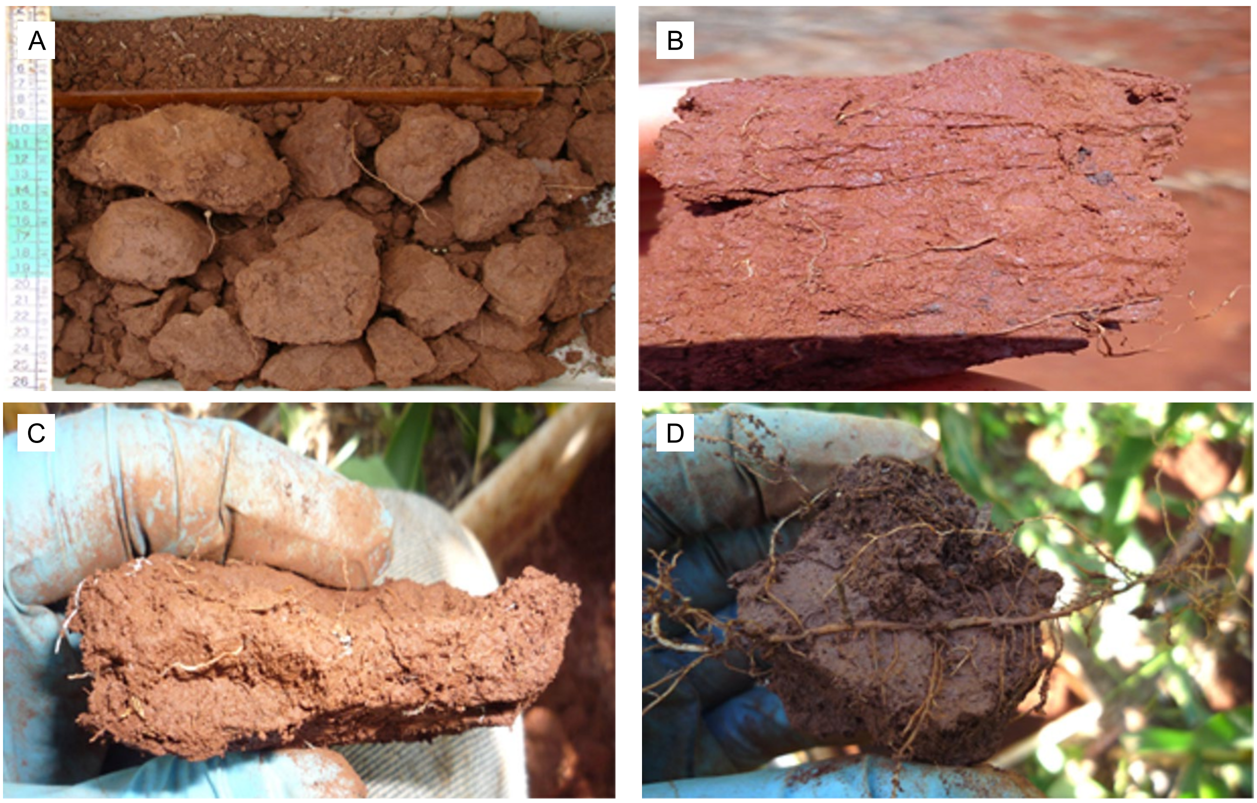


Figure 10. Poor-quality aggregates. A) High proportion of pulverized aggregates (<1 cm), and below the ruler, larger aggregates (>4 cm) showing planar faces and low porosity. B) Large aggregate (>4 cm) with pores parallel to the surface and fine roots growing horizontally without penetrating the aggregate. C,D) Aggregates displaying low porosity and lateral root growth due to soil compaction, which created physical impedance to root penetration.

Figure 11. Illustration of the steps for the Field Visual Evaluation of Soil Structural Quality (VESS) in Argentina. A) “Burst testing”; B) Sorting soil fragments into size categories; C) Weighing each soil aggregate size fraction; D) Measuring the thickness of representative soil structural units; E) Evaluation of laminar soil structure.
Source: Peralta et al. (2019).

The “Laminar structures evaluation” is important in Argentinean soils under no-till systems, because the passage of heavy tractors, combined with some crop rotations that contribute with low residue and/or root biomass, predisposes the soil to form laminar structures. This type of structure affects water and air movement, as well as root growth. Larger laminar structures located closer to the soil surface generally indicate a more advanced state of soil degradation. A shovel of 20 cm wide × 20 cm is used examine the presence of laminar structures in 10 points of the plot by gently striking the shovel containing the undisturbed soil sample against the ground to promote the natural breakdown of soil clods. If there are laminar structures, measure the approximate thickness (Figura 11E) and record each observation. Then calculate the frequency (*Equation 1*), the average thickness (*Equation 2*) and the weighted thickness of the laminar structures (*Equation 3*).

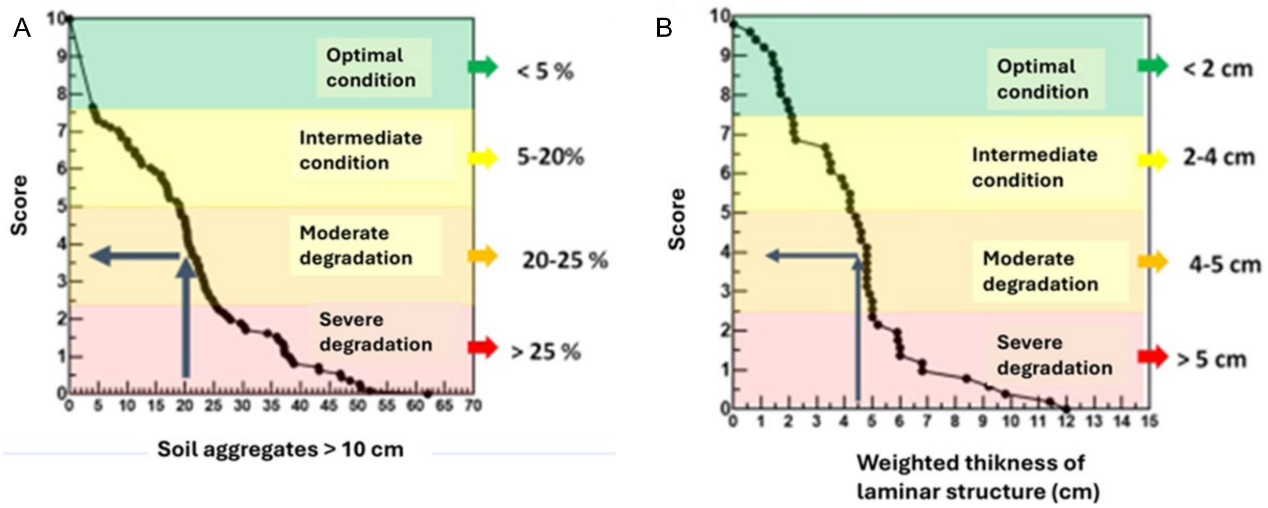
$$Laminar\ structure\ frequency = \frac{number\ of\ observations\ with\ laminar\ structure}{Total\ observations} \tag{1}$$

$$\sum thickness\ of\ laminar\ structures = \frac{\sum laminar\ thickness}{Number\ of\ laminar\ presence\ observations} \tag{2}$$

$$Thickness\ weighted\ laminar\ structures = Frequency * Thickness \tag{3}$$

Next, rate the structural quality according to the results of the burst test (Figure 12A) and the evaluation of laminar structures (Figure 12B) using the score classifications graphs. Once scores are calculated, apply the following equation. With the final score, the integrated diagnostic of the quality structure can be performed by the table presented in Figure 12C.

$$Final\ score = \frac{(Burst\ Test\ Score + Weighted\ Thickness\ Score)}{2}$$



C

Average score	Soil quality structure classification
<2.5	Severe degradation
2.5-5	Moderate degradation
5-7.5	Intermedial condition
>7.5	Optimal condition

Figure 12. Scoring graphs for: A) Burst test evaluation; B) Laminar structure evaluation; and C) Table for soil quality structure classification.
Source: Adapted from Peralta et al. (2019).

Final Remarks

- Ecosystem service assessment methods in each country are based on similar principles and enable correlating results, provided they are conducted on the same soils and land uses. There are minor differences for carbon storage: in Brazil, an additional soil layer is sampled with varying thicknesses; in Argentina, bulk density sampling is performed on an additional trench wall, and carbon is collected from three walls (instead of two), resulting in greater precision, albeit with increased labour. However, carbon stock calculations are identical in both countries.
- The enzyme assessment method using BioAS technology, applicable to pastures. It can also be applied to compare different land-use systems, highlighting the ecosystem service associated with nutrient cycling, particularly the cycling of carbon (C) and sulfur (S). Regarding BioAs, their application in Argentina will require calibration based on soil fertility status and crop productivity, using a network of field experiments.
- Soil structure assessment in both methods is based on visual observation and aggregate size. The Argentine protocol includes a structural feature analogous to compaction recognized in the Brazilian method, but without specific quantification.
- These methodologies are important tools to support technicians and producers in decision-making for sustainable soil management, aiming to improve or maintain ecosystem services. The Brazilian and Argentine methods for the provision of grains or pasture biomass follow equivalent principles and procedures.

Acknowledgements

We thank the European Joint Programme (EJP) for the institutional support and for fostering scientific collaboration, and Brazilian Agricultural Research Corporation (Embrapa - Brazil) for the financial support of the Project: Soil ecosystem services under sustainable intensification of agriculture - looking for innovative mapping and monitoring at multiple scales (SOIL-ES), under the number at Embrapa – 20.23.04.001.00.01.00.

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22460-000 Rio de Janeiro, RJ
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Comunicado Técnico 90
ISSN 1517-5685 / e-ISSN 2966-2486
Agosto, 2026

Edição executiva: *Marcos Antônio Nakayama*

Normalização bibliográfica: *Luciana Sampaio de Araujo* (CRB-7/5165)

Projeto gráfico: *Leandro Sousa Fazio*

Diagramação: *Alexandre Abrantes Cotta de Mello*

Publicação digital: PDF

Ministério da Agricultura e Pecuária