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Management of agricultural solid waste in the Brazilian semi-arid region: diagnosis and proposals for the Rafael Fernandes Experimental Farm — Brazil

Gerenciamento de resíduos sólidos agropecuários no semiárido brasileiro: diagnóstico e propostas para a Fazenda Experimental Rafael Fernandes — Brasil

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ABSTRACT

The rising amount of solid waste in rural areas, especially from agro-pastoral activities, has raised concerns about environmentally sound and sustainable waste management. In this context, the Rafael Fernandes experimental farm (RFEF) aims to improve how it handles waste generated from its research activities. The study plans to systematically analyze waste management at RFEF, identify operational weaknesses and legal issues, and support proposals for technical improvements to the waste management system. The research included a review of relevant technical, scientific, and legal aspects; a qualitative diagnosis with illustrations; visits to agro-pastoral areas; photographic documentation of waste handling; and an assessment of environmental liabilities. The findings showed inefficiencies in the segregation and temporary containment of waste, notably the lack of proper containers and standardized labeling for waste types. There was also no clear schedule for internal waste collection and transportation, leading to material buildup in experimental zones. Additionally, issues were found in storing hazardous waste, such as pesticide packaging that failed to meet safety standards. These results emphasize the need to implement a solid waste management plan, provide ongoing staff training, and upgrade infrastructure to promote sustainable waste practices on the farm.

Keywords: environmental liabilities; rural sustainability; hazardous waste logistics.

RESUMO

O aumento da geração de resíduos sólidos nas áreas rurais, particularmente em atividades agropecuárias, tem despertado preocupações quanto ao manejo adequado e sustentável desses materiais. Nesse contexto, a Fazenda Experimental Rafael Fernandes (FERF) busca aprimorar o gerenciamento dos resíduos oriundos de suas atividades experimentais. A pesquisa objetiva analisar, de forma sistemática, o gerenciamento dos resíduos sólidos gerados nas atividades experimentais da FERF, identificando fragilidades operacionais e não conformidades legais, a fim de subsidiar propostas de aprimoramento técnico para o sistema de gestão de resíduos da unidade. A pesquisa incluiu revisão teórica sobre aspectos técnicos, científicos e legais, diagnóstico quali-ilustrativo, visitas a áreas agropecuárias, registros fotográficos do manejo de resíduos sólidos e identificação de passivos ambientais. Os resultados revelaram a ocorrência de ineficiência nas etapas de segregação e acondicionamento temporário dos resíduos, com destaque para a falta de recipientes adequados e a ausência de rotulagem apropriada para identificação da tipologia dos resíduos. A inexistência de uma periodicidade definida para a coleta e transporte interno também foi constatada, contribuindo para o acúmulo de materiais em áreas experimentais. Identificaram-se, ainda, falhas no armazenamento de resíduos perigosos, como embalagens de agrotóxicos, que não seguiam as normas de segurança. Assim, há necessidade de implementação de um Plano de Gerenciamento de Resíduos Sólidos (PGRS), de capacitação contínua das equipes e aprimoramento da infraestrutura, o que resultaria no potencial melhoramento do manejo adequado dos resíduos na fazenda.

Palavras-chave: passivos ambientais; sustentabilidade rural; logística de resíduos perigosos.

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Introduction

Brazilian agriculture has undergone exponential growth in recent decades, consolidating its position as the main structuring vector of the national economy (Santos and Spolador, 2022). This advancement is intrinsically linked to increased productivity, the expansion of agricultural frontiers, and technological intensification, elements that directly influence environmental systems, territorial management, and the sustainability of natural resources (Panta et al., 2023). Concurrently, the modernization process of the rural environment, coupled with increased consumption in production units, has significantly expanded the generation of solid waste in agro-pastoral or strictly agricultural contexts (Bhatia and Sindhu, 2024). On a global scale, agricultural solid waste (ASW) production shows an annual growth close to 7.5%, as reported by Adejumo and Adebiyi (2020), intensifying pressures on rural communities and elevating the risks associated with public health, environmental quality, and ecosystem integrity (Khan et al., 2024).

The implementation of public policies for solid waste management in Brazil has become an instrument of paramount importance. Oliveira et al. (2025) emphasize that changes in social and cultural behavior in Brazil, along with the creation of legal mechanisms, have proven necessary concerning solid waste management practices. For environmentally efficient solid waste management in rural areas, Panta et al. (2023) affirm that it is essential to consider structuring variables, such as the demographic dynamics of the resident population and the intensification of local productive activities. These factors directly influence the generation, typology, and flow of waste, conditioning the capacity for planning, system sizing, and the implementation of sustainable management strategies (Santos and Spolador, 2022).

Conceptually, according to Singh et al. (2024), solid waste is defined as all solid or semi-solid matter generated by anthropogenic activities. In Brazil, Federal Law No. 12,305/2010 defines solid waste as materials or substances in solid or semi-solid states liable to disposal, including gases and liquids that cannot be directly discharged into water bodies or sewage systems (Brasil, 2010). Agro-pastoral solid waste is defined as materials originating exclusively from agricultural and livestock activities, encompassing both hazardous and non-hazardous fractions (Ferreira et al., 2025). This waste is generated throughout different stages of rural production systems, resulting from processes of soil management, harvesting, area preparation, and animal husbandry (Bhatia and Sindhu, 2024). This set includes organic residues with low polluting potential, such as crop residues and residual plant biomass (roots, leaves, and senescent branches), as well as animal excreta, among other biodegradable materials (Singh et al., 2024).

The inadequate management of ASW constitutes a significant environmental threat, as the decomposition of the organic fraction releases gases such as CH_4 and CO_2, which are associated with unpleasant odors and the degradation of air, water, and soil quality (FAO, 2021; Silva et al., 2021). According to data from the Intergovernmental Panel on Climate Change (IPCC), approximately 23% of the total greenhouse gas emissions into the atmosphere originate from agriculture, forestry, and other rural land-use sectors (IPCC, 2019).

In Brazil, solid waste management was driven by the creation of Law No. 11,445/07, which established the national guidelines for basic sanitation (Brasil, 2007). In 2010, the National Solid Waste Policy (NSWP), Law No. 12,305, was instituted, making the implementation of a solid waste management plan (SWMP) mandatory for different types of waste-generating enterprises (Brasil, 2010). Additionally, the NSWP establishes a management hierarchy: non-generation, reduction, reuse, recycling, and treatment of solid waste, as well as the environmentally adequate final disposal of rejects. Subsequently, in 2019, the National Rural Sanitation Program was instituted by Ordinance No. 3,174, seeking to enhance actions for the universalization of access to basic sanitation in rural areas, such as traditional communities (Brasil, 2019).

The increasing generation of solid waste in rural areas, particularly from agro-pastoral activities, has raised concerns about the adequate and sustainable handling of these materials (Ferreira et al., 2025; Saxena et al., 2025). It is reported that, due to the remote distances of rural areas from urban centers, waste collection services tend to be inefficient; consequently, service provision is often more precarious (SNIS, 2021). Deficiencies in solid waste collection services in rural areas significantly compromise the efficiency of initial handling stages and subsequent phases of the waste management system, affecting storage, containment, pre-treatment, and final disposal in public or collective infrastructures (Bhatia and Sindhu, 2024). This also increases the costs of waste transportation from its origin to the final destination (Oliveira et al., 2025). Other contributing problems include issues related to waste composition and financial constraints for producers and public management (Moh and Abd Manaf, 2017); weaknesses in local environmental legislation and environmentally adequate social management (Freitas et al. 2024); and the scarcity of discussions at the grassroots level concerning the management of generated solid waste, especially among the rural population (Lima et al., 2018).

The Rafael Fernandes experimental farm (RFEF) stands out as a research unit linked to the Federal Rural University of the Semi-Arid Region (UFERSA), conducting studies in Agrarian Sciences and Engineering. It houses the Center for Technological Training in Apiculture, which researches bee compounds. The agro-pastoral and administrative activities generate specific waste, such as packaging from agricultural inputs, veterinary medicines, fertilizers, plastic materials, liquid waste, and grease and oil packaging for machinery (Linhares, 2023). Simonetti et al. (2021) and Ferreira et al. (2024) highlight that all agents involved in the scope of production of a good are responsible for the management of the generated waste. Zago and Barros (2019) advocate that waste management must consider the particularities of the production chain and the local context.

Research at RFEF began in the 1970s at the former Higher School of Agronomy of Mossoró, focusing on alcohol production from sorghum. Currently, extension and research projects on plant nurseries, apiculture, meliponiculture, green manuring in vegetables with native Caatinga species, genetic improvement in fruit culture, weed control, and technologies for melon production are carried out. These activities cater to the undergraduate courses of Agronomy, Agricultural and Environmental Engineering, Forest Engineering, Animal Science, and the postgraduate programs in Soil and Water Management, Crop Science, Animal Science, and Animal Production.

Although the NSWP provides general guidelines, there are gaps in studies on waste management in the agro-pastoral sector in semi-arid regions. This research gap, coupled with the growing concern about environmental impacts resulting from inadequate management practices, reinforces the need for technical and critical analyses that support the adoption of sustainable strategies and compliance with regulatory requirements and environmental safety (Singh et al., 2024). It is noteworthy that the UFERSA Mossoró campus has had a SWMP since 2013; however, it does not encompass the waste generated in the rural agro-pastoral experimental units (Ferreira et al., 2025). In this context, evaluating the waste management processes at RFEF is essential to propose replicable improvements and solutions, contributing to sustainable development and environmental preservation on rural properties.

The present article aims to systematically analyze the management of solid waste generated in the experimental activities of the RFEF, identifying operational weaknesses and legal non-conformities, in order to support proposals for technical improvement of the unit's waste management system.

Materials and Methods

Study area location and characteristics

The study area encompasses the RFEF, located in the municipality of Mossoró, Rio Grande do Norte, Brazil (Figure 1). The farm covers a total area of 418.67 ha, comprising 85.8 ha designated as a Legal Reserve Area, 136.86 ha for agricultural experiments, rural and administrative constructions, and 281.8 ha consisting of remnant native vegetation of the Caatinga Biome. The predominant soils on the farm are classified as Typic Dystrophic Red Argisol, Argissolic Dystrophic Red Latosol, and Typic Eutrophic Argilluvic Plinthosol (Rêgo et al., 2016). The region's climate, according to Köppen's classification, is BShw — dry and very hot, characterized by two well-defined seasons: a dry season typically from June to January and a rainy season from February to May (Beck et al., 2018). The average temperature in the city of Mossoró is 27.6 °C (IBGE, 2023). It features highly irregular annual rainfall, with an average of 695.8 mm (Alvares et al., 2013), recording 965.4 mm in 2024, the year of the study (EMPARN, 2020).

The RFEF staff consists of a manager responsible for activity coordination and nine employees hired through an outsourced services company. The duties of these employees include performing cultural practices, pruning, assembly, and maintenance of irrigation systems, in addition to a heavy machinery operator responsible for handling agricultural equipment.

Methodological procedures

Research design

The research was conducted through two methodological stages: exploratory and descriptive. The exploratory phase involved a detailed theoretical review based on the National Solid Waste Policy (Law No. 12.305/2010), CONAMA Resolution No. 275/2001 of the National Environmental Council (CONAMA), ABNT standards, and academic literature addressing agricultural waste management. The descriptive phase characterized the waste management stages in RFEF's experimental areas, applying a qualitative-illustrative diagnostic approach, as proposed by Gil (2010), to characterize phenomena and establish relationships between variables.

Identification of agricultural solid waste management stages at Rafael Fernandes experimental farm

To identify the practices adopted in the handling of waste generated by RFEF's experimental activities, a survey was conducted in the areas designated for agricultural experiments. This action provided elements allowing for the identification of waste management stages. The diagnostic phases included consulting the current management regarding the waste handling methods adopted on the farm and conducting on-site visits (in loco).

The purpose of the on-site visits was to obtain, validate, and/or challenge previously conveyed information (Ferreira et al., 2025). The visits were carried out through direct observation in the agro-pastoral experimental areas, followed by the collection of qualitative-illustrative data on current waste handling practices. This involved taking photographic records and developing an image database to identify the current scenario of the waste management stages. The visitation period spanned the months of March and May 2023, specifically on the sixth, eighth, and tenth of March, and the eighth, tenth, and twelfth of May, which corresponded to Mondays, Wednesdays, and Fridays, respectively.

For better understanding, the stages adopted during the waste management diagnosis at FERF are available in Figure 2.

Analysis of agricultural solid waste management stages at Rafael Fernandes experimental farm

The analysis consisted of a survey of the agricultural waste management processes adopted at RFEF, considering the existence and quality of execution of the stages established by the NSWP for the proper management of solid waste. The scope of stages includes collection, segregation, containment, storage, transport, transshipment, treatment, and environmentally sound final destination of solid waste, and environmentally sound disposal of rejects (Brasil, 2010). Brazilian environmental and sanitary regulations were reviewed to identify the best practices applicable to the farm.

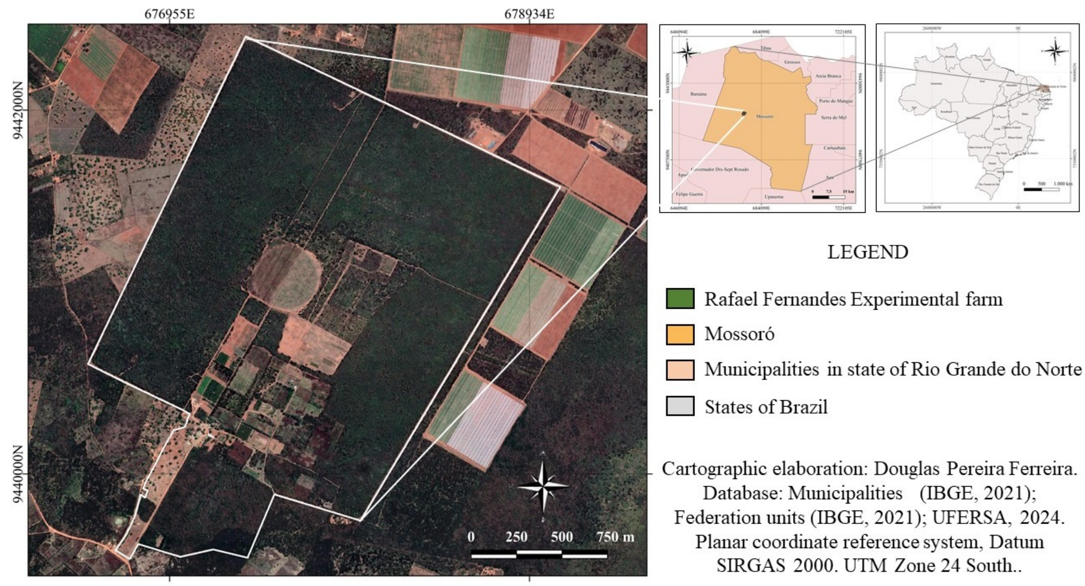

Figure 1 – Location of the Rafael Fernandes experimental farm.

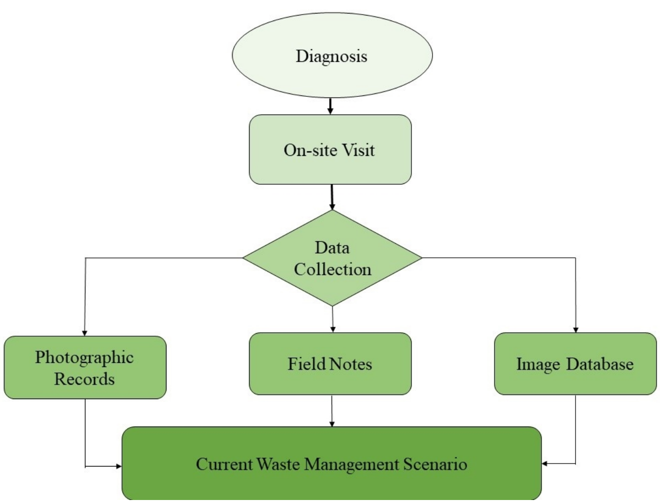

Figure 2 – Flowchart of the stages adopted in waste diagnosis and management.

Development of intervention proposals

The formulation of the intervention proposals considered the critical issues found in RFEF's current ASW management system. Weaknesses related to segregation, containment, transport, and final destination of waste were assessed, using Law No. 12.305/2010 (NSWP) and correlated resolutions, such as CONAMA No. 275/2001 (Brasil, 2001) and No. 450/2012 (Brasil, 2012), as reference. Based on this diagnosis, practical measures aimed at environmental and operational adequacy were structured, organized into five main axes: adequate segregation and containment, improvement of internal transport and temporary storage, external transport, staff training, and development of an agricultural SWMP.

Results and Discussion

Identification of the agricultural waste management stages

Based on information obtained from the farm's management, ASW management is currently executed without the implementation of a formal SWMP, despite the creation of such an instrument being a legal mandate established by Federal Law No. 12,305/2010, which requires waste-generating enterprises to adopt formal control measures and ensure the environmentally sound disposal of discarded materials (Brasil, 2010). Although a formal SWMP is not in place, waste management practices are adopted on an *ad hoc* basis, driven by identified needs and specific requests from the teams and faculty members responsible for the experiments. The process was detailed to include collection in the experimental areas, internal transportation, storage of agrochemicals, insecticides, and lubricating oil packaging, in addition to the final disposal of these materials, organic residues, and undifferentiated waste generated during the experimental activities.

During on-site (*in loco*) visits, the occurrence of independent segregation and conditioning processes by the teams responsible for the activities was validated. Furthermore, the use of trucks with an approximate capacity of 8.3 m³ for waste collection in the experimental areas was documented. A designated space for the temporary storage of potentially contaminated packaging was identified. Finally, practices involving the reuse of recyclable materials and the final disposal of undifferentiated waste, along with the treatment and utilization of organic waste, were observed.

Analysis of the agricultural waste management stages

Segregation and conditioning

The management process analysis confirmed the absence of an effective source waste segregation system, coupled with the lack of adequate receptacles for the receiving and conditioning of different waste streams in the areas designated for agro-pastoral experiments. It was observed that, across several sectors, the generated waste is frequently mixed, which significantly compromises its potential for reuse and recycling. Waste management practices adopted empirically and lacking technical-scientific endorsement represent a major impediment to the implementation of efficient management systems in rural areas worldwide (Azevedo et al., 2021). The deficit in appropriate guidelines compromises waste segregation, conditioning, and treatment, further intensifying environmental and sanitary risks resulting from inadequate handling (Freitas et al., 2024). Such non-conformities are in direct opposition to the principles established by the NSWP, which advocates for the segregation of solid waste at the source to facilitate subsequent management and ensure its environmentally appropriate final destination (Brasil, 2010).

On-site visits identified only 14 polyethylene containers (200 L) designated for waste collection, a quantity demonstrably insufficient given the total extent of the experimental areas, which spans approximately 160 ha. This deficiency in collection points constitutes a critical obstacle to proper waste handling, hindering effective segregation. Additionally, the lack of visual identification on the containers was verified, which conflicts with CONAMA Resolution No. 275/2001. This resolution mandates the use of standardized color codes for selective collection to differentiate waste typologies and ensure the correct signaling of receptacles, particularly in areas of public use and high circulation (Brasil, 2001).

Machinery and agricultural vehicles shed

In the machinery and agricultural vehicles shed (Figure 3), both hazardous (Class I) and non-hazardous non-inert (Class II A) waste were identified, with either inadequate or entirely absent segregation. The most frequently observed hazardous waste included batteries, oil containers, soiled rags/wipes, grease, and oil residues from machine maintenance. These materials were stored separately in sealed 200 L polyethylene and metallic containers and, when necessary, transported to the central campus for adequate disposal according to the UFERSA Mossoró campus SWMP, in compliance with CONAMA Resolution No. 450/2012.

Non-hazardous and potentially recyclable waste, such as disposable cups, polyethylene terephthalate (PET) packaging, and electronic components (fuses), were temporarily stored and forwarded to the packaging shelter. Undifferentiated waste, including tree leaves, paper towels, and other residues from cleaning activities, was conditioned in plastic bags and transported to the UFERSA Mossoró campus alongside domestic waste collected by the service provider company, ultimately being directed to the university's waste shelter.

During the on-site inspection, it was noted that, despite the partial execution of waste sorting and conditioning within the Machinery and Agricultural Vehicles Shed sector, the surrounding area showed evidence of improperly discarded materials. These included food packaging (aluminum and polystyrene meal containers), aluminum cans, disposable cups, and lubricating oil containers, as further illustrated in Figure 4.

The presence of inappropriately discarded waste around the RFEF machinery shed (Figure 4) may have been exacerbated by operational failures in the collection and conditioning system, compounded by a lack of employee awareness and training regarding proper disposal practices. Aluminum food packaging and disposable cups, classified as non-hazardous Class II A waste, generate visual pollution and, depending on degradation conditions, can release contaminant substances into the soil. According to Simonetti et al. (2021), lubricating oil containers pose a greater risk, with the potential to contaminate both soil and aquifers due to the presence of toxic and persistent substances.

Area designated for agricultural experiments

The agricultural experiments sector represents the largest area dedicated to experimental activities, spanning 160 ha, and hosts the greatest number of experiments executed simultaneously and alternately throughout the year. Currently, the waste generated in these agricultural experimental areas lacks complete segregation at the source. Only one polyethylene container was identified next to the shed housing the Agricultural Laboratory (Figure 5); this single container was designated for the storage of diverse waste types, thereby impeding the execution of subsequent management stages.

Figure 3 – Machinery and agricultural vehicles shed: Waste conditioning drums.

Figure 4 – Inappropriate disposal around the machinery and agricultural vehicles shed.

Figure 5 – Agricultural laboratory on the left, agricultural inputs storage on the right, and waste conditioning container.

The lack of appropriate receptacles for the temporary on-site storage of waste in the immediate vicinity of the experimental areas severely compromises the efficacy of waste segregation at the point of generation, as well as the proper conditioning of materials discarded by the research teams and RFEF employees. Furthermore, along internal access roads and in plots designated for agricultural fallow, a pervasive scenario of abandoned experimental residues improperly discarded was identified (Figure 6).

Regarding the deficit of collection points, Simonetti et al. (2021) address that the scarcity of strategically positioned collectors can instigate irregular waste disposal practices. The resulting deficit in infrastructure for correct waste disposal tends to stimulate unauthorized dumping in open lots and green spaces, leading to adverse environmental impacts and impeding sustainable waste management across the campus (Ferreira et al., 2024).

The irregular disposal on the farm's internal roads and fallow experimental areas (Figure 6) reflects the absence of an efficient waste collection and management system. The lack of suitable collectors and the abandonment of experiments demonstrate significant failures in handling, compromising the environmental quality of the space, with risks of soil contamination, vector proliferation, and visual degradation. According to Portela (2022), the strategic distribution of collector receptacles directly influences the improvement of individuals' waste disposal actions. Furthermore, material reuse and recycling can be incentivized to reduce the environmental impacts at RFEF.

The activities within the livestock experiment sector specifically involve a Meliponary (Native Stingless Bee Apiary) and the Wax House. Waste segregation occurs during the maintenance of these experiments. Part of the waste, classified as rejects (materials with no feasible recovery), is collected and transported to the UFERSA Mossoró campus alongside domestic and administrative waste. In contrast, hazardous waste, such as personal protective equipment (PPE) from the Wax House, is conditioned and forwarded to the RFEF packaging shelter and subsequently directed for incineration, ensuring its environmentally sound final disposal. In total, five containers/drums were identified (3 metallic and 2 polyethylene); however, none featured the labeling or colors established by CONAMA Resolution No. 275/2001 (Figure 7).

Figure 7 clearly illustrates poor segregation and inadequate conditioning of waste at the Wax House, specifically concerning hazardous waste such as PPE. According to Azevedo et al. (2021), PPE contaminated with chemical agents or other highly toxic substances constitutes a potential source of risk to public health and environmental systems. Under these circumstances, their handling must follow stringent protocols, which include secure conditioning and proper labeling as hazardous waste, with the aim of preventing accidental exposures and mitigating environmental impacts (Ferreira et al., 2025).

The exposure of the uncovered metallic and polyethylene drums (Figure 7) increases the probability of soil, water, and air contamination. Furthermore, it leaves the waste accessible to insects, animals, and weather phenomena, posing a risk to the workers who handle these materials. The absence of adequate identification and labeling hinders the correct management of the waste, resulting in non-compliance with CONAMA Resolution No. 275/2001. Another problem identified was the presence of undifferentiated waste generated in the vicinity of the Wax House (Figure 8), where photographic records captured discarded boxes and national hives (beehives).

In the Meliponary unit, hazardous waste, such as PPE, is stored and designated, being transferred to the packaging shelter and subsequently directed for incineration, ensuring environmentally sound disposal. Only one polyethylene drum was identified for general waste conditioning in the area. This receptacle lacked the appropriate identification via labeling or color coding, as mandated by CONAMA Resolution No. 275/2001. Moreover, this container was frequently observed to hold both sweeping and pruning residues (Figure 9).

Internal collection and transportation actions

The waste stored in the polyethylene drums within the experimental areas is manually collected by the farm's team and transported via internal vehicles, based on requests from the research teams or designation by the RFEF management. It was verified that no established periodicity exists for collection and transportation. Packaging with potential contaminants is directed to the packaging shelter, whereas recyclable waste and rejects are taken to the waste shelter at the UFERSA Mossoró campus. Along with the domestic waste generated and collected on the campus itself, these materials are subsequently directed to the municipal sanitary landfill.

During the visit, it was observed that all employees involved in the internal waste collection and transportation process were wearing appropriate PPE, including boots, gloves, long pants, durable fabric shirts, and respiratory masks, thus complying with the provisions of Law No. 6,514/77, which mandates the provision and obligatory use of Individual Protection Equipment (Brasil, 1977).

Figure 6 – Disposal on internal roads and fallow experimental areas of *Fazenda Experimental Rafael Fernandes*.

Figure 7 – Waste conditioning drums at the Wax House.

Waste storage

The waste generated by agro-pastoral activities is temporarily conditioned in two distinct locations, according to the management's planning. Undifferentiated waste is taken to the Machinery and Agricultural Vehicles Shed, where it is temporarily stored awaiting external collection services, and subsequently directed to the UFERSA Mossoró waste shelter. Hazardous waste, such as pesticide packaging, lubricating oil containers, fertilizer containers, formicide packaging, general PPE, etc., is directed to the RFEF packaging shelter, a room located within the Agricultural Laboratory. Agricultural input packaging undergoes the triple rinsing procedure, as established by Law No. 7,802 of the Brazilian Constitution (Brasil, 1989). This procedure ensures the material meets the appropriate conditions for transport, temporary storage, and final disposal, contributing to accident prevention and compliance with hazardous waste management standards (Panta et al., 2023). Following triple rinsing, the packaging is directed to the empty packaging receiving center (InpEV) in the city of Mossoró.

However, failures in the storage process were identified, where part of the agricultural packaging was improperly conditioned in an unsuitable receptacle in the area external to the packaging shelter (Figure 10). The improper disposal of agricultural defense product packaging can represent a potential risk of local contamination (Chekol, 2025). This compromises the quality of natural resources, potentially causing risks to human health, fauna, and environmental damage (Ferreira et al., 2024). Improperly discarded pesticide and poison packaging in the environment poses a risk to the quality of natural resources and the health of rural communities (Freire et al., 2016).

Figure 8 – Undifferentiated waste improperly disposed near the Wax House.

Figure 9 – Meliponary and waste conditioning drums.

Figure 10 – Improper storage of agrochemical packaging in the exterior area of the packaging shelter.

Another problem identified during the visits was the inappropriate co-storage of agricultural supplies, such as plot markers for planting, plastic seed trays, and irrigation system hoses, alongside plastic packaging stored for recycling and pesticide containers. This highlights the disorganization of the environment and the lack of control in handling the packaging materials (Figure 11).

External waste transportation

The external transport of both recyclable and undifferentiated waste streams is conducted by truck, via a third-party company contracted by UFERSA. These wastes are transferred to the Mossoró campus waste shelter in properly sealed 200 L polyethylene drums. Subsequently, the residues undergo a sorting process and are prepared for final disposal in compliance with relevant environmental regulations. Figure 12 illustrates the vehicle executing the designated route between RFEF and the UFERSA Mossoró waste shelter.

Figure 11 – Improper storage and inappropriate organization of the packaging shelter.

Final disposal

Table 1 presents the final destination for the different types of solid waste generated at RFEF, highlighting management practices, reuse, and disposal, including recycling initiatives, agricultural repurposing, and proper routing, in addition to instances of inadequate management observed during the visits. The rigorous characterization of waste origin and composition is a fundamental step for defining technically appropriate strategies for treatment, conditioning, and environmentally safe final disposal (Freitas et al., 2024). Additionally, collection must be conducted in compliance with current technical and normative guidelines to ensure management effectiveness (Singh et al., 2024).

During the visits, the occurrence of waste burning was identified, carried out in a metallic container that was previously used for sweeping residue conditioning in the Wax House (Figure 13). Istrate et al. (2021) warn that the burning of waste with varied compositions promotes the release of contaminant particulates, which can lead to various health problems for the population exposed to the pollution. This process releases dioxins and similar compounds with dioxin-like toxic properties, such as polychlorinated dibenzofurans (Talang and Sirivithayapakorn, 2021). Assimilation through respiration and ingestion, along with food, can cause hepatic, neurological, immunological, reproductive, and hematological alterations (Gujre et al., 2021).

Proposals for interventions directed at agricultural waste management

To enhance the ASW management stages at RFEF, and based on the deficiencies identified, intervention actions are proposed in Table 2. These actions are designed to achieve process optimization and compliance with current environmental regulations, with particular attention to Federal Law No. 12,305/2010, which established the NSWP.

Figure 12 – Vehicle used for waste transportation, external transport route, and UFERSA Mossoró waste shelter.

Table 1 – Final disposal employed for different waste types at *Fazenda Experimental Rafael Fernandes*.

Waste type	Final disposal
Agrochemical packaging	Sent to the INPEV Center for Empty Pesticide Packaging in Mossoró. Transportation occurs as needed, without a defined periodicity.
Organic waste	Reused as straw bedding (mulch) in banana and coconut tree areas. They contribute to soil cover, the reduction of irrigation impacts, and an increase in organic matter after decomposition.
Undifferentiated waste	Forwarded to the UFERSA waste shelter on the Mossoró campus and subsequently destined for the Mossoró municipal sanitary landfill.
Recyclable waste	Transported to the UFERSA campus for screening (or sorting) and subsequently sent to the partner recycling cooperative. Some of the plastic packaging, such as PET bottles, is reused by employees for storing grains or producing seedlings.
Waste burning	Inadequate burning of waste of varied composition was identified in several locations; at the Wax House, the burning occurred in metallic containers.

Table 2 – Proposed interventions for the management of agricultural waste at *Fazenda Experimental Rafael Fernandes*.

Proposed interventions	Description
Segregation and adequate conditioning in the experimental areas	Installation of receptacles identified and segregated by waste type (organic, recyclable, hazardous) in compliance with CONAMA Resolution No. 275/2001. Strategic reorganization of the existing 200 L polyethylene drums, development of a good practice manual, environmental education campaigns, and training sessions. Implementation of signage and monitoring in the machinery shed for hazardous (Class I) waste.
Improvement in internal transport and temporary storage of waste	Establishment of a regular internal collection route, infrastructural readjustment of temporary storage facilities, segregation by risk categories, and installation of easily accessible storage units. Implementation of regular monitoring in the shelters to prevent accumulation and improper disposal.
Off-site transportation	Definition of periodicity for external waste transportation, ensuring constant removal. Acquisition of appropriate vehicles, equipped with internal containers protected against adverse weather conditions, to mitigate contamination risks during transport.
Capacity building for farm employees	Implementation of continuous training and capacity-building programs for employees on the segregation, conditioning, transportation, and final disposal of solid waste, including hazardous waste (Class I). This action aims to reinforce environmental awareness, compliance with legal standards, and the adoption of best practices, ensuring greater efficiency and safety across all stages of management.
Elaboration of an agricultural solid waste management plan (SWMP)	Development and implementation of an SWMP (solid waste management plan) in compliance with the NSWP (National Solid Waste Policy — PNRS), detailing the segregation, transport, storage, and final disposal of waste. The plan must include continuous monitoring and ensure conformity with CONAMA Resolution No. 450/2012, prioritizing hazardous waste (Class I) and recyclable waste (Class II A).

Figure 13 – Waste burning in a metallic container.

The intervention proposals presented in Table 2 consist of a set of strategic measures aimed at optimizing the management of ASW generated at RFEF, promoting greater compliance with the precepts established by the National Solid Waste Policy (Law No. 12,305/2010) and its supplementary regulations. The relevance of these actions lies in the strengthening of segregation and conditioning stages, the enhancement of internal collection, transportation, and temporary storage processes, as well as the continuous training of employees and the development of the SWMP. As highlighted by Mondelli et al. (2022), the rigorous adherence to waste management stages constitutes a structural element of the NSWP, ensuring the adoption of technically adequate practices, the mitigation of contamination risks, and the promotion of the operational sustainability of the activities carried out on the experimental farm.

Conclusion

The diagnostic study systematically allowed the identification of the management stages of the solid waste generated during the setup and management of experiments at the RFEF. It was established that, although sporadic practices of collection, internal transport, and disposal exist, the absence of a SWMP compromises the standardization and efficiency of the entire system, directly contravening the principles of the Brazilian NSWP.

The analyses revealed significant deficiencies in waste segregation and conditioning, particularly in the larger experimental areas. These failures include a deficit of suitable receptacles, the lack of standardized visual identification, and widespread inadequate disposal practices. This scenario reduces the potential for material reuse and recycling while simultaneously escalating the risks of environmental and occupational contamination, clearly underscoring the urgent need for a reorganization of internal procedures.

Furthermore, it was determined that the storage and internal transport of waste occur without a defined periodicity, which favors accumulation and inadequate handling situations. The presence of poorly conditioned hazardous waste reinforces the necessity for generating specific control and signage protocols to mitigate risks to both human health and the environment.

Based on the results obtained, the priority recommendations include the installation of typology-identified collection bins, the development of best practice manuals, continuous staff training and monitoring of storage facilities, and the urgent implementation of an agro-pastoral SWMP.

Authors' Contributions

Ferreira, D.P.: conceptualization, methodology, formal analysis, investigation, visualization, writing – original draft, project administration, supervision. **Bezerra**, J.M.: project supervision, methodology, validation, resources, software, writing – review and editing. **Silva**, J.P.P.: data curation, investigation, visualization, writing – review and editing. **Carlos Junior**, A.A.: Validation, Writing — review and editing. **Silva**, P.C.M.: validation, writing – review and editing.

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