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Sustainability and Agricultural Production: Comparison between Conservation and Traditional Management in the Semi-Arid Region of Alagoas

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A B S T R A C T

Soil degradation is one of the main limitations to agricultural sustainability in the semi-arid region of Brazil, especially under conventional soil tillage systems. This study aimed to compare different soil conservation practices in maize cultivation, looking at soil loss and biomass production. The study was carried out at UNEAL in Santana do Ipanema (AL), using four treatments: maize under conventional tillage (ST); maize under no-till on a level field (PCM); maize under no-till with sorghum barriers (PCMS); and maize under no-till with stone and sorghum barriers (PCLMS), all equipped with a drainage system made up of small channels at the lower end. Soil loss, maize green biomass, and physical-chemical characteristics were evaluated. The highest soil losses occurred in the conventional treatment (142.9 kg.ha^{-1}). The level no-till system (PCM) was the most effective practice in reducing soil loss, recording only 35 kg.ha^{-1} of loss and showing the highest biomass productivity (11 t.ha^{-1}). The level no-till system (PCM) proved to be more efficient in controlling soil loss, being the most effective practice, with losses of 35 kg.ha^{-1} and the highest biomass production (11 t.ha^{-1}).

R E S U M O

A degradação do solo é uma das principais limitações à sustentabilidade agrícola na região semiárida brasileira, especialmente sob sistemas de preparo convencional do solo. Este estudo teve como objetivo comparar diferentes práticas de conservação do solo no cultivo de milho, avaliando as perdas de solo e a produção de biomassa. O estudo foi conduzido na UNEAL, em Santana do Ipanema (AL), utilizando quatro tratamentos: milho em sistema de preparo convencional (ST); milho em sistema de plantio direto em nível (PCM); milho em sistema de plantio direto com barreiras de sorgo (PCMS); e milho em sistema de plantio direto com barreiras de pedra e sorgo (PCLMS), todos equipados com um sistema de drenagem composto por canaletas na extremidade inferior. Foram avaliadas a perda de solo, a biomassa verde do milho e as características físico-químicas. As maiores perdas de solo ocorreram no tratamento convencional (142,9 kg.ha^{-1}). O sistema de plantio direto em nível (PCM) foi a prática mais eficaz na redução da perda de solo, registrando apenas 35 kg.ha^{-1} de perda e apresentando a maior produtividade de biomassa (11 t.ha^{-1}). O sistema de plantio direto em nível (PCM) demonstrou maior eficiência no controle da perda de solo, sendo a prática mais eficiente, com perdas de 35 kg.ha^{-1} e a maior produção de biomassa (11 t.ha^{-1}).

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Introduction

In the Brazilian Northeast, and particularly in the municipality of Santana do Ipanema, Alagoas, soil conservation is an ongoing challenge for family farmers who rely directly on the land for their livelihood and income. Located in the semi-arid region of Alagoas, the municipality is characterized by specific soil and climate conditions and is already considered susceptible to desertification (Santos; Aquino, 2016, Baptista; Góis; Oliveira, 2011). In this scenario, the soil, one of the main natural resources responsible for sustaining life and agricultural production, has its functionality limited by low rainfall and the irregularity of the rains typical of the region.

Traditional farming systems, based on planting downslope and excessive soil tillage, increase water erosion and reduce water infiltration in semi-arid regions, compromising the soil's physical and biological structure (Falcão et al., 2022). In Santana do Ipanema, deforestation and poor animal management worsen water erosion, causing the loss of the finer soil particles, essential nutrients, and even the soil itself due to increased surface runoff. These practices make naturally thin soils even thinner, and given the water scarcity typical of the semi-arid region, they lead to low productivity and make it hard to maintain sustainable farms.

The improper and intensive use over the years has caused serious degradation processes. Environmental problems in the region include the expansion of the desertification phenomenon related to natural factors, worsened by overgrazing (Oliveira et al., 2021), inadequate reception of technology (Brito et al., 2016), farming with intensive soil tillage, and excessive use of pesticides (Cirilo et al., 2024).

Given this scenario, adopting conservation practices has proven to be an essential alternative for sustainable land management. Among these possibilities, no-till farming is a technique that preserves plant cover and minimizes soil disturbance, providing better moisture retention and microbiological balance (Guerra et al., 2022). Another alternative is the use of contour lines and belts of dense vegetation that help contain surface runoff (Paiva and Araújo, 2012), reducing soil loss and increasing water infiltration (Silva et al., 2011, Zonta et al., 2012).

The combination of alternating harvesting and mulch are also practices that act as a natural physical barrier against erosion. These strategies, when applied together, produce significant results in conserving natural resources and improving agricultural productivity.

In the productive context of the Alagoas backlands, crops like maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* L.), stand out for their economic importance and their ability to adapt to water stress conditions. Sorghum performs well even under water deficit, being widely used in animal feed and as forage (Menezes et al., 2022), while maize farming is a staple of family agriculture and in animal feed it is crucial for supplementation during dry periods, with potential for increased productivity when grown under conservation systems (Leitão, 2020).

Whole plant silage is excellent for ruminants because it's nutritious, palatable, and storable, making use of the leaves, stem, and grains.

In the semi-arid Northeast, accelerated erosion is a process that has been affecting soil functions on multiple levels. Pests are directly linked to this process in a vicious cycle, since the loss of soil quality weakens plants' natural defenses and destroys biological predators, resulting in increasingly severe infestations. In this context, integrated pest management, like with the fall armyworm (*Spodoptera frugiperda*) and ants of the genera Atta and Acromyrmex, from the soil, and the rational use of irrigation, are essential to ensure plant development and avoid significant losses during the germination and vegetative growth phase (Lima et al., 2008; Yokota et al., 2021).

Despite the importance of these crops and the mentioned management techniques, there is a lack of experimental studies in the semi-arid region of Alagoas that practically assess and compare the impact of different soil management systems. It is essential to evaluate how these interventions specifically affect moisture conservation and the physical structure of the soil under local edaphoclimatic conditions, since pests and accelerated erosion continue to impact soil functions at various levels without enough comparative data to guide farmers. Adopting sustainable methods not only improves productivity but also promotes the preservation of natural resources, reduces costs, and ensures long-term production viability.

Specific studies focused on the semi-arid region of Alagoas, and on the municipality of Santana do Ipanema, are extremely scarce, and when carried out in the field, they are directly subject to local climate variations, which makes collecting this data even more complex, dynamic, and essential to understand the real behavior of the region under different weather scenarios. In this regard, and with the aim of showing the impacts of different management practices on maize productivity, we evaluated biomass production and soil loss under a traditional tillage system, compared to three management systems that combined vegetative and mechanical practices, in a case study at Campus II of the State University of Alagoas (*Universidade Estadual de Alagoas* - UNEAL), in Santana do Ipanema. The goal is to provide technical support to show soil degradation and the feasibility of sustainable agricultural practices for family farmers and extension workers working in the Alagoas semi-arid region.

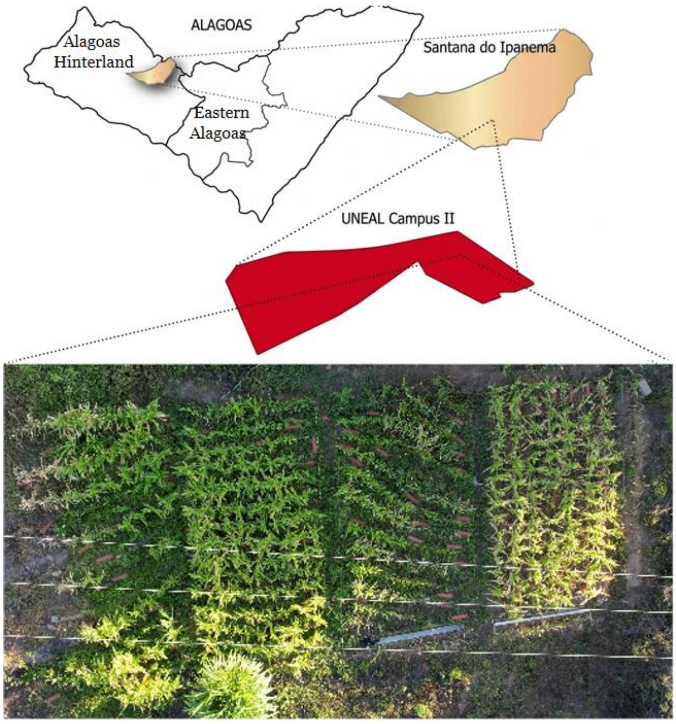
Materials and methods

The study was conducted at Campus II of the State University of Alagoas (*Universidade Estadual de Alagoas* - UNEAL), in Santana do Ipanema, and is located at coordinates: 9°22’31.17”S and 37°13’55.41”W. The municipality is situated in the Alagoas backlands and has hypoxerophilous Caatinga vegetation with a semi-arid climate, very hot, with rainfall concentrated in four to five months and an annual average of around 800 mm (Figure 1).

Minimum temperatures range from 18°C to 21°C and maximum temperatures from 27°C to 33°C (EMBRAPA, 2012).

Figure 1.

Location of the area under study.



Source: Personal file obtained by drone DJI 2s (2025).

The area has an average slope of 12.8%, determined in the field with a manual topographic instrument of the A-frame level type, and the soil was classified as Eutrophic Red Argisol with a cambic horizon (EMBRAPA, 2020).

The execution took place from August 25th to November 11th, 2025. The crop coincided with the end of the rainy season, so additional irrigation was needed to ensure the plants got established. Initially, a sprinkler irrigation system was used, providing even water distribution and supporting the early growth of the maize. Later, as the plants grew bigger, the system was switched to drip irrigation, allowing for more precise and localized water application, reducing evaporation losses and improving water use efficiency. For the green biomass assessment, the entire above-ground part of the maize plants was cut close to the soil and immediately weighed.

The results of the fertility assessment analyses, according to the methodology recommended by EMBRAPA (2018), showed that the soil has a medium texture (loam-sandy clay), with low phosphorus (P) levels and adequate potassium levels (K^+) for maize cultivation. The calcium levels (Ca^{2+}) and magnesium (Mg^{2+}) were considered satisfactory, while the Cation Exchange Capacity (CEC) showed average values. Base saturation (V) proved favorable for crop development, and the organic matter content (*matéria orgânica* - MOrg) was very low. The chemical and physical attributes supported the assessment of nutrient availability and the soil's productive capacity to meet the requirements of maize cultivation, simulating the typical soil scenario of family farming management in the semi-arid region of Alagoas and its impact on biomass production (Table 1).

Table 1.

Soil chemical analysis.

	Sorptive complex ---------------------- mmole.dm^{-3} ----------------------							%	mg.dm^{-3}		g.kg^{-}	Granulometry g.kg^{-}		
pH$_{H_2O}$	Ca^{+2}	Mg^{+2}	K^{+}	Na^{+}	Al^{+3}	H+Al	CTCph 7	V	P	K^{+}	MOrg	Ar[1]	Sil[2]	Arg[3]
6,9	36	10	5,1	0,8	0	12	69,9	74	4	199	8,6	569	144	287

[1]CTC - Cation exchange capacity; [2]V - Base saturation, [3]MOrg - Organic matter, [4]Ar - Sand; [5] Sil - silt and [6]Arg - Clay

Source: Analytical Center (2025).

This research is characterized as a case study, conducted in a region of the Alagoas semi-arid area, in which a sampling design was adopted to represent the spatial variability of the study area. Table 2 presents the four treatments addressed and their description.

Table 2.

Experimental design consisting of four treatments, distributed in plots of 28 m² (4 m × 7 m), with a 0.5 m spacing between blocks.

Treatment	Description
I	It consisted of sowing maize (*Zea mays* L.) in furrows along the slope of the land, with 0.40 m spacing between rows, characterizing the traditional system with conventional tillage and complete clearing of the area (ST).
II	It involved cutting the spontaneous vegetation, stump removal, and planting directly in furrows arranged along the contour, keeping a spacing of 0.40 m between rows; between the maize rows, a dense row of sorghum (*Sorghum bicolor* L.) was planted, acting as a vegetative barrier to reduce the speed of surface runoff and soil loss (PCMS).
III	It consisted of no-till farming along contour lines with exclusive maize cultivation, carried out in contour furrows and respecting the natural terrain relief (PCM).
IV	Characterized by the intercropping of maize and sorghum along the contour, combined with the installation of small mechanical barriers made of stones (about 10cm high) arranged along the level curve, aimed at retaining part of the runoff and significantly reducing soil and nutrient loss (PCLMS).

Source: The authors (2025).

For the execution of the sampling plan (Table 2), collector gutters were installed at the lower end of each plot to capture sediments. Every week, the material carried and retained in the gutters was collected and weighed to measure soil loss and compare the efficiency of management systems in controlling water erosion. To make it easier to compare the variables "soil loss" and "biomass productivity," the units of measurement were converted to kg/ha.

Results and discussion

After 31 years of conventional management with various crops, the experimental area at UNEAL Campus II shows variations in the chemical and physical properties of the topsoil, which affected the development and productivity of maize biomass. In all treatments, the values found (Figure 3) were much lower than the averages reported by Santos et al. (2010) in the semi-arid region of Pernambuco (38.7 and 40.0 $t.ha^{-1}$) and by Brito (2016) in the Agreste of Alagoas (69 $t.ha^{-1}$), for the rainfed maize crop.

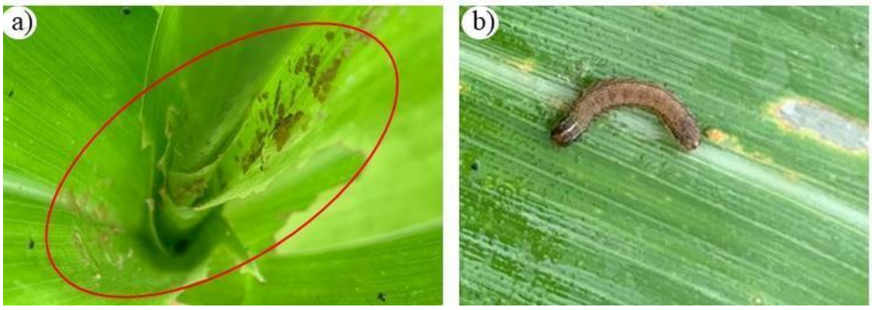
Although there was good initial development, the lack of vegetation cover and the tilling of the soil for planting increased vulnerability to water stress and the erosive process, with significant losses of the topsoil due to erosion. The soil changes caused by agricultural use and their impacts on soil properties were also reported by Lima et al. (2016) and Cavalcante et al. (2011). This condition is common in the region and is associated with reduced agricultural productivity and the expansion of livestock farming into caatinga areas (Macêdo et al., 2025).

At the end of the vegetative period, 60 days after emergence (DAE), infestation by the fall armyworm was observed (*Spodoptera frugiperda*) (Wolfart et al., 2024). However, the control carried out through manual picking proved to be effective, preventing the infestation from spreading and preserving the crop's development (Figure 2).

However, 78 days after planting, the study was stopped because the water scarcity in the region made continuing the cycle unfeasible, requiring an early final assessment. In the Santana do Ipanema region, where most of the available water is brackish (CPRM, 2005), irrigation becomes impractical, which highlights the need for practices that reduce dependence on weather conditions and increase the soil's water retention capacity.

Figure 2.

a) Maize earworm infestation in maize and b) Detail of Spodoptera frugiperda.



Source: Personal archive (2025).

Maize productivity in rainfed areas of the semi-arid region of Alagoas heavily depends on soil and climate conditions, which, combined with management practices, have been factors that caused variations in productivity, since the soil acts as a reservoir capable of providing nutrients based on the balance of its components. The physical and chemical attributes of the 0-15 cm soil layer (Table 1) indicated a high silt content (144 g/kg), which favors compaction and reduces the water infiltration rate (Santos et al., 2012), affecting root growth and, consequently, biomass production.

The levels of organic matter (*matéria orgânica* - MOrg) are an important attribute for soil quality, as they help retain moisture and stabilize soil aggregates (Lal, 2020), and they were also not favorable for crop performance, especially during drought periods. Low organic matter levels, combined with the predominantly sandy soil texture, increase the crop's reliance on irrigation, highlighting the need for management practices that improve soil moisture retention.

Chemically, high levels of potassium (K^+), contribute to greater tolerance to water stress through stomatal regulation, but low phosphorus (P) levels limited biomass production due to its essential role in photosynthesis, respiration, and plant development processes. Silva et al. (2014), in a maize experiment in the semi-arid region, found a soil P value of 7.97 mg.dm-3 as the critical level for maximizing economic maize yield, which is much higher than what was found in this soil. Paiva et al. (2012), in a semi-arid experiment, point out that, in addition to irregular rainfall, low nitrogen and phosphorus levels in the soil are factors responsible for the low maize productivity in the semi-arid region.

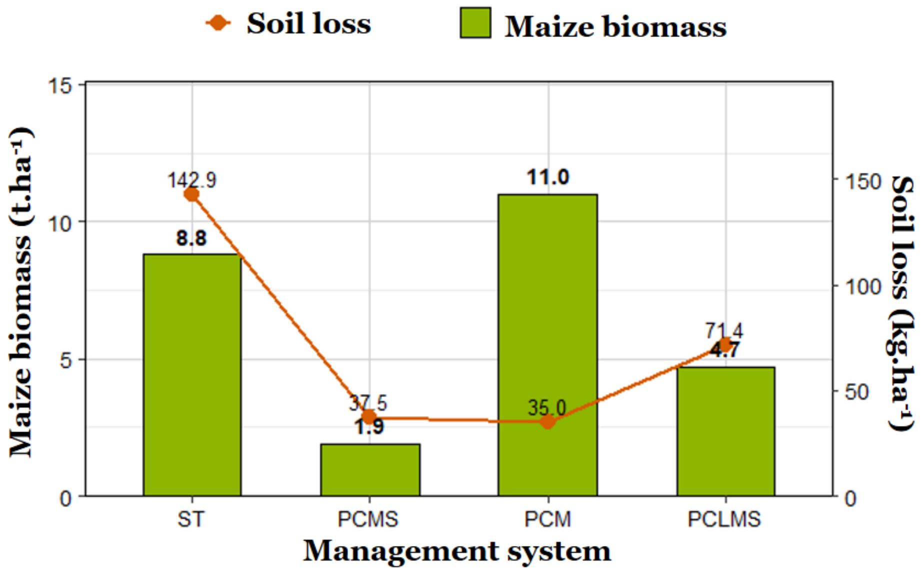
The analysis of the physical and nutritional limitations of the soil combined with the conservation practices adopted in the systems shows that soil cover and the accumulation of organic matter led to higher productivity in the PCM compared to the ST.

In no-till farming systems, keeping plant residues on the soil surface boosts microbial activity and helps phosphorus mineralization, making it more available for plants. According to Barros et al. (2026), conservation systems, like no-till combined with cover crops, increase soil biological activity, enhance nutrient cycling, and help improve soil quality.

In this context, the highest biomass production observed in the PCM system (11 $t.ha^{-1}$) may be associated with the improvement of the soil's physical and biological conditions, favored by the adoption of contour no-till farming combined with crop residue. Supporting the results observed in this study, Cherubin et al. (2016) and Iqbal et al. (2025) report that even under low phosphorus availability, the cycling of organic phosphorus can keep the soil productive.

Figure 3.

Maize Biomass versus Soil Loss.



Source: Graph created in R software (2026).

Figure 3 shows the variation in soil loss and maize biomass across the treatments, highlighting their connection to the variability of the soil's physical and chemical properties with the management practices used. The results indicate that differences in soil conditions and management systems affect soil conservation and plant performance, showing how important this knowledge is for planning and conserving agricultural systems.

The inclusion of contour strips with sorghum in the PCMS and PCLMS systems affected biomass production, and the values obtained were lower than those of the ST (8.8 $t.ha^{-1}$). The results can be explained, in part, by interspecific competition in the maize-sorghum consortium, which reduces the availability of water, light, and nutrients for the maize (Oliveira et al., 2021; Távora et al., 2007). However, they were also influenced by the presence of physical barriers from a hardened subsurface horizon, with gravel and contact with rock at shallow depths, which limited root development and water storage capacity in both systems. These conditions caused waterlogging in specific spots, especially in the PCLMS system, as the installation of a mechanical barrier with stones restricted drainage and led to rapid soil saturation on heavy rain days. We observed that in these spots, the resulting anaerobiosis harmed root respiration and plant vigor.

The spatial variability of these physical characteristics, combined with the management practices used, directly influenced maize development. In the PCMS and PCLMS systems, there was more variability in plant growth, shown by plants of different sizes and development stages across the experimental area. In contrast, in the ST and PCM systems, growth was more uniform, reflecting less variation in soil depth and no interspecific competition with sorghum. These results suggest that more uniform soil conditions helped the crop establish more evenly, while environmental variability and competition for resources led to uneven plant growth (Figure 4).

Figure 4.

Detail showing the systems and the irregularity in the height of the plants in the PCLMS and PCMS.

High variability **Low variability** **Medium variability** **Medium variability**

Source: Personal file (2025).

Contour planting is widely documented as an essential technique for soil and water conservation (Silva et al., 2015). When done well, the practice can also increase crop productivity by retaining soil moisture in semi-arid regions.

Soil losses in the traditional system were about four times higher than in the PCMS and PCM treatments and roughly twice as high compared to the PCLMS. This shows how effective adopting contour farming practices can be compared to planting parallel to the slope line (Figure 3). According to Farahani et al. (2016), planting along the contour lines, compared to planting parallel to the slope, reduces yearly soil and water losses by 49.5% and 32%, respectively.

The soil loss data (Figure 3) show more erosion in the traditional system (142.9 $kg.ha^{-1}$), because the activities of farming and soil preparation downhill and the lack of plant cover favor water runoff. According to Silva and Maria (2011), the main reason for adopting the no-till system is related to the lower occurrence of losses of soil, water, and nutrients due to erosion compared to conventional systems. The lower losses in the conservation systems PCM and PCMS, respectively 35 $kg.ha^{-1}$ and 35.7 $kg.ha^{-1}$ showing that combining practices promotes greater runoff energy dissipation and sediment retention.

The reduction of runoff and soil loss with the use of mulch and ground cover compared to bare soil was also observed by Lima et al. (2020). Compared to other conservation systems, the greatest soil loss is in PCLMS (71.4 $kg.ha^{-1}$) highlights the importance of assessing the spatial variation of soil attributes when choosing practices. The increase was linked to the negative effect of installing stone lines at two points in the area, where the lithic contact reduced the effective soil depth, which led to waterlogging and surface runoff, consequently causing soil erosion during intense rainfall events, which are common in the region. In this context, Silva et al. (2015) report that contour farming on medium-sloped hills with small irregular morphological features is less effective in controlling runoff, since these features, when storing water, are more prone to overflowing.

Biomass production was directly influenced by soil management, being higher in the PCM system (11 $t.ha^{-1}$), followed by ST (8.8 $t.ha^{-1}$), PCLMS (4.7 $t.ha^{-1}$) and PCMS (1.9 $t.ha^{-1}$). The best performance of PCM is linked to better soil water dynamics in the adopted management system. The relatively superior performance of PCLMS compared to PCMS might be related to the higher organic matter content, which helped reduce competition for water and nutrients in the mix. Borges et al. (2014) and Paiva and Araújo (2012) reported that using practices like plant strips and stone lines along contours, as well as mulch covers, in areas with low and irregular rainfall, is beneficial and economically viable for maize crops.

CONCLUSION

The traditional system showed the greatest soil loss (142.9 kg ha^{-1}), while conservationist systems significantly reduced sediment transport, with soil losses between two and three times lower than those observed in conventional planting. No-till planting on contour lines (PCM) was the most efficient practice in controlling erosion, recording soil loss of only 35 kg ha^{-1} and the largest biomass production (11 t ha^{-1}). These results show that conservation practices simultaneously help with soil conservation and maintaining productivity, making them important practices for agriculture in the semi-arid region of Alagoas.

However, the efficiency of these practices depends on local factors, especially the spatial variability of soil properties and the climatic randomness of the semi-arid region. Low levels of phosphorus and organic matter, along with limitations in effective soil depth and interspecific competition in sorghum strips, negatively affected biomass production, showing that adopting conservation practices requires integrated fertility management strategies and planning that match the local soil and climate characteristics.

The results of this study should be interpreted considering its methodological limitations, especially the assessment 78 days after emergence, the temporal variability of rainfall, and the spatial variability of soil, which can influence the magnitude of soil loss and the performance of conservation practices between crop years. Assessments under different soil and precipitation conditions, with more robust experimental designs, are essential to measure the resilience of these practices in the face of climate fluctuations in the semi-arid region and to promote more consistent recommendations for rainfed agricultural systems.

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