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Soil Moisture Patterns under Sesame Straw Mulch in an Uncropped Vertisol of Eastern Sudan

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Abstract

Rainfed farming in eastern Sudan depends on rainfall that occurs within a short and uneven season. In the cracking Vertisols of Gedaref, soil moisture after wetting can decline quickly, especially when the surface remains exposed. This study examined whether observed soil moisture differed among sesame straw mulch rates after a standardized wetting event in an uncropped Vertisol containing 76% clay, 14% sand, and 10% silt. The field experiment was arranged in a randomized complete block design with three replications and five mulch rates: 0, 1.39, 2.78, 4.17, and 5.56 t ha^{-1}, equivalent to 0, 0.5, 1.0, 1.5, and 2.0 kg per 3.6 m^2 plot. Each plot received 100 L of water, equivalent to 27.78 mm. Mulch was applied four days after wetting, and soil moisture was then measured weekly for eight weeks at 0 - 30 and 30 - 60 cm depths. No soil-moisture measurement was taken before mulch application. A repeated-measures linear mixed-effects model showed that soil moisture increased by 0.592 percentage points for each additional t ha^{-1} of sesame straw mulch, while it declined by 0.482 percentage points per week. The mulch treatment × sampling week interaction was not significant ($F = 0.33$, $p > 0.99$), so treatment-specific slopes were treated only as descriptive summaries. Across depths and weeks, mean soil moisture was 23.27% under the 5.56 t ha^{-1} treatment and 19.69% in the control, giving an observed difference of 18.2%. The results show that observed soil moisture differed among sesame straw mulch rates after a standardized wetting event under uncropped conditions. Evaporation, soil cracking, crop emergence, and yield were not measured. The findings should be treated as preliminary field dry-down evidence and tested under cropped conditions before field recommendations are made.

Keywords

Vertisol, Cracking Clay, Sesame Straw Mulch, Observed Soil Moisture, Field Dry-Down, Uncropped Soil, Rainfall Concentration, Gedaref, Eastern Sudan

1. Introduction

1.1. Rainfall Usefulness in Rainfed Vertisols

Rainfed agriculture does not fail only because rainfall is low. It often fails because rainfall is not held in the soil long enough to support crop growth. A seasonal rainfall total may appear sufficient on paper, but that total can lose much of its value when rain comes in a short season, arrives in uneven pulses, or is followed by rapid drying of the surface soil. For farmers, the useful part of rainfall is therefore not the rain that falls, but the rain that remains available in the root zone after wetting.

This distinction is central to the rainfed farming systems of Gedaref, eastern Sudan. The area depends mainly on seasonal rainfall and is widely cultivated under dryland and semi-mechanized rainfed agriculture. Sudanese Vertisols have long been described as heavy clay soils with strong shrink-swell behaviour, particularly across the central clay plain and Gezira region [1] [2]. In Gedaref, these clay soils support large rainfed sorghum-sesame systems, but their high water-holding capacity does not guarantee that water remains available after wetting. Once drying begins, the surface can harden and shrink, and cracks may develop under suitable drying conditions.

This creates a soil-specific dry-down problem. In many soils, evaporation is controlled mainly by the exposed surface and by water movement toward that surface. In Vertisols, drying may also open cracks that increase contact between the subsoil and the atmosphere [2]-[4]. The present study did not measure crack width or crack depth, so this pathway is used here as background to explain why moisture loss in Vertisols can differ from lighter-textured soils, not as a directly tested mechanism.

The rainfall regime of Gedaref makes this issue more important. Rainfall is seasonal and concentrated within a limited part of the year. Monthly rainfall records are useful for describing this concentration, even when they cannot resolve daily dry-spell length. A concentrated rainfall regime increases the value of practices that help keep soil moisture available after wetting. In this context, soil management should not be judged only by its ability to receive rainfall. It should also be judged by its ability to keep rainfall useful for longer.

1.2. Mulch as A Physical Control of Post-Wetting Dry-Down

Surface mulch modifies the physical conditions at the soil-atmosphere boundary. By covering the wet soil surface, it reduces direct exposure to radiation and moving air, weakens the vapor-pressure gradient near the surface, limits raindrop impact, and can improve the partitioning of rainfall toward infiltration rather than rapid surface loss. These effects have long been recognized in soil evaporation, dryland water management, and crop-residue studies [5]-[10].

In cracking clay soils, the value of mulch may extend beyond simple surface protection. Vertisols shrink as they dry, and cracks may increase contact between deeper soil layers and the atmosphere. Once this connection develops, water stored below the surface can become more exposed to evaporative loss through crack walls [2] [3] [11]. A mulch layer may influence this process by changing the surface condition during drying. In this study, this cracking-related pathway was treated as a possible explanation, not as a directly measured process.

Sesame straw is a practical mulch material for eastern Sudan because sesame is widely grown in the rainfed production system. The residue is locally available, low-cost, and biodegradable, and its use as mulch links water conservation with residue recycling. This is relevant in farming systems where external inputs are costly and crop residues often have competing uses, including livestock feed, fuel, field clearing, and soil cover.

In this study, sesame straw mulch was examined as a surface cover placed on a wet Vertisol after a standardized water application. The aim was to compare observed soil moisture among mulch rates during a dry-down period. This focus is relevant in Gedaref because rainfall is seasonal, and short wetting periods are often followed by dry intervals.

1.3. Climate Framing and Study Hypothesis

Monthly rainfall data cannot be used to calculate daily dry-spell duration. They can, however, show how strongly rainfall is concentrated within the rainy season. The Precipitation Concentration Index provides a useful way to describe whether rainfall is evenly distributed or concentrated within a short period [12]. In rainfed Vertisols, this matters because concentrated rainfall makes the timing of soil water loss as important as the amount of rainfall received. When rainfall comes in pulses, the soil's ability to retain water after each pulse becomes a key part of rainfall usefulness.

The rainfall record was used to describe the seasonal setting of Gedaref, while the field experiment followed soil moisture after a single standardized wetting event. The experiment compared five sesame straw mulch rates under uncropped conditions. This design removed crop water uptake from the measurements, but it does not represent a cropped field.

The study examined whether observed soil moisture after wetting differed among mulch rates during monitoring. The 30 - 60 cm layer was included to show whether the observed moisture pattern was limited to the surface layer or also appeared below it. Crack development was not measured, so cracking was treated only as background information for interpreting Vertisol dry-down.

Figure 1 summarizes the rainfall setting, the standardized wetting step, the bare

Vertisol dry-down condition, and the mulch-covered condition.

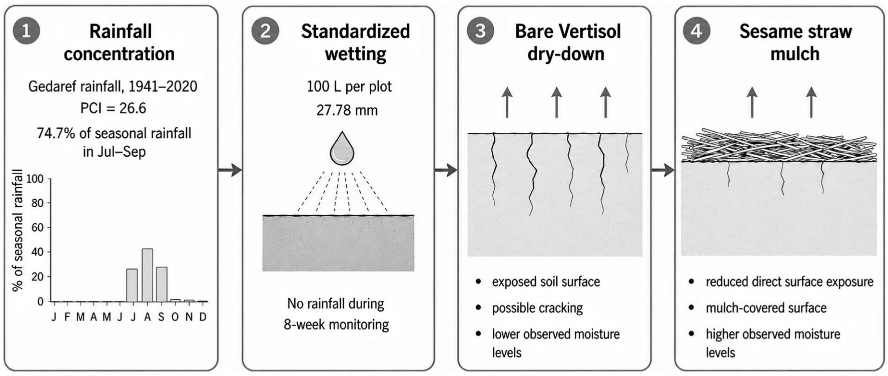

Figure 1. Conceptual link between rainfall concentration, standardized wetting, vertisol dry-down, and mulch response.

2. Materials and Methods

2.1. Study Area and Soil Setting

The experiment was conducted at the pilot farm of the Faculty of Agricultural and Environmental Sciences, University of Gedaref, in the Twawa area of eastern Sudan. The site represents a rainfed agricultural setting within the clay plains of Gedaref, where crop production depends mainly on seasonal rainfall and where heavy cracking Vertisols dominate large parts of the cultivated landscape. The site is located near 14.02˚N and 35.24˚E, at an altitude of about 599 m above sea level (Figure 2). The experiment was conducted during the winter dry season to avoid rainfall interference and to examine soil dry-down under relatively low evaporative demand.

The experimental soil was a heavy clay Vertisol, with 76% clay, 14% sand, and 10% silt. This texture gives the soil a high water-holding capacity, but also a strong shrink-swell behavior. When wet, the soil swells, becomes sticky, and transmits water slowly. During drying, the surface hardens and shrinkage cracks develop. This behavior makes the soil suitable for studying post-wetting dry-down because water loss can occur through both the exposed surface and crack-related pathways once drying advances.

The field soil was alkaline to slightly alkaline, with low organic carbon and moderate carbonate content. Bulk density was higher in the 30 - 60 cm layer than in the 0 - 30 cm layer, reflecting the dense sub-surface structure commonly associated with cultivated cracking clays. These properties provided a suitable physical setting for comparing observed soil moisture among surface-applied sesame straw mulch rates after wetting.

Long-term rainfall data from Gedaref station were used to describe the climatic setting of the experiment. The record covered the April-November rainy season from 1941 to 2020. Monthly rainfall totals were used to calculate seasonal rainfall, monthly rainfall contribution, rainfall concentration, and long-term variability indicators. These climate metrics were used to frame the exposure of the rainfed system to seasonal rainfall concentration. Weekly soil moisture during the experiment was analysed independently because no rainfall occurred during the eight-week monitoring period.

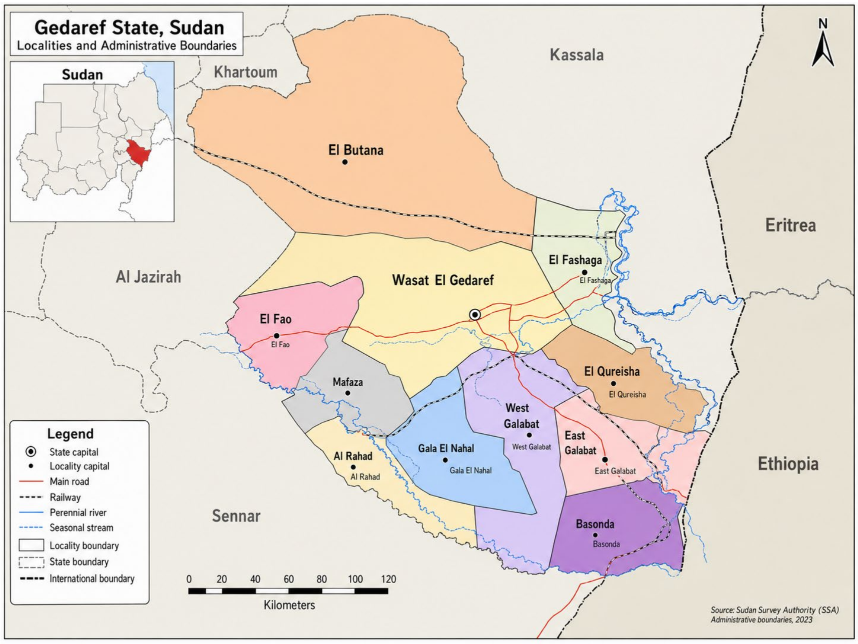

Figure 2. Location of Gedaref State and the study area in eastern Sudan.

2.2. Experimental Design and Mulch Treatments

The experiment followed a randomized complete block design with three replications. Each plot measured 1.2 m × 3.0 m, giving a plot area of 3.6 m^2. Five sesame straw mulch treatments were applied: 0, 0.5, 1.0, 1.5, and 2.0 kg $plot^{-1}$ (**Figure 3**). These rates were equivalent to 0, 1.39, 2.78, 4.17, and 5.56 t ha^{-1}, respectively. The sesame straw was crushed before application and spread uniformly over the soil surface according to the assigned treatment.

Before mulch application, each plot received 100 L of water, equivalent to 27.78 mm over the 3.6 m^2 plot area. The water pulse was applied evenly across the bare soil surface using a calibrated watering can fitted with a fine rose head. This amount was used as a standardized wetting event and was not intended to represent total seasonal rainfall. After wetting, the soil was left for four days before mulch application to allow water to move into the heavy clay profile. This sequence separated the initial wetting and redistribution phase from the mulch-covered monitoring period. Evaporation during these four days was not measured. The interval occurred during winter, and the soil surface was still visibly moist when the mulch was applied. Sesame straw mulch was then applied, and soil moisture was monitored under no-rainfall conditions.

The plots were kept uncropped so that soil-moisture change could be followed without root water uptake or canopy shading. This design does not represent a cropped field, but it allowed soil moisture to be followed under different surface-cover treatments after wetting.

Figure 3. Sesame straw mulch treatments after application across field plots.

2.3. Soil Moisture Sampling and Laboratory Measurements

Soil moisture was sampled once each week for eight consecutive weeks, with sampling carried out on Sunday. The first measurement was taken seven days after mulch application and 11 days after the wetting pulse. No soil-moisture measurement was taken before mulch application. The eight sampling dates covered a 49-day interval from the first to the final measurement.

At each sampling date, one auger sample was collected from each plot at each of the two depth intervals, 0 - 30 and 30 - 60 cm. Each sample was analysed separately and represented its plot and depth. Sampling positions were selected randomly within each plot and changed from one week to the next to avoid previously sampled locations. The two depths were used to compare the exposed surface layer with the subsurface layer, where moisture conditions were expected to differ from those near the soil surface.

Gravimetric soil moisture was determined by oven drying at 105˚C for 24 h. The dataset included 240 observations from five mulch treatments, three replications, two soil depths, and eight weekly sampling dates. The data were used to assess moisture response across mulch rates, soil depths, and sampling weeks.

Selected soil properties were measured before and after the experiment. These included pH, electrical conductivity, calcium carbonate, bulk density, total nitrogen, and organic carbon. Particle-size analysis showed that the soil contained 76% clay, 14% sand, and 10% silt. Bulk density was 1.50 g cm^{-3} in the 0 - 30 cm layer and 1.70 g cm^{-3} in the 30 - 60 cm layer. Organic carbon ranged from 0.42 to 0.52% in the surface layer and from 0.53 to 0.73% in the subsurface layer. Soil pH ranged from 7.7 to 8.3. These results describe a dense, alkaline Vertisol with high clay content, low organic carbon, and a strong tendency to shrink and crack during drying.

2.4. Rainfall Concentration Analysis

Seasonal rainfall was calculated as the sum of April-November rainfall. These months represent the main rainfall period used to frame rainfed production in Gedaref. Monthly rainfall totals were used to calculate total seasonal rainfall, monthly rainfall shares, long-term rainfall variability, and rainfall concentration.

Rainfall concentration was quantified using the Precipitation Concentration Index:

$$PCI = 100 \times \Sigma pi^2/P^2$$

where pi is rainfall in month i, and P is the total seasonal rainfall for April-November. PCI values below 10 indicate uniform rainfall distribution, values from 11 to 15 indicate moderate concentration, values from 16 to 20 indicate irregular distribution, and values above 20 indicate strong rainfall concentration [12] [13].

Long-term trend direction in seasonal rainfall was evaluated using the Mann-Kendall test and Sen's slope estimator. The Mann-Kendall test was used to detect monotonic trend direction, while Sen's slope was used to estimate the magnitude of change through time [14]-[16].

The rainfall analysis was used to define the climatic setting of the rainfed system. Weekly soil moisture response was interpreted from the field dry-down experiment, while rainfall concentration was used to explain why post-wetting soil moisture patterns are important in Gedaref Vertisols.

2.5. Soil Moisture Summaries

Mean gravimetric soil moisture was calculated by mulch treatment, soil depth, and sampling week. This was the main moisture variable used in the statistical analysis.

Two secondary descriptive summaries were also calculated. The first was the area under the weekly soil-moisture curve, using linear interpolation between weekly measurements. For this calculation, the first sampling date was treated as day 0 and the final sampling date as day 49. The second was a reference-based index using 18.0% for the 0 - 30 cm layer and 17.5% for the 30 - 60 cm layer as lower comparison values. These values were selected after considering texture, bulk density, organic carbon, and published pedotransfer relationships [17]. They were not measured field capacity, permanent wilting point, or crop water-stress limits.

These two summaries were used only to check whether the observed moisture pattern was consistent across simple descriptive measures. They were not used for hypothesis testing and were not treated as evidence of hydraulic thresholds, crop water supply, or treatment effects.

2.6. Statistical Analysis

Gravimetric soil moisture was analysed in R version 4.6.0 [18]. A repeated-measures linear mixed-effects model was fitted using the lme4 package [19]. Mulch rate and week after mulch application were included as continuous fixed effects, while soil depth was included as a two-level categorical fixed effect.

The experiment included 15 field plots as the main experimental units. The 240 soil-moisture observations came from repeated measurements across two depths and eight sampling dates. The repeated-measures structure was used to avoid treating these observations as independent field units.

An initial model also treated mulch treatment and sampling week as categorical factors and included their interaction to test whether the pattern of moisture change over time differed among treatments. The mulch treatment × sampling week interaction was not significant and was not retained in the final model.

Block was included as a random intercept, and plot nested within block was used as the repeated subject. Weekly observations were analysed within the same plot-depth combination.

The final model was fitted by restricted maximum likelihood. Fixed effects in the final model were tested using Wald z-tests. The interaction in the initial model was evaluated using an omnibus F-test. Residuals were checked using residuals-versus-fitted plots and normal quantile-quantile plots. Statistical significance was evaluated at $p < 0.05$.

AUC, the reference-based index, and treatment-specific slopes were summarized only as secondary descriptive checks and were not used for inferential testing.

3. Results

3.1. Long-Term Rainfall Concentration in Gedaref

The April-November rainfall record for Gedaref during 1941-2020 showed a strongly seasonal rainfall regime. Mean seasonal rainfall was 593.5 mm, with a minimum of 322.0 mm and a maximum of 910.7 mm. The coefficient of variation was 20.0%, indicating moderate interannual variability in seasonal totals. The mean Precipitation Concentration Index was 26.6, which falls within the class of strong rainfall concentration.

Rainfall was concentrated within the core rainy months. July-September contributed 74.7% of total seasonal rainfall, while June-September contributed 89.7%. This pattern shows that most annual water input occurs within a short seasonal window. The Mann-Kendall test did not detect a significant long-term monotonic trend in seasonal rainfall over the 80-year record ($\tau = 0.102$, $p = 0.181$). Sen's slope indicated a weak positive tendency of 8.67 mm decade^{-1}, but this increase was not statistically significant.

As shown in **Figure 4**, the rainfall record was marked by large year-to-year fluctuations rather than a clear linear trend. **Figure 5** further shows that rainfall usefulness in Gedaref depends strongly on the July-September period. These results frame the dry-down experiment in a rainfall system where post-wetting soil moisture patterns are important.

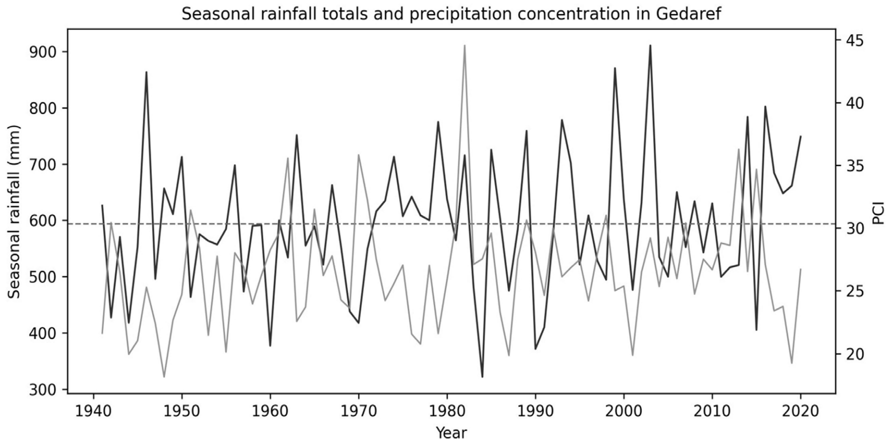

Figure 4. Seasonal rainfall totals and precipitation concentration index in Gedaref during 1941-2020.

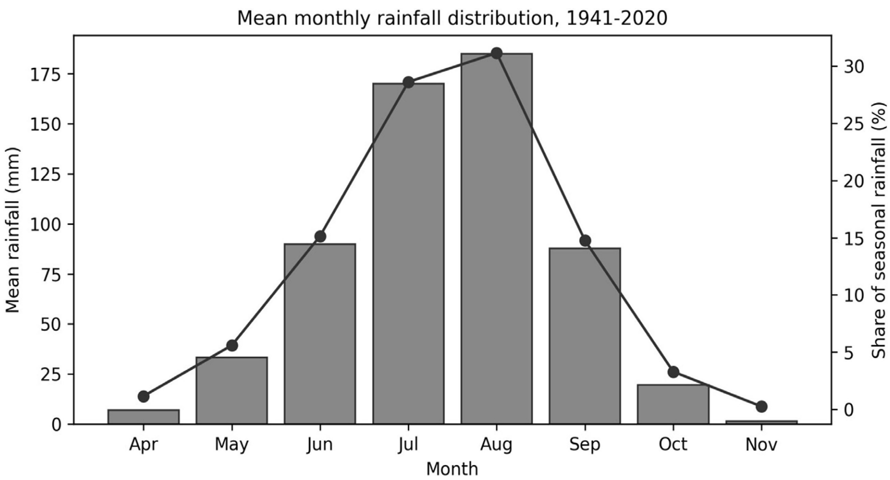

Figure 5. Mean monthly rainfall and percentage contribution to April-November seasonal rainfall.

The main rainfall variability and concentration indicators are summarized in Table 1.

Table 1. Long-term rainfall variability and concentration indicators for Gedaref, 1941-2020.

Indicator	Value
Mean seasonal rainfall (mm)	593.48
Minimum seasonal rainfall (mm)	322.00
Maximum seasonal rainfall (mm)	910.70
Coefficient of variation (%)	19.96
Mean PCI	26.59

Continued

July-September rainfall share (%)	74.71
June-September rainfall share (%)	89.71
Mann-Kendall τ	0.102
Mann-Kendall p-value	0.181
Sen's slope (mm decade^{-1})	8.67

3.2. Weekly Soil Moisture Response to Sesame Straw Mulch

Gravimetric soil moisture differed among mulch rates during the monitoring period. Across both depths and all weekly measurements, mean soil moisture was 23.27% under 5.56 t ha^{-1} and 19.69% in the control. This represents an observed difference of 18.2%.

The same pattern appeared in both sampled layers. In the 0 - 30 cm layer, mean moisture was 22.08% under 5.56 t ha^{-1} and 18.96% in the control, giving an observed difference of 3.12 percentage points. In the 30 - 60 cm layer, mean moisture was 24.46% under 5.56 t ha^{-1} and 20.42% in the control, giving an observed difference of 4.04 percentage points.

Mean moisture was numerically higher in the 30 - 60 cm layer than in the 0 - 30 cm layer. This depth pattern should be read cautiously because the depth effect did not reach the 0.05 significance level in the mixed model.

As shown in Figure 6, the mulched treatments generally had higher moisture values than the control during the monitoring period, particularly in the later weeks. This pattern is descriptive and does not indicate a statistically significant difference in dry-down slopes among treatments.

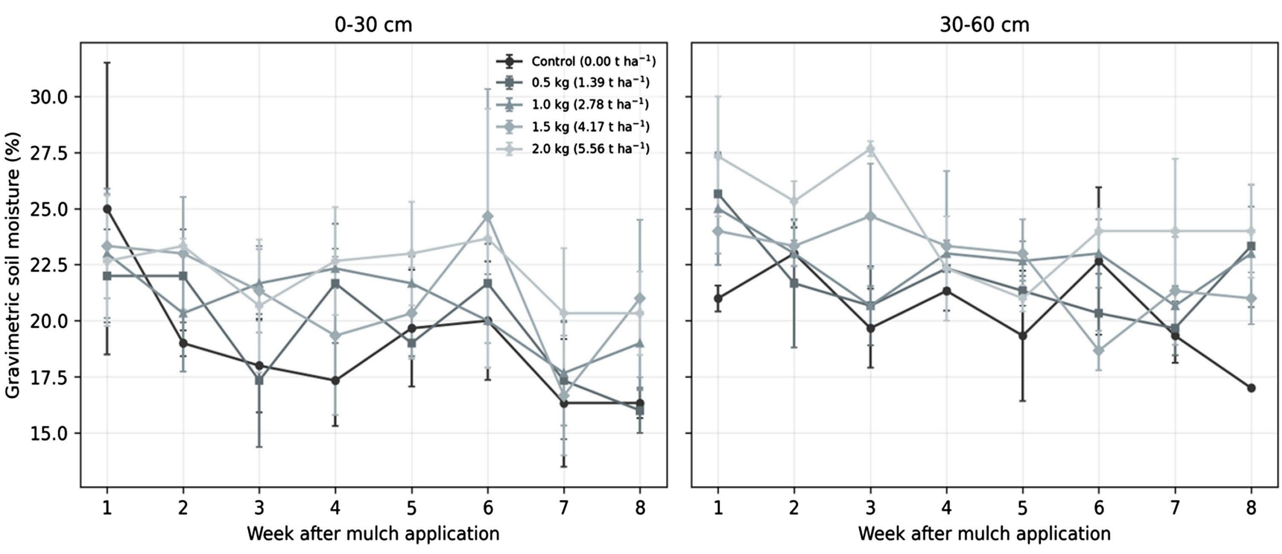

Figure 6. Weekly gravimetric soil moisture under sesame straw mulch rates at 0 - 30 and 30 - 60 cm depths.

The treatment and depth means are summarized in Table 2.

Table 2. Mean gravimetric soil moisture by mulch rate and soil depth. Values are means ± SE.

Treatment	Rate (t ha^{-1})	Depth	Moisture (%)
Control	0.00	0 - 30 cm	18.96 ± 1.05
Control	0.00	30 - 60 cm	20.42 ± 0.66
0.5 kg $plot^{-1}$	1.39	0 - 30 cm	19.62 ± 0.79
0.5 kg $plot^{-1}$	1.39	30 - 60 cm	21.88 ± 0.66
1.0 kg $plot^{-1}$	2.78	0 - 30 cm	20.71 ± 0.70
1.0 kg $plot^{-1}$	2.78	30 - 60 cm	22.62 ± 0.50
1.5 kg $plot^{-1}$	4.17	0 - 30 cm	21.21 ± 1.07
1.5 kg $plot^{-1}$	4.17	30 - 60 cm	22.42 ± 0.68
2.0 kg $plot^{-1}$	5.56	0 - 30 cm	22.08 ± 0.94
2.0 kg $plot^{-1}$	5.56	30 - 60 cm	24.46 ± 0.72

3.3. Repeated-Measures Mixed-Effects Model

The repeated-measures mixed-effects model showed a significant positive effect of mulch rate on gravimetric soil moisture. Soil moisture increased by 0.592 percentage points for each additional t ha^{-1} of sesame straw mulch ($p = 0.018$). This means that higher mulch rates were associated with higher mean soil moisture across the measured weeks and depths.

Week had a significant negative effect on soil moisture (estimate = −0.482 percentage points $week^{-1}$, $p < 0.001$), showing that soil moisture declined during the monitoring period. The 30 - 60 cm layer had a positive coefficient of 1.842 percentage points, but this effect did not reach the 0.05 significance level ($p = 0.062$).

The mulch treatment × sampling week interaction tested in the initial model was not significant ($F = 0.33$, $p > 0.99$). There was therefore no statistical evidence that the weekly pattern of moisture decline differed among mulch treatments.

Table 3. Repeated-measures linear mixed-effects model for gravimetric soil moisture.

Fixed effect	Estimate	SE	Wald statistic	p-value	95% CI
Intercept	20.56	1.03	20.03	<0.001	18.55 to 22.57
Mulch rate (t ha^{-1})	0.59	0.25	2.36	0.018	0.10 to 1.09
Depth: 30 - 60 cm	1.84	0.99	1.86	0.062	−0.10 to 3.78
Week after mulch	−0.48	0.08	−6.08	<0.001	−0.64 to −0.33

Note. The mulch treatment × sampling week interaction was tested in an initial model and was not significant ($F = 0.33$, $p > 0.99$). It was not retained in the final model. The depth effect was positive but did not reach the 0.05 significance level.

The final model supports two main inferential results: soil moisture declined through time, and higher mulch rates were associated with higher observed mean soil moisture during monitoring. Differences among treatment-specific slopes and depth-specific residence-time values were interpreted only as descriptive summaries.

The fixed-effect estimates from the final mixed-effects model are summarized in Table 3.

Residual plots did not show a clear funnel-shaped pattern. The normal Q-Q plot showed some upper-tail departure, but the diagnostics were considered acceptable for the descriptive and inferential aims of the model.

The residual diagnostics are shown in Figure 7.

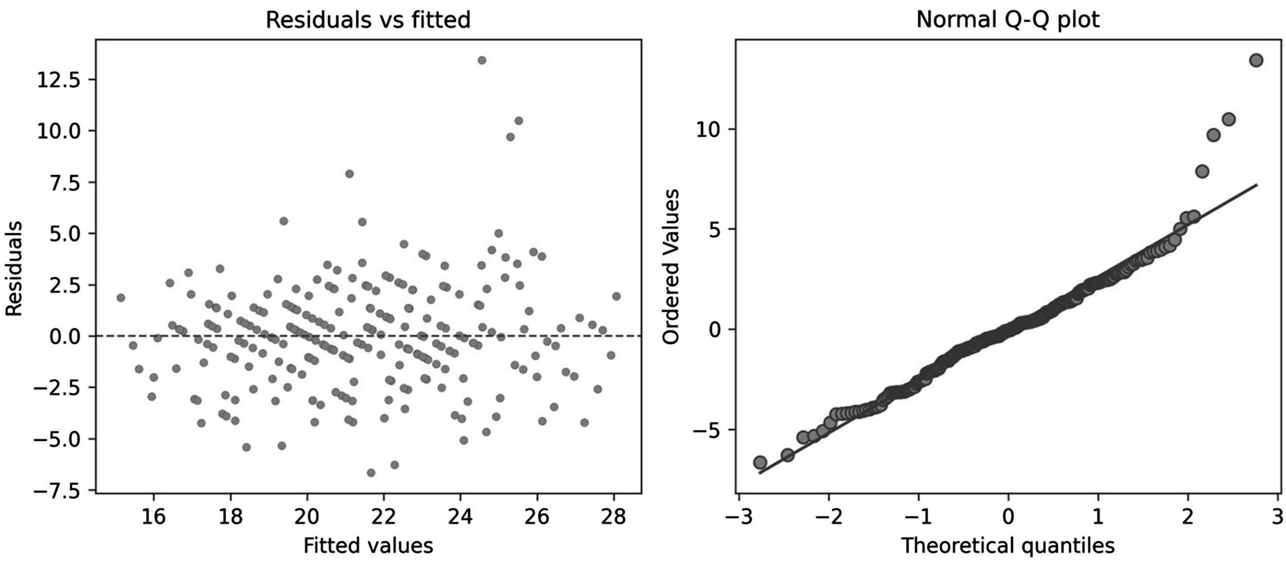

Figure 7. Diagnostic plots used to inspect normality and homoscedasticity of mixed-model residuals.

3.4. Secondary Descriptive Summaries

As a secondary check, AUC was calculated from the weekly soil-moisture values. Across depths, AUC was 137.67 %-week in the control and 162.58 %-week under 5.56 t ha^{-1}. A reference-based index showed the same general pattern, with an 11.8-day difference between the control and the highest mulch rate within the measured interval.

These values were not tested inferentially and were not used as evidence of treatment effects. They are reported only to show that the main moisture pattern was similar when summarized across the monitoring period.

3.5. Descriptive Moisture-Change Slopes

Treatment-specific linear slopes were calculated only as descriptive summaries of moisture change during monitoring. They were not used to test treatment differences because the mulch treatment × sampling week interaction was not significant. The surface layer showed less negative numerical slopes under some mulch treatments than in the control, while the 30 - 60 cm layer showed a less consistent pattern, including a more negative slope under 4.17 t ha^{-1}.

3.6. Field Surface Condition

The field images show the surface condition created by the treatments. Bare control plots exposed the cracking clay surface directly to the atmosphere, while mulched plots had a sesame straw layer covering the soil. This surface difference provides visual context for the soil-moisture results.

Figure 8 shows the distribution of sesame straw over the experimental plots. The image also shows the heavy clay surface and the plot-level treatment layout. These images support the interpretation of the study as an uncropped field dry-down experiment with different surface-cover conditions.

Figure 8. Sesame straw mulch applied to field plots on cracking clay soil.

4. Discussion

4.1. Mulch-Rate-Dependent Soil Moisture Response after Wetting

The main result was a rate-related pattern in observed soil moisture after wetting. Mean soil moisture was highest under 5.56 t ha^{-1} and lowest in the control. Across depths and weeks, the observed values were 23.27% under 5.56 t ha^{-1} and 19.69% in the control, giving an 18.2% difference.

The mixed model estimated a positive mulch-rate effect on mean soil moisture. The treatment × sampling week interaction was not significant, so the data do not show different weekly dry-down slopes among mulch rates. The main supported result is that higher mulch rates were associated with higher observed soil moisture during monitoring.

The secondary AUC and reference-based summaries followed the same direction as the mean moisture values, but they were not used as separate evidence of treatment effects.

For rainfed fields in Gedaref, this response is relevant because rainfall is concentrated within a short season. A single weekly moisture value does not fully describe how long moisture remains after wetting.

The pattern is consistent with earlier work on surface cover and soil evaporation. Exposed wet soil can lose water rapidly at the surface, and later drying depends more on water movement through the soil and vapor transfer to the atmosphere [5] [7] [9]. Straw mulch can change this surface condition by reducing direct exposure to radiation and moving air. Similar surface-cover effects have been reported in mulch studies [6] [10].

Evaporation and cracking were not measured in this experiment. For that reason, the data should be read as soil-moisture observations under different surface-cover treatments, not as a direct test of evaporation reduction or crack development.

Recent work on straw and organic mulching also shows that mulch effects on soil water depend on soil texture, mulch amount, climate, and field management [20]-[23]. The present experiment was conducted under uncropped dry-down conditions after a single standardized wetting event. The results should therefore be interpreted as a soil-moisture response to sesame straw mulch, not as a direct agronomic recommendation. Cropped-field trials are needed to test whether this moisture response improves crop establishment, rooting, biomass, or yield under real rainfall conditions.

4.2. Subsurface Moisture Pattern in the Vertisol Profile

Mean soil moisture was numerically higher in the 30 - 60 cm layer than in the 0 - 30 cm layer, but the depth effect did not reach the 0.05 significance level in the mixed model. At 30 - 60 cm, mean moisture was 24.46% under 5.56 t ha^{-1} and 20.42% in the control. This shows an observed subsurface difference, not a statistically confirmed depth effect.

This pattern is useful to report because the soil is a Vertisol. Cracking clay soils can shrink during drying, and cracks may affect air and water movement within the profile [2]-[4] [11] [24]. Crack width, crack depth, and timing of crack development were not measured here, so this explanation remains background rather than a measured result.

4.3. Rainfall Concentration as the Field Context

The rainfall analysis provides the field context for interpreting the moisture results. Gedaref received a mean April-November seasonal rainfall of 593.5 mm during 1941-2020, but this rainfall was strongly concentrated. The mean PCI was 26.6, July - September supplied 74.7% of seasonal rainfall, and June-September supplied 89.7%.

This rainfall pattern explains why post-wetting soil moisture is relevant in Gedaref. Most seasonal rainfall occurs within a short period, so soil water after a wetting event can be important during dry intervals. The field experiment used a single standardized wetting pulse and did not simulate a full rainy season.

Under 5.56 t ha^{-1}, observed mean soil moisture was higher than in the control. These results describe an uncropped dry-down pattern. They should not be used to predict crop performance during the rainy season.

4.4. Mechanistic Limits: Evaporation and Cracking

The study measured soil moisture, but it did not measure evaporation, crack width, crack depth, or the timing of crack development. These processes are relevant in Vertisol dry-down, but they were not directly quantified in this experiment.

The observed response is consistent with a surface-cover effect. A mulch layer can reduce direct exposure of the wet soil surface and change the boundary between soil and the atmosphere. The data show differences in observed soil moisture, but they do not separate evaporation, cracking, redistribution, or subsurface vapor movement.

4.5. Limits of the Uncropped Design

The uncropped design removed root water uptake and canopy shading from the experiment. This made it easier to follow soil-moisture change after a common wetting pulse, but it also limits direct transfer of the results to cropped fields.

In a cropped plot, soil moisture decline would reflect soil evaporation, root uptake, transpiration, canopy shading, crop stage, and rainfall timing. The present experiment did not test crop emergence, rooting depth, biomass, or yield.

The results should therefore be treated as a field dry-down assessment under controlled surface-cover conditions. Cropped trials are needed to test whether the observed soil-moisture response is associated with better crop establishment, root growth, biomass production, or yield stability under real rainfall sequences.

4.6. Implications for Dryland Soil-Water Management

The results link rainfall concentration in Gedaref with a measured soil-moisture response under sesame straw mulch. The rainfall record shows that most seasonal rainfall occurs within a short part of the year. The field experiment showed higher observed soil moisture under mulched plots after a standardized wetting event.

The practical value of this result should be stated carefully. The experiment was uncropped, conducted during the winter dry season, and used a single 27.78 mm wetting pulse. It did not simulate the full rainy season and did not measure crop response.

Within these limits, sesame straw mulch can be treated as a local surface-cover option that deserves further testing. Field recommendations should wait until cropped-season trials measure crop establishment, soil water use, cracking, biomass, and yield.

4.7. Study Limitations

Several limits affect how the results should be read. No soil-moisture measurement was taken before mulch application, so the reported differences are post-application differences, not baseline-adjusted changes. The experiment also had 15 field plots as the main experimental units. The 240 moisture values came from repeated sampling across depths and weeks and should not be read as 240 independent field units.

The experiment did not measure evaporation, crack width, crack depth, crop emergence, biomass, or yield. It was also conducted under uncropped winter dry-season conditions after a single 27.78 mm water application. These points limit the use of the results for field recommendation.

The study therefore provides preliminary field evidence that observed soil moisture differed among sesame straw mulch rates after wetting. It does not establish crop response, seasonal performance, or an agronomic application rate.

5. Conclusions

This study showed a rate-related pattern in observed soil moisture under sesame straw mulch in an uncropped Vertisol from eastern Sudan. After a standardized wetting pulse of 100 L per plot, equivalent to 27.78 mm, soil moisture was monitored weekly at 0 - 30 and 30 - 60 cm depths.

The mixed model estimated a positive association between mulch rate and mean gravimetric soil moisture during monitoring. Soil moisture also declined with time. The mulch treatment × sampling week interaction was not significant, so the study does not show different weekly dry-down slopes among mulch treatments.

The highest observed moisture values were recorded under 5.56 t ha^{-1}. Across depths and weeks, mean soil moisture was 23.27% under this treatment and 19.69% in the control. This difference was observed after mulch application and should not be read as a baseline-adjusted change.

Because pre-mulch moisture was not measured, the results should be interpreted as an association between mulch rate and observed post-application moisture levels. Evaporation, cracking, crop emergence, and yield were also not measured. The results should therefore be treated as preliminary field dry-down evidence, not as a final basis for field recommendations.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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