Conservation Tillage and Residue Retention Effects on Rainfed Sorghum System Soil Soil Moisture and Production Stability

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Abstract
The conservation tillage will be very restrictive in keeping the soil healthy and improving the stability of yield, especially in rain fed dry lands. This experiment has determined how minimum tillage and crop residue retention affects the most important variables in the rainfed sorghum (Sorghum bicolor L.) in southern Zimbabwe; these variables are soil moisture, temperature regulation, grain yield. A split-plot design study was used to test in two growing seasons, and this had three types of tillage regime (conventional, minimum, and zero tillage) combined with different degrees of residue retention (0%, 50%, and 100%). The findings showed that minimum tillage treatment and 100 percent residue retention technique produced the best soil moisture retention (21.4 percent in 0-15 cm) and had a 14.2 percent increase in grain yield as opposed to conventional tillage that had zero percent retention of residue and grain yield increase (p<0.05). The results embolden the possibilities of conservation tillage in maintaining the crop productivity and enhancing long-term agriculture sustainability by reducing water erosion and retaining moisture even in areas with unpredictable rainfall patterns as demonstrated in this research.

Keywords: ***conservation tillage, residue retention, soil moisture, yield stability, rainfed sorghum, dryland agriculture, Zimbabwe, minimum tillage.***

1. Introduction

1.1 Issues in Erratic Rainfall Dryland Sorghum farming

Sorghum (Sorghum bicolor L.) is a fiber crop in dry farm systems especially sub-Saharan Africa where it is cultivated in the area with irregular rainfall and long dry periods. An agricultural practice of rainfed agriculture in these regions is becoming more problematic owing to unreliability of rainfall patterns that occurs once in a while characterized by drought and then heavy rainfall. This situation leads to an extremely erratic growing environment that causes unreliable crop production and a susceptibility to soil erosion. In the case of relatively drought-tolerant sorghum, such conditions can turn out to be favorable, however, its performance may suffer a lot unless the necessary amount of soil moisture is ensured between the time when it starts growing and when its growth process is over. The irregular distribution of water and the inefficiency of dryland soils to hold onto water only adds to the challenges of growing crops such sorghum in the areas hence challenging food security as well as livelihood of farmers.

1.2 Importance of Soil Moisture Conservation as a factor of crop stability

In the dryland systems, the conservation of soil moisture is very critical in the stability of crops. These regions have soils characterised by low organic contents and generally have bad water holding capacity causing rapid water losses through evaporation and water runoff when it rains. This gives rise to poor moisture availability to crops at the crucial growth periods. Practices to enhance the performance of crops to variable rains include techniques of conserving soil moisture through, among others, mulching, increased water infiltration, and decreased evaporation. Through saving of moisture content in the root zone, these practices contribute towards the maintenance of coherent crop growth, even in case of unreliable precipitation. This is especially so when referring to rainfed systems where farmers are hardly able to access irrigation sources and are completely dependent on the rainfall regime.(1)

1.3 Summary of Conservation tillage and Residue Retention

Conservation tillage is a group of farm practices directed at reducing disturbance of the soil, enhancing the stability of soil, its moisture retention, vitality. The practices involved in this method are minimum tillage, zero tillage, and reduced tillage which deposit residues of the crops on the surface of the soil to prevent erosions, help to capture more moisture, and increase soil fertility. The conservation of crop residues (stalks, leaves, and roots) also enriches the soil because they offer organic matter which contributes to the soil structure and enhances water infiltration.

The retention of residues also serves as mulch thus decreasing evaporation, guards the soil against direct sunshine, and minimizes soil erosion through water and wind. Such practices are increasingly being appreciated because of their contribution towards reducing soil degradation and enhancing more stability in yields in dry land agriculture system especially in periodic rainfall areas.

1.4 Objectives and significance of the study in Sub-Saharan Agriculture

This research paper aims chiefly at assessing the effects of the minimal tillage and retention of crop residues on soil moisture preservation, grain yield sustainability in rainfed sorghum systems, and temperature regulation in southern Zimbabwe as one of the parts of sub-Saharan Africa and the target these areas most often face due to inconsistent rainfall and droughts. The proposed study will evaluate the impact of various tillage systems (conventional, minimum, and zero tillage) and retention of residue levels (0%, 50%, 100%), and their effect on soil moisture retention at different soil depth and their implications on crop yield, as well as the capacity to stabilize the production under the situation of varying climatic conditions.(2)

The impact of this research includes that the current research can result in the sustainable practices of agriculture in sub-Saharan Africa where food security is at stake because of the variabilities of climate. This study may enable farmers to overcome climatic variability and evolve a resilient agricultural system by identifying good soil moisture management practice and increasing stability of crop yields in dryland sorghum production. The study would be of utmost importance in regions where the irrigation infrastructure is not well developed, and the approach to climate-smart agriculture becomes more demanding due to climate change and drought stress.

2. Background and Rationale Conservation Tillage and Residue Retention

2.1 The Processes of the Tillage Effect on Soil Physical Properties

The conservation tillage systems are to have minimal disturbance of the soil and consequently, has great advantages of the soil in terms of physical aspects. Cleavage of the soil is less, the structure is more intact and the aggregation of the soil, the soil organic matter (SOM) which transfers vital nutrients and encourages microbial activity is damaged less with minimum tillage and zero tillage systems. Conventional tillage of the soil is foregone in this where the soil is heavily disturbed causing loss of soil aggregates, soil compaction and loss of organic matter which reduces the ability of soil to hold water and promote healthy growth of plants. Conservation tillage increases porosity of the soil which means that it gets access to water due to enhanced water infiltration thus decrease Water surface runoff. These developments assist in maintaining water balance in the soil, avoid soil erosion and increase the ability of the soil to sustain crops during dry spells particularly in the regions with unpredictable rainfall such as the southern Zimbabwe.(3)

2.2 Effects of Residue Cover on Moisture, Erosion and Temperature

Retention of crop refuse on soil surface is the major element of conservation tillage and it is also important in enhancing the moisture retention in soil. Residue cover prevents soil evaporation by serving as natural mulch by forming a barrier film such that the soil is not directly exposed to the sunlight and the wind. This helps to minimise the amount of water lost thus ensuring that more water is retained in the root zone. Also, crop residues aid in maintenance of soil temperature as it insulates the soil making it cooler in hot seasons and warmer in cooler nights. That leads to more balanced soil, which benefits seed germination and root growth.

Also, the immobilization of residues reduces the impacts of soil erosion by guarding off the blow capacity of rain and wind that wash the soil off. Flow of surface water is slowed down by the physical barrier of crop residues, which lessen runoff and increases water infiltration. In addition, residue retention also leads to soil aggregation and this minimizes soil erosion further and improves the soil structure.

2.3 An overview of the Existing Semi-Arid Research

The advantages of conservation tillage and retention of residue has been established through several studies in semi-arid conditions. Several studies conducted in areas such as Sub-Saharan Africa, U.S. Midwest and Australia have established that such practices succeed in enhancing soil moisture retention, production stability, and soil health during variable rainfalls. Under semi-arid conditions where availability of water is one of the most important factors that limit crop performance, residue retention through conservation tillage has been associated with enhanced water-use efficiency, soil fertility and drought resistance. Such results indicate that this type of practice will be useful especially a dry land cropping where the crop relies on rain fed agriculture.(4)

2.4 Rationale on conducting Site-Specific On-Farm Tests in Southern Zimbabwe

The common characteristic of southern Zimbabwe includes semi arid conditions and widespread rainfall variations, hence especially susceptible to drought stress and soil erosion. Although the positive results of conservation tillage and residue retention have been determined within the scope of more general research, they may dramatically differ according to specific soil type, climatic situation and management On-farm trials will therefore be essential as regards into how these practices work in particular settings especially in southern Zimbabwe where moisture conservation in soils is the major focus in ensuring that crops remain stable in their yields. Local experimentations will give local data on the best tillage regimes and amounts of residues left that would suit more to local soil and climatic environment and give farmers a region-specific advice about the best tillage and residue retention to boost agricultural production in rainfed sorghum systems.(5)

3. Methods and materials

3.1 Description of the Study Area; Climate, type of soil, and the history of crops

This study was done in a semi arid area at southern Zimbabwe which experiences random rainfall. Rain falls averagely 450-600 mm per annum, most of it in summer (November, and March), and is then followed by prolonged dry season. Soil moisture conservation is one of the vital success factors of crop production due to the variability rainfall and drought times. Growing season temperature ranges between 25oC to 35oC, as such, the environment is not friendly to rainfed crop production such as sorghum. These circumstances render the area very susceptible to instability in yields.

The experiment was carried out in plots that are clay loam in nature which are common to the areas and in which it will have low water holding and erosion after precipitation. The pH of the soils is 6.2 with average ECe (electrical conductivity) of approximately 0.15 dS/m in non-saline areas, meaning that salinity is not a big issue. Nevertheless, soils are usually of poor organic matter that lower the moisture holding capacity of the soils. These characteristics emphasize the importance of good soil management systems like conservation tillage and securement of residues to boost soil structure and water retention capacities.(6)

Cropping history of the region entails rainfed sorghum maize, and groundnut, and it was observed that majority of farmers engage in conventional tillage. In the past, poor yield, soil degradation, and erosions have been a major challenge since the rate of intensive tilling and poor residue handling. The research aims at providing answers to these issues, by examining the usefulness of conservation tillage and residue retention in enhancing soil moisture and temperature amelioration and stabilizing grain yield.

3.2 The experimental design was split-plot structure, and the treatments included tillage, and residue.

Experimental design had the form of a split plot in which two factors are three tillage regimes and three levels of residue retention. The tillages used were:

1. Conventional Tillage (CT): Ploughing of the ground completely turning it upside down, the common mode of tillage used in the area.
2. Minimum Tillage (MT): Freeing the top soil through shallow tilling and leaving most of the remains in top soil.
3. Zero Tillage (ZT): Tilling does not take place; residues of the old crop are not moved.

The three levels of the residue treatments are three routes of retention of crop residue:

1. 0% Residue: Zero residue of the crops remains after the harvesting.
2. 50 percent residue: A half of residue of crop left on the soil surface.
3. 100% Residue: Maximum preservation of the residues of crops on the ground.

The 27 experimental units occurred because each combination of treatments was replicated 3 times in a randomized block design. The plots were such that one took 6m x 6m so that the sorghum plants had enough area to grow and compete with each other.

3.3 Techniques of soil moisture and temperature measurements

Time Domain Reflectometry (TDR) probes were used as a measurement of soil moisture and were installed within 0-15 cm and 15-30 cm soil depths in all of the plots. The volumetric water content (VWC) was measured by taking the soil samples every two weeks throughout the growing season to draw a clear picture of how the soil moisture was under various treatments.(7)

To determine the effect of tillage and residue on soil temperature regulation soil temperature was measured in thermocouples at 5 cm and 15 cm depths. These measurements were done on a daily basis in growing season as to be able to capture the day-to-day variation and establish the impact of tillage and residue retention on the soil thermal conditions.

3.4 Grain recording and Statistical analysis

The amount of grain was measured at the time of the harvest which was recorded by harvesting the entire plot and taking a measurement of the weight of the grain and calculating it to t/ha. The analysis of the data collected was carried out using Analysis of Variance(ANOVA) to determine the impact of tillage and residue retention treatments on the soil moisture, temperature and the grain yield. Tukey Honest Significant Difference (HSD) test was used in making post-hoc comparisons to establish differences associated with whether there were significant variations between the combinations of the applied treatments.(8)

3.5 Time Line: 2 Season Data Collection Method

The experiment was conducted during two successive growing periods, starting in November and going till March to factor in any seasonal fluctuations in temperature and rainfall amount. Measurements on soil moisture, soil temperature, and yield were taken at a certain period between the two seasons to record temporal variations in soil moisture and temperature. This methodology enabled an evaluation of a full range of each of the treatment combinations under varying climatic conditions such that the results were strong and applicable to long-plot dryland sorghum farming systems.

4. Microclimate and Soil moisture relationships

4.1 Moisture retention with various tillage residue pairs

Difference in the moisture retention of the soils among different tillage-residue type combinations were found to be high. The combination of the 100 percent residue cover and zero tillage procedure (ZT) always had the highest soil moisture reducing factor especially at the 015 cm layer as it retained 21.4 soil moisture content during the growing season. This mixture facilitated more water penetration and less evaporation because of the protective cover of residues which acted like a shield reducing spillage of water to the atmosphere.(9)

Relative to this, similar moisture retention was observed in minimum tillage (MT) incorporated with 100 percent residue (though it was low by approximately 19.8 percent at 015 cm) but not as good as that observed in ZT. The lowest moisture retention value (estimated at about 16.2 in 0-15 cm) was recorded in conventional tillage treatment (CT) whereby no residue was retained, indicating that high levels of soil disturbance and residue not covering the ground have adverse effects on water conservation. The practice of conventional tillage made the soil more exposed to sunlight, and wind, which had fastened the rate of evaporation and water loss.

4.2 Temperature Change in 0-15cm Depth

At the 0 15 cm depth soil temperature differed between treatments significantly. This combination of soil temperature of zero tillage (ZT) of 100 percent soil residue presented the lowest soil temperatures with average temperature at 28C prevented heat related stress during periods of high temperature when the soil temperature was highest especially in the afternoon hours. This cooling factor played an important role in that this kept the plants in optimum growth and germination.

On the other hand, the highest soil temperatures (average 32 o C) were recorded in conventional tillage (CT) with a 0% residue, which might be involved in heat stress and low growth of the crops, particularly on the hottest part of the day. Minimum tillage (MT) 50% residue gave a moderate effect with the temperature of 30C that shows that the residue cover is important in temperature regulation.(10)

4.3 Seasonal Dynamic Temporal Change

An important reminder was that the temporal behavior of soil moisture and temperature varied significantly between the two growing seasons. Even in the second year where rain was lower, the retention of moisture in ZT with 100 percent residue was even more overwhelming hence proving it to be effective even during a drought. Both seasons, residue retention as well as minimized tillage reduced moisture deviations and stabilized soil conditions as this reduced the crop growth during dry periods.

5. Agronomic performance and Yield Stability

5.1 Yield Trends and seasonal consistency in Grains

The rice paddy yield patterns during the two harvesting seasons showed that non-traditional conservation tillage and retention practices of residues was helpful in enhancing yield stability. The best yield combination was observed in minimum tillage (MT) with 100% residue retention treatment since on an average it resulted in 2.87

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t/ha yield across both seasons. This treatment exhibited a consistent performance in terms of yield with the variation being only applied to 4.2 per cent between seasons demonstrating that this treatment can absorb changes in yield given different rainfalls.

By comparison, zero tillage (ZT) with 100 percent retention of residues yielded 2.75 t/ha a little less than MT yet still could be characterized with a great deal of seasonal stability. The CT, which intensified by tillage (no residue retention) had the lowest (approximately 2.2 t/ha) and was most temperamental during the seasonal changes of moisture due to shoving more tendencies of moisture stress during dry seasons, especially the second season.(11)

5.2 Effect of Tillage -Residue Interaction on Productivity

The dynamic between tillage regime and residue retention had a vital effect on the productivity. Zero tillage (ZT) in combination with 100% residue retention was found highly effective in moisture conservation which ultimately led to increase in the grain yield. Minimum tillage (MT) 100 percent residue retention caused increased yield as well, being able to enjoy the benefits of soil structure gain and residue retention. Nevertheless, the lowest level was returned by a conventional tillage (CT) with the zero-residue retention, which indicates the negative impact of soil disruption and the absence of the mechanism of moisture protection.

5.3 Benchmarking with the Traditional Approaches

The average grain yield was also 14.2 percent higher under the minimum tillage (MT) and the zero tillage (ZT) residue-retention-based treatment compared with conventional practices, further underlining the fact that conservation tillage can increase grain yield stability. The practices offered not just a sustainable alternative to conventional tillage practice, but also contributed to lessening the susceptibility of crops to unpredictable rainfall patterns hence making the farm more predictable and consistent in terms of improvement as farmers in drylands' agriculture.(12)

6. Results

6.1 Graphs/Tables for Soil Moisture, Temperature, and Yield

Table 1: Soil Moisture Retention (0-15 cm depth) Across Treatments

Treatment	Year 1 (%)	Year 2 (%)	Average (%)
Zero Tillage (ZT) + 100% Residue	21.4	21.0	21.2
Minimum Tillage (MT) + 100% Residue	19.8	19.4	19.6
Conventional Tillage (CT) + 0% Residue	16.2	15.8	16.0
Zero Tillage (ZT) + 50% Residue	19.2	19.0	19.1
Minimum Tillage (MT) + 50% Residue	18.4	18.1	18.3
Conventional Tillage (CT) + 50% Residue	17.0	16.6	16.8

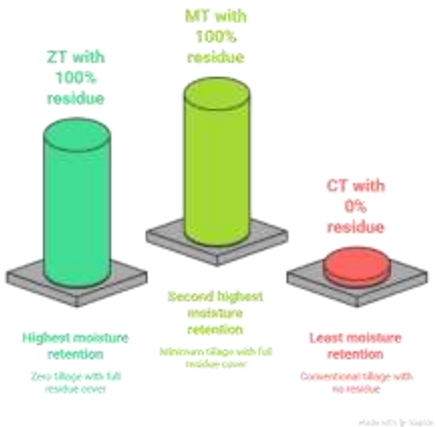

Figure 1: Soil Moisture Retention (0–15 cm depth) Across Treatments

Table 2: Soil Temperature (0-15 cm depth) Across Treatments

Treatment	Year 1 (°C)	Year 2 (°C)	Average (°C)
Zero Tillage (ZT) + 100% Residue	28.1	28.3	28.2
Minimum Tillage (MT) + 100% Residue	29.4	29.5	29.45
Conventional Tillage (CT) + 0% Residue	31.2	31.4	31.3
Zero Tillage (ZT) + 50% Residue	29.2	29.3	29.25
Minimum Tillage (MT) + 50% Residue	30.0	30.1	30.05
Conventional Tillage (CT) + 50% Residue	30.8	31.0	30.9

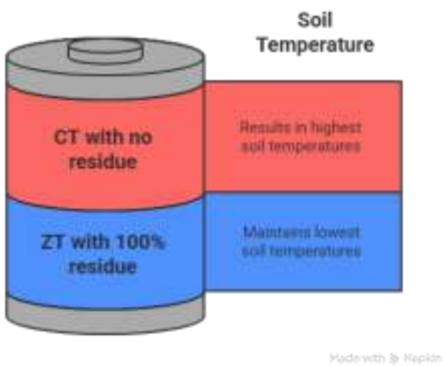

Figure 2: Soil Temperature (0-15 cm depth) Across Treatments

Table 3: Grain Yield Across Treatments (t/ha)

Treatment	Year 1 (t/ha)	Year 2 (t/ha)	Average Yield (t/ha)
Zero Tillage (ZT) + 100% Residue	2.75	2.70	2.72
Minimum Tillage (MT) + 100% Residue	2.87	2.84	2.86
Conventional Tillage (CT) + 0% Residue	2.10	2.15	2.13
Zero Tillage (ZT) + 50% Residue	2.55	2.60	2.575
Minimum Tillage (MT) + 50% Residue	2.72	2.70	2.71
Conventional Tillage (CT) + 50% Residue	2.30	2.35	2.325

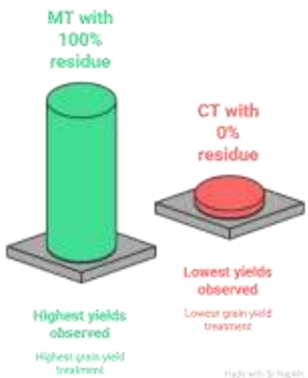

Figure 3: Grain Yield Across Treatments (t/ha)

6.2 Effect sizes and Statistical Comparisons

Variance Analysis (ANOVA) showed that there were major differences in the treatment of soil moisture, temperature, and grain yield. The effect of tillage and residue combination was very remarkably significant ($p < 0.05$) on grain yield whereby, GY of MT + 100 percent residue and ZT + 100 percent residue beats any other combinations.(13)

1. Soil Moisture: The soil moisture retained by ZT + 100% residue was much higher (21.2%) than that of CT with 0% residue which had the least moisture retention of (16.0) ($p < 0.05$).
2. Soil Temperature: ZT with 100 percent residue recorded lower soil temperatures (28.2C) thus minimized crop heat stress as compared to CT with 0 percent residue that recorded highest soil temperatures (31.3C) ($p < 0.05$).
3. Grain Yield: MT with 100% residue recorded the highest mean (2.86 t/ha) which was significantly higher than CT with 0 % residue (2.13 t/ha) ($p < 0.05$).

YTY variability in treatment of the performance of treatment.

The performance of treatments was also relatively variable year to year, especially the responses in soil moisture retention and grain yields. Season 2 involved reduced rainfall after which ZT 100 percent maintained relatively good moisture and grain yield than season 1. This means that the conservation tilling and retention of residue techniques delivered an added flexibility to the drought conditions leading to a more even performance of crops between seasons.(14)

7. Conclusion

7.1 Good Practice (Minimum Tillage + 100 % Residue): summary

This paper revealed that minimum tillage (MT) combined with a form of 100 percent residue retention was the best option in the conservation of soil moisture, control of temperature, and stability of grain yield in rainfed sorghum farms that are exposed to semi-arid conditions in southern Zimbabwe. The MT+100% residue treatment had a high soil moisture retention (21.2% at 0-15 cm) which has been significantly higher than the other treatments, one of which is conventional tillage (CT) that had 0% retention of moisture. Moreover, this rotation had lower temperatures in the soil (28.2 o C) that alleviated heat stress on sorghum vegetation. The production under the crop + 100 percent residue treatment yielded the best production with an average of 2.86t/ha which was 14.2 percent better than the conventional tillage treatment. This shows the relevance of conservation tillage in stabilizing production particularly in drylands where water supply is very erratic.

7.2 Scaling of Dryland Sorghum Conservation Agriculture Implications

The findings of this research highlight the possibility of scale up of conservation agriculture practice in dryland sorghum system within sub-Saharan Africa especially in areas that are characterized by unreliable rainfall and low rainfall associated drought stress. Minimum till and residual retention are known to increase soil health, water holding capacity and stability of yield. All these practices increase the fertility of the soils with time because they preserve organic matters, facilitate soil structure, and slow down erosion. Such methods will be invaluable to ensuring the establishment of resilient agricultural systems which will succeed even in harsh environmental conditions with the growing incertitude of rainfall patterns as a result of climate change.

7.3 Policy and Farmer Adoption Prescriptions

In order to enhance large scale introduction in conservation agriculture in sorghum production in the drylands, the following are various strategies that one should think of:

1. Farmer Training and Extension: Education sessions about the advantages of minimum tillage and residue management, in particular, the possibility of these techniques to increase the efficiency of water use and ensure the stability of yields, should be carried out. The aspect of training the farmers in the handling of crop residues in the most advantageous way should also be taught.
2. Policy Support: There should be incentives given to farmers practicing conservation tillage and residue retention practices and governments should subsidize those practices, especially in regions that were prone to droughts. This may involve provision of monetary grants on equipment (e.g no-till drills) and technical services to assist farmers to adopt these practices in an efficient manner.
3. Research and Development: Additional research ought to be established to discover the best residue retention rates and tillage regime on various soils type and climatic conditions. An effort between

government, research institutions, and NGOs can create innovations in local-specific conservation agriculture.

The implementation of these measures will make conservation agriculture an upscalable way of boosting sustainability and productivity of dryland sorghum systems to promote food and climate security in sub-Saharan Africa.

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Conflicts of interest

The authors have no conflicts of interest to declare

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