Query Details

Back to Main Page

1. Kindly check and verify that the author name(s) and the identification of the corresponding author(s) are correctly recognized and presented in the correct sequence order and spellings, i.e., given name, middle name/initial, and family name for the authors. In addition, please verify that the E-mail addresses and Affiliation(s) of the corresponding author(s) and co-author(s) shown on the metadata page are valid, and make any necessary amendments if required.

2. Please be aware that your name and affiliation and if applicable those of your co-author(s) will be published as presented in this proof. If you want to make any changes, please correct the details now. Please note that after publication corrections won't be possible. Due to data protection we standardly publish professional email addresses, but not private ones, even if they have been provided in the manuscript and are visible in this proof. If you or your co-author(s) have a different preference regarding the publication of your mail address(s) please indicate this clearly. If no changes are required for your name(s) and affiliation(s) and if you agree with the handling of email addresses, please respond with "Ok".

3. References Kestra et al. (2016), Rodríguez-Seijo et al. (2019), Nga et al. (2016), Long (1993), IUSS-WRB (2022) are cited in the text but not provided in the reference list. Please provide the respective references in the list or delete these citations.

Testing Used Tyres as Soil and Water Conservation Control Measures to Favour Circular Economy in Mali

Mahamadou Lamine Katile AQ1

Email : mahamadoulaminekatile@gmail.com

Affiliationids : Aff1, Correspondingaffiliationid : Aff1

Aboubakar Bengaly Affiliationids : Aff2

Souleymane Sidi Traore Affiliationids : Aff3

Jesús Rodrigo-Comino Affiliationids : Aff4

Hama Kasse Affiliationids : Aff5 Aff6

Aff1 West African Science Service Center On Climate Change and Adapted Land Use, Bamako, Mali

Aff2 Département de Science Des Sols Et Des Techniques de Culture/Institute Polytechnique Rural de Formation Et de RechercheAppliquée (IPR/IFRA) de Katibougou, Bamako, Mali

Aff3 Université Des Sciences Sociales Et Gestion de Bamako (USSGB), Bamako, Mali

Aff4 Department of Regional Geographical Analysis and Physical Geography, Faculty of Philosophy and Letters University of Granada, Granada, Spain

Aff5 Fisheries and Food, Research Institute for Agriculture, Merelbeke, Belgium

Aff6 Hama KASSE, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Bamako, Mali

Abstract

Microplastics are an emerging global threat in all ecosystems and have potential negative effects through multiple exposure pathways. In Mali, innovations such as the manufacture of chairs, sandals, decorative objects, etc. are being developed to reuse used tyres in order to combat environmental pollution. The special feature of this study is the experimentation with old tyres in agricultural plots to examine their effects on infiltration, runoff, moisture and soil loss. "Pneusol" works on the basis of gathering old tyres, cutting them into arcs, and positioning them in the ridges perpendicular to the direction of flows. The experimental set-up composed by control plot pair with a "pneusol" plot (30 m long and 10 m wide) has been installed on erosion crusted soil in Djindjila. Each plot has been isolated by corrugated sheets 30 cm high above the ground, embedded 20 cm deep. The results show the effectiveness of pneusol is quite significant, since it reduces the amount of water runoff by 34%, increase average moisture by 22.33% and reduce soil lost by 52.63% compared to control plot. The ability of tyres to limit runoff, improve infiltration and increase soil moisture, thereby stimulating agricultural production, has been demonstrated in this study. This result offers interesting prospects for farmers who are already experiencing the harmful effects of climate change. The effect of capturing and infiltrating runoff water, combined with the soil amendment, make "pneusol" an effective agricultural production technique on degraded land,

directly from the first year of implementation. Also, the repurposing of used tyres in a circular economy makes it possible to turn a potentially problematic waste into a resource, promoting a more environmentally friendly and long-lasting model.

Keywords
Agriculture
Soil and water conservation
Circular economy
Tyres
Mali

1. Introduction

It is undeniable that environmental degradation, the pressures of human activity on biodiversity and climate change are having a considerable negative impact on populations and lifestyles (IPCC, 2022). Soil conservation has become even more important to safeguard the natural resources of our world as the human population grows and the demand for land resources rises (Kestra et al., 2016). Soils are essential but finite resource for maintaining life on Earth (Dagmar et al., 2005; Paustian et al., 1997). Preserving pure water is just as important as conserving soil (Kumar, 2024). Reducing soil erosion and conserving water are major challenges for achieving food security in sub-Saharan Africa (Akplo et al., 2022). AQ2

One of the best strategies to reduce soil erosion and associated degradation processes is the use of nature-based solutions such as soil-vegetation (based on the concept of soil health) and Landscape solutions (based on the concept of connectivity) (Kestra et al., 2018). However, in many cases, other strategies must be designed considering other available resources. More than 1.5 billion tyres are thrown away annually (Innes, 2024; Williams, 2017), generating vast areas of soil contamination, even worse when they are burnt. The smoke they give off causes serious health problems. Reusing tyres on a large scale could be a serious solution to this bulky waste. In environmental terms, tyre management will be a serious problem if they are not recycled. Tyres are solid, heavy and reflective objects because they are made of rubber. Luo et al. (2020) showed that tyre microplastics are identified as one of the most abundant types of microplastics in water and soils and may directly or indirectly cause adverse impacts on the environment and human health. Microplastics are an emerging global threat in all ecosystems and have potential negative effects through multiple exposure pathways (Kumar et al., 2020; Rodríguez-Seijo et al., 2019). In Ngaoundéré (Cameroon), research has been carried out in 2016 to evaluate the metal contamination of soils exposed to the burning of car tyres. In this study, 30 soil samples were collected in small wells and around them in three sites where the incineration activity takes place. The results show that all of heavy metals have high levels in the studied soils compared to the reference values used (Nga et al., 2016).

In recent years, the recycling of used tyres into construction and road materials has emerged as a potential innovative solution to the growing used tyre dilemma (Mohajerani et al., 2022). There has been growing interest in the use of recycled tyres in civil engineering applications, particularly in the context of retaining structures, slope stiffening, tracks with non-cohesive materials of low stability, energy absorbers, lightweight backfill on compressible soils. This aspect is clearly visible in the study on the effect of the use of rubber grains on the shear strength behaviour of sand from the river Chlef in Algeria (Kheira & Ahmed, 2019).

In 2019, 300 tyres were recycled to transform rubbish dumps in Conakry's Ratoma district. In 2020, more than 500 tyres were recycled to decorate small crossroads in Taouyah, in Conakry's Ratoma district. In 2021, production has been tripled to reach the recycling target of 1,500 tyres. The area of operation is due to be extended to other districts and communes in the city of Conakry (Initiatives Climat, 2021). In Mali, innovations such as the manufacture of chairs, sandals, decorative objects, etc. are being developed to reuse used tyres to combat pollution (Dagnoko, 2017).

Experiments or trials highlighting the importance of recycling and reusing old tyres, and how to apply the technology in farmers' fields to increase agricultural productivity is not widespread. Especially, the technology does not exist in the WOCAT database with more than 1446 Sustainable Land Management Technologies and 549 Sustainable Land Management Approaches. Some authors defined the soils where tyres are integrated into the soil profiles after long term as “Pneusoil” or “Tyresoil”. It can be defined as the association of two elements, used tyre and soil (Long, 1993; Abdurahman, 1995).

To avoid a simple accumulation of this product and find a utility for the Pneusoils, we designed an experimental trial with used tyres in agricultural fields was designed to examine their effects increasing infiltration and reducing runoff and soil loss. The experimental set-up was composed by a control plot compared to a “pneusol” one (30 m long and 10 m wide) which has been evaluated on highly eroded crusted soils, located in Djindjila (Mali). Each plot has been isolated by corrugated sheets 30 cm high above the ground, embedded 20 cm deep. Its efficiency as soil erosion control measure will be tested but at the moment the logical effects of soil contamination due to micro-plastic contents, which is also a key topic nowadays (Rodrigo-Comino & Seeger, 2024), will be omitted.

2. Methodology

2.1. Study Area

The trial was conducted during the 2023 rainy season in the village of Djindjila, located in the rural commune of Meguetan which experiences a Sudanese-Sahelian climate (Coulibaly, 2022). The zone is characterized by three distinct seasons: (i) the hot dry season lasts from February to June, marked by winds throughout the day and night. The period is characterized by relatively low humidity and high evapotranspiration; (ii) the cool dry season occurs from November to February, with relatively low wind and temperature; and, (iii) the wet, warm season from June to October, being the most favourable period for vegetation growth. Throughout the year, the temperature in varies between 17 and 45 °C, while the average annual rainfall ranges from 700 to 900 mm.

Djindjila is characterized by hydromorphic soils (IUSS-WRB, 2022). These have an average depth of about 125 cm at foot slopes and are considered heavy and challenging to work by farmers. Approximately, 41% of Méguétan farmers cultivate this soil and the main crops grown in these soils are sorghum, maize and millet (Coulibaly, 2022). They are also affected by streams or temporary channels, which can be transformed into rills and ephemeral gullies after strong rainfall events. These soils also experience gleyfication in very deep horizons (140 cm) located in the temporary flood zone of the swamps. Tropical ferruginous soils can be found on spreading pediments with a depth of 140 cm. They account for a significant portion of the zone's land and are utilized for cultivating sorghum, cotton, millet, and maize. We can also find soils with high gravel content and crust blocks which are less prevalent in the area. They have a depth of less than 50 cm and are not suitable for mechanization using animal traction. The main crops grown in these soils include cowpeas, sorghum, millet, and groundnuts. Finally, leptosoils located in slightly sloping areas have a shallow crust of about 25 cm (International Union of Soil Sciences, 2022).

Soil management is primarily focused on both food and cash crop, although there are still some underexploited plains. Various food crops cultivated in the region include *Zea mays* (maize), *Pennisetum glaucum* (millet), *Sorghum bicolor* (sorghum), *Oryza sativa* (rice), *Vigna unguculata* (cowpea) and *Vigna subterranea* (wandzou). Cash crops, on the other hand, consist of *Gossypium spp.* (cotton), *Rachis hypogaea* (groundnut) and *Sesamum indicum* (sesame). Also, some fruit trees can be found such as *Vitellaria paradoxa* (shea), *Parkia biglobosa* (néré), *Khaya senegalensis* (baobab), *Coccoloba uvifera* (grape) as well as plantations such as *Magifera indica* (mango), orange trees, *Psidium guajava* (guava), *Citrus limon* (lemon) and *Anacardium occidentale* (cashew). However, agricultural sector in the region faces several challenges including: (i) non-degradation of plastic waste in nature; (ii) loss of land due to erosion and soil poverty; and, (iii) the scarcity and irregular distribution of rainfall. To address these challenges and enhance agricultural productivity, farmers use a combination of agricultural inputs. These inputs include chemical fertilizers like diammonium phosphate, urea, cereal complex, and cotton complex, as well as organic fertilizers like manure and other organic materials (Coulibaly, 2022). By utilizing a mix of these inputs, farmers aim to improve soil fertility and enhance crop yields in the area.

2.2. Experimental Setup

The experimental set-up (Fig. 1) has been installed on erosion crusted soil in Djindjila. It was composed of a complete randomized block with two repetitions A and B. Each block consisted of two plots (30 m long and 10 m wide) each receiving a specific treatment: a control plot pair with a “pneusol” plot. Each plot has been isolated by corrugated sheets 30 cm high above the ground, embedded 20 cm deep. The principle behind "pneusol" is to collect used tyres, cut them into arcs and place them in the ridges perpendicular to the direction of flows (see Figs. 1, 2).

Fig. 1

Illustration of experimental setup

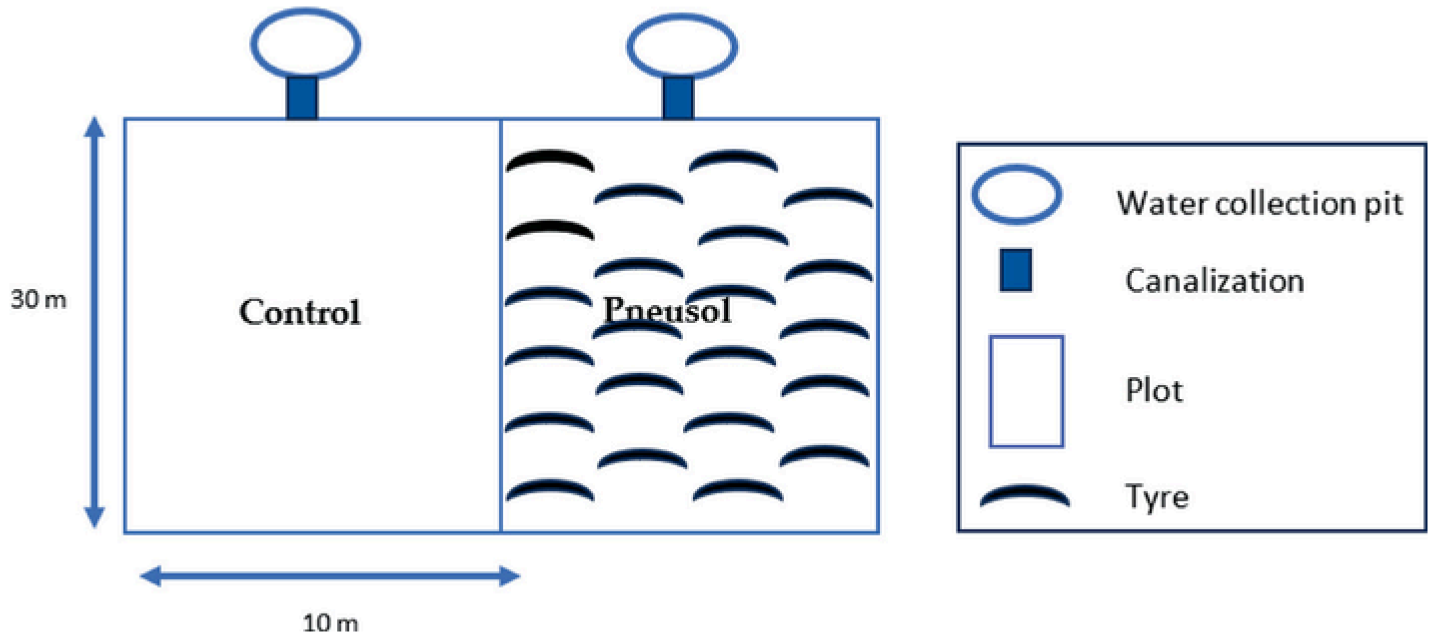


Fig. 2

Image of the tyres in the plot

2.3. Estimating Runoff and Erosion

First, a Time-Domain Reflectometry (TDR) probe at 10 days intervals was sampled to measure soil moisture in both managed and control plot. Runoff and soil loss were measured using soil erosion plots after building two experimental areas. Water runoff, noted Lr, expressed in millimetres, corresponding to the quantity of rain that did not infiltrate the soil was then measured. Its value has been calculated from the volume of water runoff measured from the barrels (Eq. 1) (Le Bissonnais et al., 1996).

$$\mathrm{Lr} = \frac{\mathrm{V} \times 1000}{\mathrm{S}} \tag{1}$$

The runoff coefficient (Cr) is expressed as a percentage, and represents the proportion of precipitation (P in mm) that did not infiltrate the soil. It was determined using Eq. 2 designed by Le Bissonnais (Le Bissonnais et al., 1996).

$$\mathrm{Cr} = \frac{\mathrm{Lr}}{\mathrm{Rainfall}} \times 100 \tag{2}$$

For the erosion measurement, after each rainfall event resulting in runoff, the water collected in the drum has been thoroughly mixed and a 1 L sample has been taken. These samples are then sent to the laboratory for oven drying and weighing of the sediment. These data are scaled to determine sediment erosion and nutrient content per hectare.

The total soil loss has been calculated using Eq. 3 (Kouelo, 2016):

$$\mathrm{PT} = \mathrm{Tf} + \mathrm{Cs}\left(\frac{\mathrm{Vr}}{\mathrm{Qa}}\right) \times 100 \tag{3}$$

Tf = sediments deposited at the bottom of the tanks; Vr: volume of runoff; Cs: Sediment load and Qa: amount of aliquot taken.

2.4. Crop Growth Parameter

This operation was carried out by selecting 10 plants in each experimental unit on days 30, 45 and 60 after plantation. Observations were made on each plot in accordance with the experimental protocol throughout the trial and focused on: (i) measurement of plant height (from the crown to the terminal bud); (ii) diameter at the crown (using a calliper); (iii) number of leaves by counting the number of leaves on each plant; (iv) weighting of 1000 seeds to assess the physiological maturity. After harvesting, the panicles were dried and dehulled. The seeds were weighed to determine the weight of 1000 seeds. **AQ3**

2.5. Statistical Analysis

A three-way ANOVA using PROC MIXED procedure was conducted. Tillage system and fertilizer input rates were taken as a fixed effect, while pneusol was considered as a random effect. Significant fixed effects were further dissected by extracting means and performing Tukey's Honestly Significant Difference pairwise comparisons with an alpha of 0.05. The normality and homogeneity of the data for each variable were tested by the Shapiro–Wilk test (Shapiro & Wilk, 1965) and by Bartlett's test (Bartlett, 1937), respectively. All statistical analyses were conducted in SAS9.4 (SASInstitute, 2013).

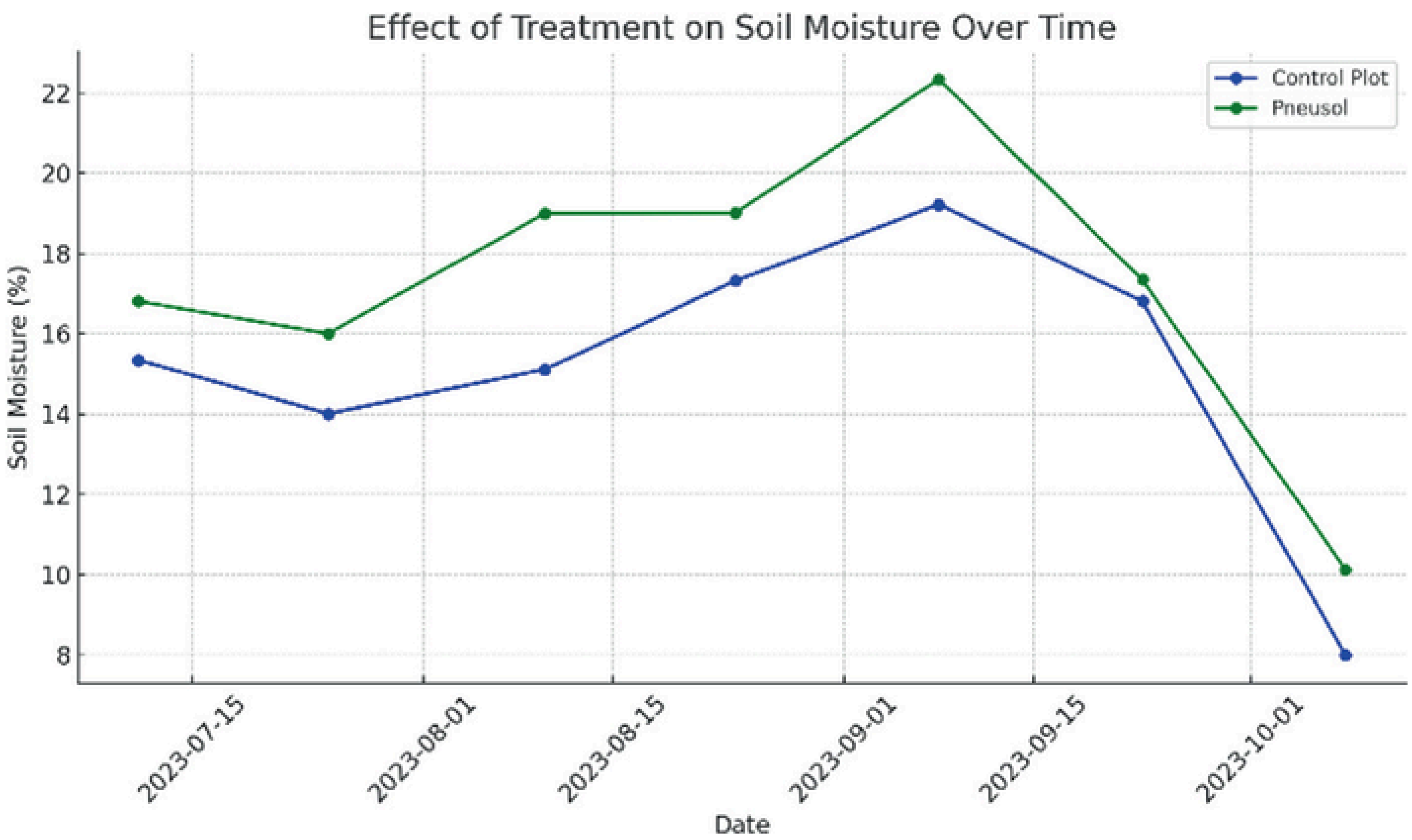
3. Results and Discussion

3.1. Effect of Treatment on Soil Moisture

For the management of water resources and agricultural productivity, soil moisture is essential (Gupta et al., 2024). Figure 3 shows the effect of treatment on soil moisture over time for both the control plot and the Pneusol-treated plot. The soil moisture levels are plotted across different dates, highlighting the differences between the two treatments. At initial condition, the control plot starts with a soil moisture level of 15.33%, while the Pneusol-treated plot has a higher value at 16.8%. This indicates that the pneusol treatment potentially retains more moisture than the control initially. Both plots reach their peak soil moisture levels on September 8, 2023. The control plot has 19.21%, while the Pneusol plot reaches 22.33%. The consistent higher value for the pneusol treatment indicates that it is more efficient at retaining moisture. The results showed that moisture levels were always higher in the managed plots than the controls one. Previous studies show that contour ridging, slope ridging, and no-tillage (Akplo et al., 2022) mulch which is widely recognized (Araya et al. 2015; Toom et al., 2019) and crop residues as mulch at the soil surface (Balesdent et al., 2000) maintain soil moisture.

Fig. 3

Effect of treatment on soil moisture over time

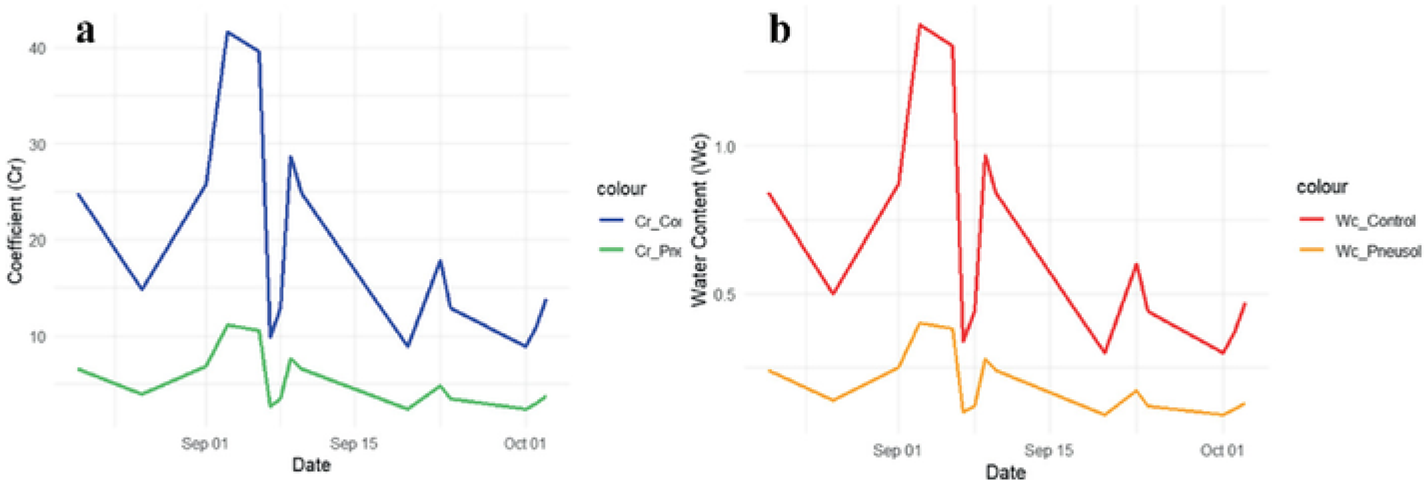


3.2. Effect of Treatment on Runoff Coefficient

The ability of tyres to reduce the runoff coefficient (Fig. 4a) and the amount of water collected (Fig. 4b) after rainfall has been observed. The control plot had the highest runoff coefficients, which led to the migration of soil particles.

Fig. 4

Runoff coefficient (a) water collected (b)



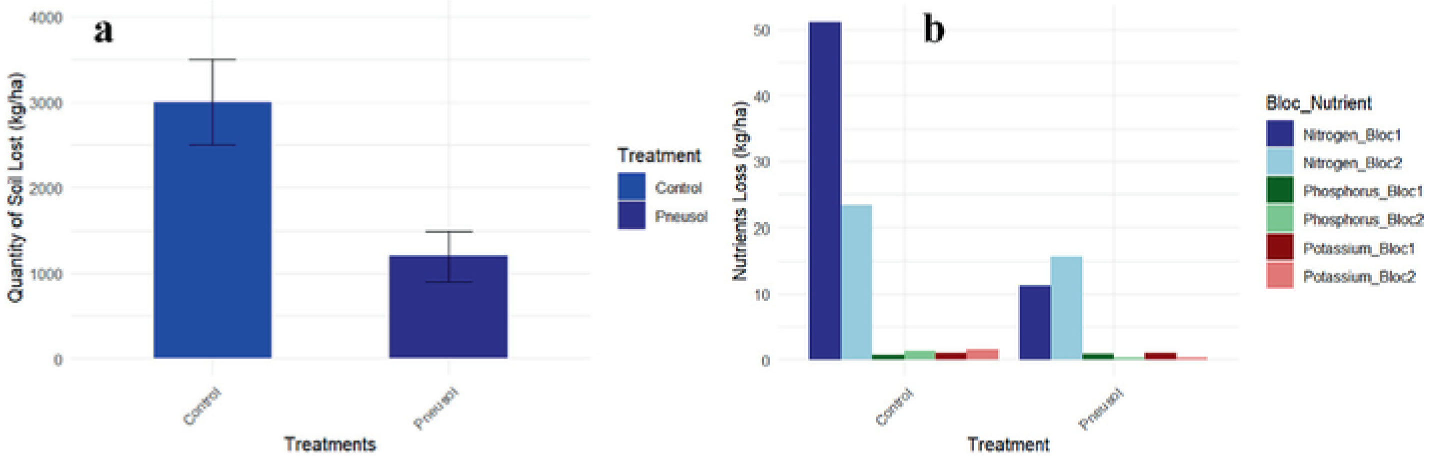
The results of Zoure et al. (2017) in Burkina Faso show that agricultural practices reduce runoff by almost 30% (± 5%). Pneusol provides a better runoff rate, but the scientific literature does not contain any contradictory publications. This finding agrees with the result of (Abu-Zreig et al., 2011)., which indicated that plots with 5% and 15% rock fragment coverage had runoff depth reductions of 17% and 30%, respectively, as compared to the control. In their overview of soil and water conservation, (Gachene et al., 2019) also confirm that crop management practices (Nyawade et al., 2018b), conservation tillage, soil management practices (Otieno et al., 2018; Rodrigues et al., 2018), contour farming and Contour Bands (Thierfelder & Wall, 2009), grass strips and vegetative buffers, diversion bitches, infiltration ditches, waterways, terraces, water retention pits, structural measures of soil and water conservation slow down runoff. A study on the effect of tillage and mulching on soil water erosion in Linsinlin watershed, centre of Benin indicated that these factors were significant on decreasing runoff and soil loss (Akplo et al., 2017).

3.3. Effect of Treatment on Soil and Nutrient Losses

Pneusol consistently shows reduced nutrient loss across all parameters (nitrogen, phosphorus, and potassium) as well as soil loss compared to the control (see Fig. 5). It is effective at minimizing nutrient runoff, which could lead to better soil fertility retention. The results concerning soil loss corroborate those of Ouédraogo et al. (2019) in Burkina Faso, Bwandamuka et al. (2021) in R D Congo, Dicko et al., 2022 at Katibougou research station (Mali), and Akplo et al. (2022) in central Benin. All these studies have demonstrated that soil and water conservation managed plots have a much greater tendency to reduce soil and nutrients loss than control plots. Using Soil and Water Conservation (SWC) measures on farmland greatly enhanced the majority of the soil's physicochemical characteristics when compared to farms that did not use SWC measures. SWC measures have been developed to reduce soil loss (Leykoun et al., 2023). In southern Ethiopia, the study on assessing soil erosion and farmers' decision of reducing erosion for sustainable soil and water conservation showed that farmers were using traditional techniques to reduce erosion and that the government had introduced conservation measures such as soil and stone bunds (Djillo et al., 2024).

Fig. 5

Soil (a) and nutrient (b) loss under pneusol and control plot



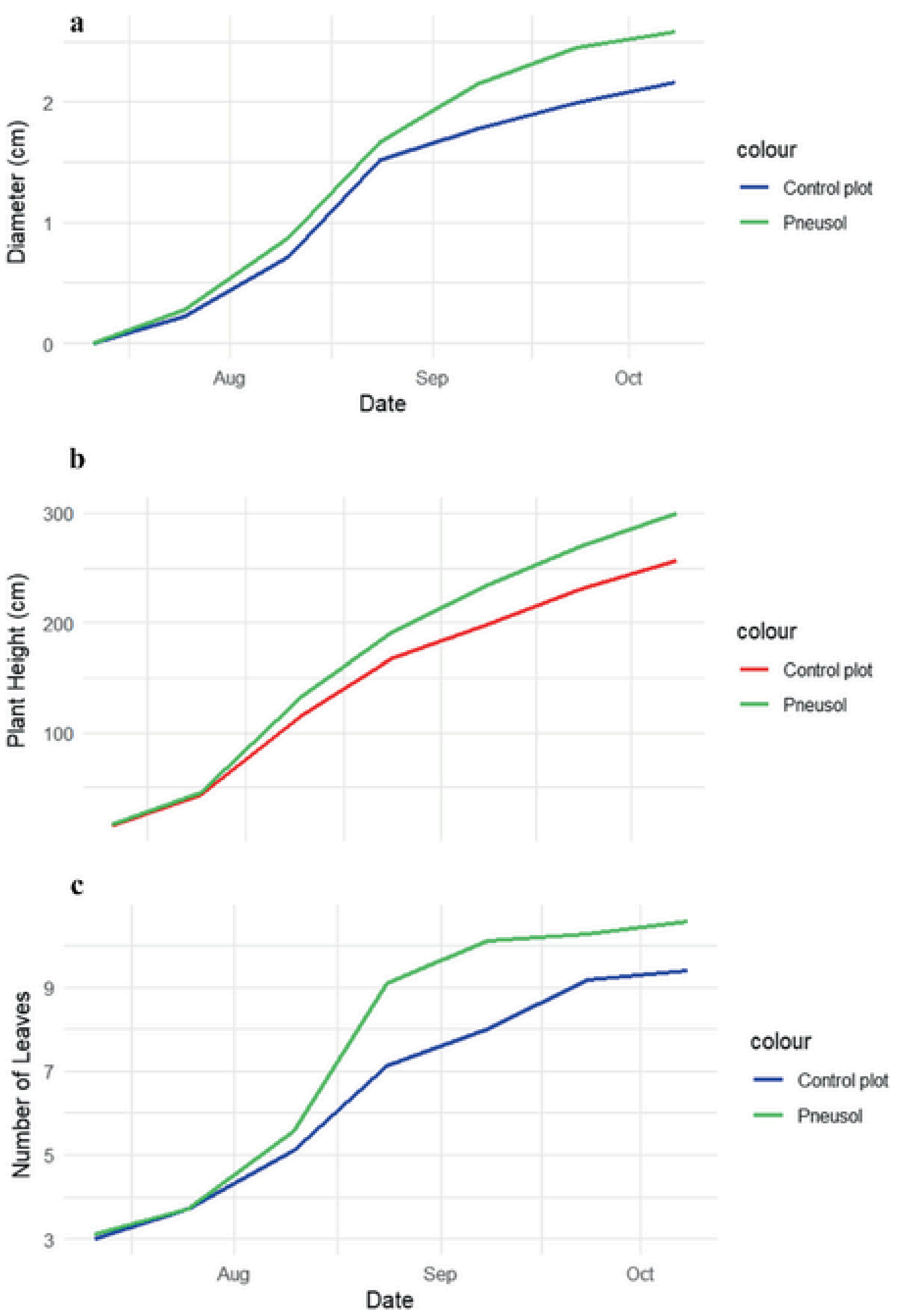
3.4. Effect of Treatment on Crop Growth Parameters

The need to effectively maximize the use of arable land through the adoption of sustainable agricultural practices will grow as agriculture attempts to fulfil the expanding demands of a growing human population for enough food and textiles (Lizotte & Locke, 2018).

For this reason, effective soil management practices need to be implemented on agricultural land. Regarding soil and nutrient loss, the results showed a significant effect of the use of used tyres. During the experiment, not only number of leaves but also plant height and the diameter have progressively increased (see Fig. 6). According to Pieters et al. (2022), plants are complex organisms that are subject to a variety of environmental factors that dynamically affect their physiology and phenotypic. An intriguing substitute for conditioning their surroundings is the use of used tyres as a Soil and Water Conservation (SWC) strategy, particularly in the Sahelian context where temperatures are rising more frequently.

Fig. 6

Effect of treatment on Diameter (a), Plant height (b), Number of leaves (c)



The average grain and straw yields attained during the experiment has been determine in this study. We note that the yields from pneusol plots (2,816 kg/ha) are higher than those from the control plot (2,035 kg/ha). Similarly, the biomass obtained on the managed plot was 5,608 kg compared with 4,988 kg/ha for the control plot. The results of the study conducted in drought agro-ecological zones in Rwanda showed that all water conservation techniques tested had a highly significant ($P < 0.001$) impact on maize grain yield and yield components, including plant height, cob diameter and length, number of leaves, 100 grain weight, and yield per plant (Uwizeyimana et al., 2018).

4. Challenges

Almost 280 million tyres reach the end of their useful life every year around the world. This figure underlines the importance of finding effective solutions for managing this waste. Although around 30 million tyres are reprocessed or reused, a significant proportion (around 250 million) require appropriate management, either through safe disposal or recycling. Used tyres are not just waste, they are also a resource. They can be transformed into a multitude of useful products, from sports surfaces to building materials and everyday objects. The main stages in tyre recycling, are shredding the rubber; removing the steel and textile fibres; cryogenic shredding; and pyrolysis. In terms of challenges and prospects, it is important to further develop tyre recycling and reuse. Recycling this waste offers a number of advantages, including a reduction in the environmental footprint, the creation of new resources and economic development. Recycling and reusing tyres are essential solutions for managing this waste in a sustainable way and recovering a resource that would otherwise be lost. The use of used tyres as a water and soil conservation technique is a technological innovation that could improve tyre reuse processes.

5. Conclusion

This study demonstrates the impressive benefits of using used tyres as a water and soil conservation technique. The technique's ability to limit runoff by 34% and add moisture to the soil by 22.33%, thereby boosting agricultural production by 2,816 kg/ha through the retention of soil particles and nutrients, was highlighted. This result offers interesting prospects for farmers who are already suffering the adverse effects of climate change, particularly in the West African context, which is prone to erosion and unpredictable pockets of drought. Tyres are economical and therefore competitive with traditional materials and are easy to install. Old tyres are a waste product that is well spread throughout the country and, overall, easy to find, collect, transport and use. Reusing them promotes the circular economy by turning a potential source of pollution into a beneficial resource for both agriculture and the environment. Despite the achievement of research objectives highlighting the use of used tyres in water and soil conservation, it would be interesting to investigate the potential toxic leachate from the rubber material.

Acknowledgements

The authors would like to express their gratitude to the German Federal Ministry of Education which financed this study through the West African Science Service Centre on Climate Change and Adapted Land use (WASCAL) within the framework of the PhD scholarship in Climate Change and Agriculture. Sincere thanks and gratitude to the International Conference on Circular Economy, Renewable Energies and Green Hydrogen in Africa (ICERA); and EGEMAP lab (Environment, Geography and Mapping) at UGR, IPR/IFRA and USTTB.

References

Abbas Mohajerani, Halenur Kurmus, David Conti, Lucinda Cash, Adrian Semcesen, Mohammed Abdurahman, Md Tareq Rahman, (2022). Environmental impacts and leachate analysis of waste rubber incorporated in construction and road materials: *A review, Science of The Total Environment, Volume 835*, 155269, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2022.155269

Abdurahman, M. (1995). Modélisation et simulation des ouvrages en Pneusol, *Doctoral dissertation*, Nantes.

Abu-Zreig, M. M., Tamimi, A., & Alazba, A. A. (2011). Soil erosion control and moisture conservation of arid lands with stone cover. *Arid Land Research and Management, 25*(3), 294–307. https://doi.org/10.1080/15324982.2011.565859

Akplo, T. M., Alladassi, F. K., Zoundji, M. C. C., Avakoudjo, J., Houngnandan, P., & Dagbénonbakin, D. G. (2022). Impact of conservation tillage on runoff, soil loss, and soil properties on acrisols and ferralsols in central Benin. *Canadian Journal of Soil Science., 102*(03), 659–671.

Akplo, T. M., Alladassi, F. K., Houngnandan, P., Benmansour, M., Rabesiranana, N., Mabit, L., & Alohoutade, F. M. (2017). Effect of tillage and mulching on soil water erosion in Linsinlin watershed, Centre of Benin. https://doi.org/10.18006/2017.5(4).515.524

Balesdent, J., Chenu, C., & Balabane, M. (2000). Relationship of soil organic matter dynamics to physical protection and tillage. *Soil Tillage Research, 53*, 215–230. https://doi.org/10.1016/S0167-1987(99)00107-5

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests. *Proceedings of the Royal Statistical Society, Series. A, 160*, 268–282. https://doi.org/10.1098/rspa.1937.0109

Bwandamuka, F. M. K., Mukalay, J. B., Ndandula, F. K., Masangu, F. K., Kasongo, M. M., & Makanda, G. M. (2021). Évaluation du risque d'érosion sur quelques sols de la plaine de Lubumbashi, RD Congo. *International Journal of Biological and Chemical Sciences., 15*(5), 2095–2117.

Coulibaly M., (2022). Pratiques de gestion des espaces agricoles et leurs impacts sur les ressources naturelles dans la zone soudano-sahélienne: cas de la commune de Méguetan. *IPR/IFRA* de Katibougou.

Dagnoko M. (2017). Mali: une solution innovante pour les pneus usés. https://www.youtube.com/watch?v=aV8bmS7nKlM (Last accessed: 09.01.2025)

Dicko, G., Bengaly, A., & Ballo, S. (2022). Effets des pratiques agricoles sur l'érosion hydrique en zone soudanienne du Mali (station de l'IPR/IFRA de Katibougou). *International Journal of Biological and Chemical Sciences, 16*(1), 345–352.

Djillo, S. C., Wolka, K., & Tofu, D. A. (2024). Assessing soil erosion and farmers' decision of reducing erosion for sustainable soil and water conservation in Burji woreda, southern Ethiopia. *Science and Reports, 14*, 8638. https://doi.org/10.1038/s41598-024-59076-6

Gupta, S. K., Singh, S. K., Kanga, S., Kumar, P., Meraj, G., Sahariah, D., Debnath, J., Chand, K., Sjan, B., & Singh, S. (2024). Unearthing India's soil moisture anomalies: Impact on agriculture and water resource strategies. *Theoretical and Applied Climatology, 155*, 7575–7590. https://doi.org/10.1007/s00704-024-05088-1

Handiso, M. A., Hemacho, A. H., Bongido, B. L. et al. (2023). Effect of conservation tillage on soil and water conservation, yield and yield components of Maize (*Zea mays* L.) in South Ari District, Southern Ethiopia. *Discov Agric* 1, 10 https://doi.org/10.1007/s44279-023-00008-9

Initiatives Climat. (2021). Pneus usagés: un problème environnemental négligé. *Association Initiatives Climat*. 37.

International Union of Soil Sciences—World Reference Base for Soil Resources (IUSS-WRB). (2022). International soil classification system for naming soils and creating legends for soil maps. (4th edition). *International Union of Soil Sciences (IUSS)*.

Intergovernmental Panel on Climate Change, (2022). Climate change: a threat to human wellbeing and health of the planet. Taking action now can secure our future, Working Goup II, https://www.ipcc.ch/2022/02/28/pr-wgii-ar6/ .

Innes, J. R. (2024). *One-and-a-half billion tyres wasted annually–there's a better way to recycle them*. University of Bradford.

Keesstra S., Nunes J., Novara A., Finger D., Avelar D., Kalantari Z., Cerda A. (2018). The superior effect of nature-based solutions in land management for enhancing ecosystem services, *Science of The Total Environment, 610–611*, Pages 997–1009, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2017.08.077 .

Keesstra, S. D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J. N., Pachepsky, Y., van der Putten, W. H., Bardgett, R. D., Moolenaar, S., Mol, G., Jansen, B., & Fresco, L. O. (2016). The significance of soils and soil science towards realization of the United Nations Sustainable Development Goals. *The Soil, 2*, 111–128. https://doi.org/10.5194/soil-2-111-2016

Kheira, N., Ahmed, A. (2019). A direct shear investigation on the determination of the shearing resistance of reinforced soil with waste rubber. In: Kallel, A., et al. Recent advances in geo-environmental engineering, geomechanics and geotechnics, and geohazards. CAJG 2018. *Advances in Science, Technology & Innovation. Springer, Cham.* https://doi.org/10.1007/978-3-030-01665-4_68 .

Kouelo, A. F. (2016). *Effects of farming practices on soil degradation in the three watersheds of southern Benin [Effets des pratiques culturales sur la dégradation du sol au niveau des trois bassins versants du sud Bénin]*. University of Abomey-Calavi, Benin.

Kumar, P. (2024). Soil Conservation for Global Sustainability. In: Kulkarni, S., Haghi, A. K. (eds.) *Global Sustainability. World Sustainability Series*. Springer, Cham. https://doi.org/10.1007/978-3-031-57456-6_6

Kumar, M., Xiong, X., He, M., Tsang, D. C., Gupta, J., & Khan, E. (2020). Microplastics as pollutants in agricultural soils. *Environmental Pollution., 265*, 114980.

Le Bissonnais, Y., Benkhadra, H., Gallien, E., Eimberck, M., Fox, D., Martin, P., Douyer, C., Ligneau, L., Ouvry, J. F. (1996). Runoff and interrill erosion on silty loamy soils: analysis of scale transfer from m^2 to small cultivated catchments. *Géomorphologie: Relief, Processus, Environnement, 3* pp. 51–64.

Leykun, S., Teklay, A., Gurebiyaw, K., Dile, Y. T., Bayabil, H. K., & Ashenafi, M. (2023). Impacts of soil and water conservation measures on soil physicochemical properties in the Jibgedel Watershed. *Ethiopia. Environ Monit Assess, 195*, 447. https://doi.org/10.1007/s10661-023-11059-2

Lizotte, R. E., & Locke, M. A., Jr. (2018). Assessment of runoff water quality for an integrated best management practice system in an agricultural watershed. *Journal of Soil Water Conservation, 73*(3), 247–256.

Luo, Z., Zhou, X., Su, Y., Wang, H., Yu, R., & Zhou, S. (2020). Environmental occurrence, fate, impact, and potential solution of tire microplastics: Similarities and differences with tire wear particles. *Science of the Total Environment., 2021*(795), 148902.

Nebo, G. I., Manyevere, A., Araya, T., & van Tol, J. (2020). Short-term impact of conservation agriculture on soil strength and saturated hydraulic conductivity in the South African semiarid areas. *Agriculture, 10*(9), 414. https://doi.org/10.3390/agriculture10090414

Nguyen, T. L. (1993). Le Pneusol: Recherches—Réalisations—Perpectives. Institut national des sciences appliquees de lyon. Génie civil : Sols—Matériaux—Structures et Physique du Bâtiment. Laboratoire Central des Ponts et Chaussées (LCPC). p 42

Nyawade, S., Karanja, N., Gachene, C., Parker, M., & Schulte-Geldermann, E. (2018). Susceptibility of soil organic matter fractions to soil erosion under potato-legume intercropping systems in Central Kenya. *Journal of Soil and Water Conservation, 73*, 568–577.

Otieno, H.M., Chemining'wa, G. N., Zingore, S. (2018). Effect of farmyard manure, lime and inorganic fertilizer applications on soil pH, nutrients uptake, growth and nodulation of soybean in acid soils of Western Kenya. *Journal of Agricultural Science 10*(4):199–208

Paustian, K. A. O. J. H., Andren, O., Janzen, H. H., Lal, R., Smith, P., Tian, G., & Woomer, P. L. (1997). Agricultural soils as a sink to mitigate CO_2 emissions. *Soil Use and Management, 13*, 230–244. https://doi.org/10.1111/j.1475-2743.1997.tb00594.x

Pieters, O., De Swaef, T., Stock, M. et al. (2022). Leveraging plant physiological dynamics using physical reservoir computing. *Sci Rep* 12, 12594 (2022). https://doi.org/10.1038/s41598-022-16874-0

Rodrigo-Comino, J., Seeger, M. (2024). Exploring the unintended contribution of soil erosion research to microplastic contamination, *Results in Earth Sciences*, *2*, 100043, ISSN 2211-7148, https://doi.org/10.1016/j.rines.2024.100043

Rodrigues, M. Â., Ladeira, L. C., & Arrobas, M. (2018). Azotobacter-enriched organic manures to increase nitrogen fixation and crop productivity. *European Journal of Agronomy, 93*, 88–94.

SAS Institute (2013). Base SAS 9.4 procedures guide. SAS Institute, Cary, NC.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of variance test for normality (complete samples). *Biometrika, 52*(3–4), 591–611. https://doi.org/10.1093/biomet/52.3-4.591

Schröter, D., Cramer, W., Leemans, R., Prentice, C., Araujo, M. B., Arnell, N. W., Boneua, A., Brugman, H., Carter, T. R., (….) Zierl, B. (2005). Ecosystem Service Supply and Vulnerability to Global Change in Europe. *Science 310*, 1333–1337(2005). https://doi.org/10.1126/science.1115233

Thierfelder, C., & Wall, P. C. (2009). Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. *Soil Tillage Res, 105*, 217–227.

Toom, M., Tamm, S., Talgre, L., Tamm, I., Tamm, Ü., Narits, L., et al. (2019). The effect of cover crops on the yield of spring barley in Estonia. *Agriculture, 9*, 172. https://doi.org/10.3390/agriculture9080172

United Nation Convention to Combat Desertification (2024). Global database on sustainable land management. https://qcat.wocat.net/en/wocat/

Uwizeyimana D., Mureithi S.M., Karuku G., Kironchi G. (2018). Effect of water conservation measures on soil moisture and maize yield under drought prone agro-ecological zones in Rwanda, *International Soil and Water Conservation Research*, *6*(3), pp 214–221, ISSN 2095-6339, https://doi.org/10.1016/j.iswcr.2018.03.002

Williams J. (2017). Car tyres in a circular economy: What can the world do with 1.5 billion waste tyres? *The Earthbound Report*

Zouré, C.O., Karambiri, H., Dial, N., Queloz, P., Koita, M., Fowé, T. (2017). Impacts des pratiques culturales sur le fonctionnement des hydrosystèmes dans le bassin versant de Tougou au Burkina Faso. In 2–4