D-5910
[1-6]

RESEARCH ARTICLE Agricultural Science Digest

Exploring the Impact of Tillage Methods on Crop Residue Decomposition and Nutrient Release: A Litter Bag Study

R. Mugesh Kumar[1], N. Chandra Sekaran[2], D. Selvi[1], T. Kalaiselvi[3], A. Surendrakumar[4]

10.18805/ag.D-5910

ABSTRACT

Background: Recycling of crop residues has gained attention over the past few decades due to its influence in sustaining the soil fertility and crop production. In this context, it is of crucial to study the effect of crop residue type, placement and tillage on decomposition and nutrient release in tropical agriculture.

Methods: We conducted a litter bag decomposition experiment to evaluate the rate of mass loss, carbon (C), nitrogen (N) and phosphorus (P) mineralization from crops residues. We used residues of cotton, maize and cowpea.

Result: Result indicated that cowpea and cotton residues decomposed more rapidly than maize residues, with mass loss of 50-65% occurring within 40 days of placement. Plough depth placement resulted in faster decomposition than deep placement, with 78% of initial mass and nutrient contents lost at the end of 120 days. Over 50% of nutrient mineralization occurred in the first 30 days of decomposition from cowpea residues. At the end of the 120^{th} day, 0.28%, 0.19% and 0.30% of total nitrogen content remained out of 2.15%, 0.86% and 1.22% of the initial total nitrogen in cowpea, maize and cotton residues, respectively. More than 48% of residue breakdown and nutrient mineralization occurred in the first 40 days of decomposition, suggesting that farmers can boost crop growth by choosing crop residues with a low and medium C:N ratio and placing residues at a plough depth (0-15 cm) using reduced tillage practices.

Key words: Cotton, Cowpea, Deep and profile inversion tillage, Litter bag, Maize, Shallow.

INTRODUCTION

Modern agriculture is facing significant challenges and crop residue management is one of them, which is crucial for ensuring the long-term viability of agriculture. Crop residue burning and continuous tillage practices have led to excessive soil erosion undermining sustainability (Kumawat *et al*., 2021). However, returning plant residues to cropland is an essential and cost-effective practice that enriches soil organic matter and supplies vital nutrients, particularly macronutrients and some micronutrients (Lizana *et al*., 2010). One of the key challenges in crop residue management is to synchronize nutrient release from plant residues with plant demand for nutrient-use efficiency Faust *et al*. (2019). Phosphorus, an essential nutrient, is rapidly released from plant residues and plays a key role in the cycling of this nutrient (Lupwayi *et al*., 2007). Nitrogen in plant residues leaches less than that from mineral fertilizer, benefiting groundwater quality. Various tillage methods have been explored in the quest for crop residue management solutions. Conventional tillage buries residues, slowing decomposition, whereas conservation tillage accelerates decomposition by keeping residues on the surface (Singh *et al*., 2018). Incorporating residues through tillage enhances microorganism access, promoting fast decomposition and improving soil aggregate stability.

To investigate the mass loss and nutrient release associated with crop residue decomposition under different tillage methods, we used the litterbag method, originally developed by (Bocock and Gilbert, 1957). This method allows for the assessment of decomposition rates and patterns of various crop residues at different soil depths, which is important for understanding the impacts of tillage on nutrient cycling, soil health and carbon sequestration. Furthermore, a notable advantage of the litterbag method is the ease with which residue samples can be recovered from the field and the ability to exclude specific soil invertebrates from decomposition by using different mesh sizes.

The aim of this study was to investigate how different tillage methods namely shallow tillage, plough depth tillage,

[1]Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu, India.
[2]Department of Soil Science and Agricultural Chemistry, ICAR-Krishi Vigyan Kendra, Sandhiyur, Salem-636 203, Tamil Nadu, India.
[3]Department of Agricultural Microbiology, Tamil Nadu Agricultural University, Coimbatore-641 003, Tamil Nadu, India.
[4]Department of Farm Machinery and Power Engineering, Agricultural Engeineering College and Research Institute, Coimbatore-641 003, Tamil Nadu, India.

Corresponding Author: N. Chandra Sekaran, Department of Soil Science and Agricultural Chemistry, ICAR-Krishi Vigyan Kendra, Sandhiyur, Salem-636 203, Tamil Nadu, India.
Email: rasincs@yahoo.co.in

How to cite this article: Kumar, R.M., Sekaran, N.C., Selvi, D., Kalaiselvi, T. and Surendrakumar, A. (2024). Exploring the Impact of Tillage Methods on Crop Residue Decomposition and Nutrient Release: A Litter Bag Study. Agricultural Science Digest. DOI: 10.18805/ag.D-5910.

Submitted: 03-11-2023 **Accepted:** 02-01-2024 **Online:** 31-01-2024

deep tillage and full inversion tillage influence decomposition of different types of crop residues, mass loss and the release of carbon (C), nitrogen (N) and phosphorus (P) from crop residues.

The findings of this study would contribute to the knowledge of crop residue management practices and their implications for soil fertility, crop productivity, environmental quality and agricultural sustainability.

MATERIALS AND METHODS

Study site and experimental design

The study was conducted at Field No.37 of the Eastern block farm of Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India. Monthly precipitation and monthly temperature of the study site in 2022 were shown in Fig 1. The soil is calcareous medium black soil, which belongs to Perianaickenpalayam series (*Vertic Ustropepts*). The top soil (0-15 cm) had sandy clay loam, texture (54.2% sand 8.7% silt and 35.3% clay), pH 8.21, organic matter 5.7 g kg^{-1}, with 0.98 g kg^{-1} total N and 0.38 g kg^{-1} total phosphorus. Cotton-maize-cowpea cropping system was selected for this study.

Tillage and litter bag placement

The cotton crop was cultivated in bulk crop for residue. At the end of the harvest stage, the cotton stalks were shredded up to ground surface using a cotton stalk shredder. After shredding, the residue was *in situ*-incorporated into different depths by ploughing the soil by different tillage implements of shallow tillage (0-7 cm), plough depth or medium tillage (0-15 cm), deep tillage (0-30 cm) and profile inversion (0-90 cm). We used these different ploughed plots for the litter bag residue decomposition study. The residues of such as cotton, maize and cowpea were buried at different depths: (5, 15, 30 and 90 cm depths) to simulate shallow, plough depth (medium), deep and profile inversion tillage respectively.

Litter bag experiment

The decomposition process (mass loss) and nutrient release from cotton, maize and cowpea residues in the field were studied using the litter bags technique (Rezig *et al*., 2014). Nylon bags with dimensions of 20 × 10 cm and a mesh size of 2 mm were used for this purpose. The residues of cotton, maize and cowpea were cut into pieces of about 10-20 cm long and each bag was filled with 10 g of crop residues that were dried in an oven. The bags were closed with zippers to prevent the residues from spilling out and numbered according to their depths. The total number of litter bags placed was 3 (crops resides) × 4 (tillage depth plots) × 4 (replicates) × 8 (sampling times); all litter bags were placed at their respective depths. At each sampling time; 15, 30, 45, 60, 90 and 120 days after applying the residues, 4 bags from each crop of the four depths (48 bags per sampling) were collected and the soil attached to the plant part was carefully removed. Each bag was put inside a paper envelope and taken to the laboratory for analysis. The materials that did not decompose were ground to pass a sieve of 1 mm for chemical analysis. The ground samples were analysed for N (Bremner and Mulvaney 1982),C and P (Chapman and Pratt 1961). Residue from each bag was also prepared and burned to identify soil mineral contaminants in a furnace at 550°C for 4 h. Litterbag content is reported on an ash-free dry weight basis (Dorissant *et al*. 2022).

Calculations and statistical analyses

Mass loss

The crop residues that were decomposing were dried in an oven at 65-70°C for 48 h or until they reached a constant weight and then weighed to calculate the rate of residue mass loss (Rezig *et al*., 2014). The residue mass was expressed as ash free dry mass (AFDM) after burning the samples at 550æ%C in a furnace for 4 h and all the chemical parameters of the residues were based on AFDM. The formula for measuring the mass loss of the crop residues was:

$$\text{Mass loss (\%)} = \frac{W_0 - W_1}{W_0} \times 100$$

Where,

W_0 = Initial residue weight (10 g).

W_1 = Weight after each sampling.

The nutrient content (C, N and P) of the crop residue that was decomposing was determined by Murungu *et al*. (2011).

$$\text{\% Remaining nutrient content} = \frac{Wt}{Wo} \times \frac{Ct}{Co} \times 100$$

Where,

Wt = Mass left at time t (in days).

Wo = Initial weight of the residue.

Ct = Nutrient content in the residue that was decomposing at the time of sampling.

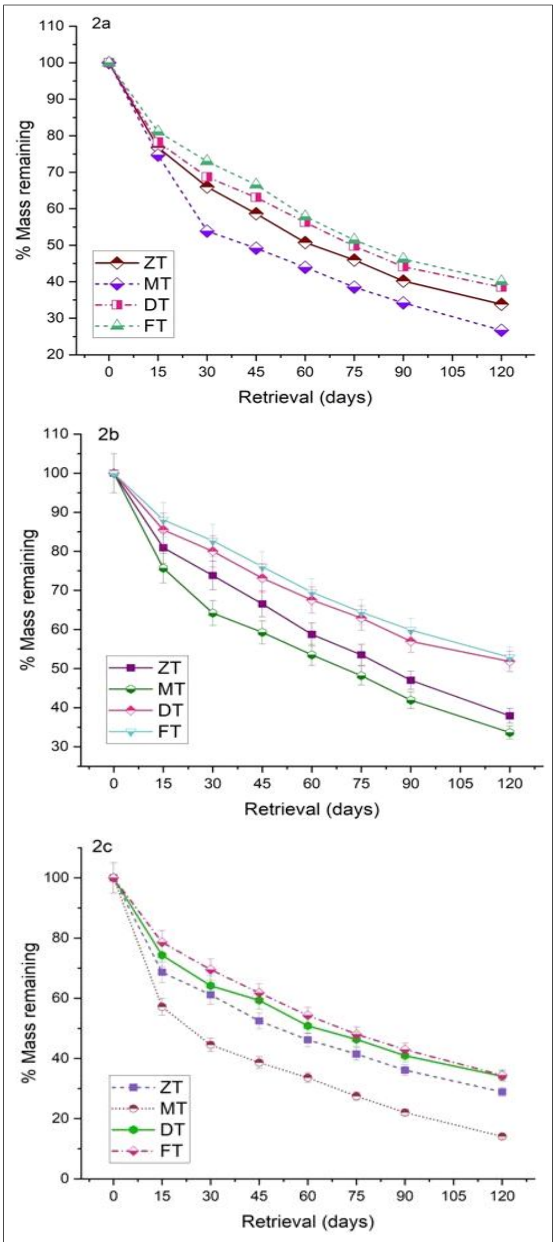
C_0 = Initial of nutrient content.

Two-way analysis of variance (ANOVA) was conducted for the effects of residue type (cotton, maize and cowpea) and tillage methods (*i.e*., ZT, MT, DT and FT). Three-way ANOVA was conducted for the effects of residue type, tillage and time interval on decomposition or nutrient releases from crop residues. All statistical analyses were done with the SPSS 17.0 software (SPSS, Chicago, IL). The Tukey's Honestly Significant Difference (HSD) post hoc test was used to compare the significant interaction between crop, tillage and time intervals after analyzing the ANOVA.

RESULTS AND DISCUSSION

Chemical composition of crop residues

Cowpea residue had the highest total nitrogen (2.15%) and phosphorus content (0.43%), while cotton residue had the highest carbon content (45.63%). Maize residue had the lowest carbon (41.32%) and nitrogen content (0.86%), but the highest cellulose (41.21%) and lignin content (15.18%). Regarding the carbon and nitrogen (C: N) ratio of the three crop residues, cowpea had the lowest (20:1), while maize had the highest (48:0). Cotton had an intermediate C: N ratio of 37.4 (Table 1).



2a- Cotton, 2b- Maize, 2c-cowpea. (ZT- Zero tillage, MT- Medium tillage, DT- Deep tillage, FT- Full inversion tillage).

Fig 1: Percentage of mas remaining under different tillage methods.

Crop residue type and tillage method on mass loss

The F-values for tillage depth (p = 0.01) and time (p = 0.01) were highly significant, suggesting that different tillage depths had a significant impact on the mass loss of residues over time. The two-way interactions of crop × tillage, crop × time and tillage × time were significant at 0.05 level of significance, while the three-way interaction of crop × tillage × time was not significant. This implies that the mass loss depended on the combination of crop residue type, tillage method and litter bag retrieval time.

Crop residue type and tillage method on mass loss

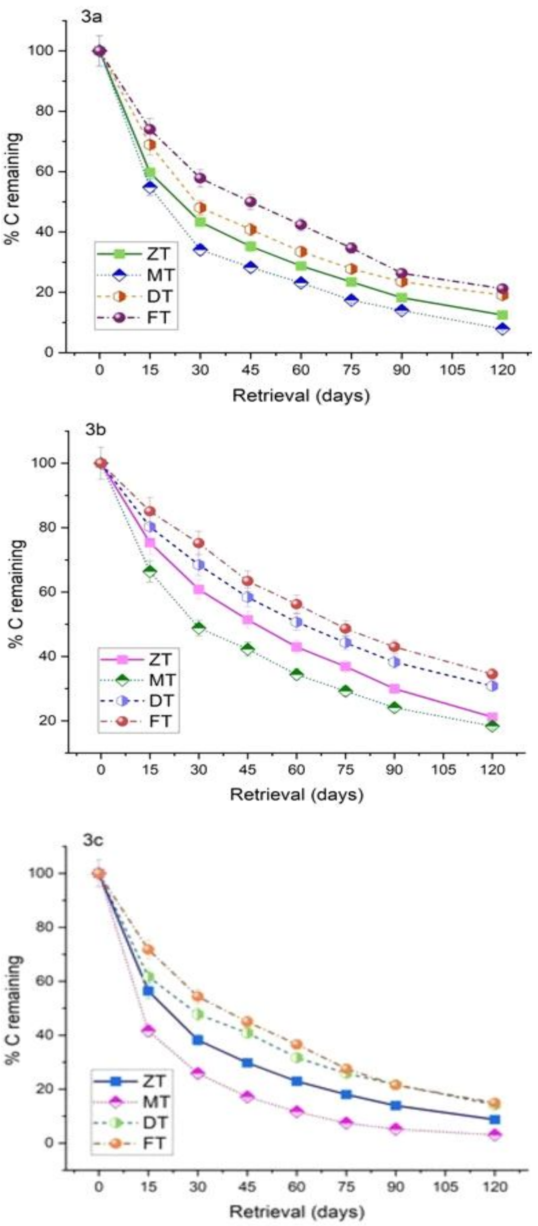
The percentage of remaining mass varied among three different crop residues at various placement depths. Cowpea exhibited the fastest decomposition rate, followed by cotton and maize over the time (Fig 1). On the 40th day, cowpea retained only 57.2% of its mass in MT, simulating plough depth tillage. By the 120th day, cowpea had lost 86% of its mass in MT, whereas cotton and maize had lost 73.3% and 66.4%, respectively. Cotton had a moderate decomposition rate, losing 46.1% of its mass in MT on the 30th day. Maize had the slowest decomposition rate, with only 24.3% of its mass lost in MT on the 30th day and retaining 34% of its mass at the end of the study period (Fig 1). The rapid decomposition of cowpea residue can be attributed to its relatively high nitrogen content and low lignin and cellulose content (Table 1). On the other hand, maize residue, with higher cellulose content and lower nitrogen content, proved to be more resistant to decomposition, consistent with previous findings (Grzyb *et al.*, 2020). The low C:N ratio of cowpea (23:1) and cotton (41:2) residues may have further contributed to their rapid decomposition.

The mass loss declined over time for all crop residues and tillage methods, indicating a gradual decomposition of the residues (Fig 1). Notably, there was a discernible difference in mass loss between plough depth tillage (MT) and full inversion tillage (FIT). FIT, which buried the residues deeper into the soil, led to a slower decomposition rate. This difference in mass loss was most pronounced for cowpea, with the smallest difference observed in maize and an intermediate difference in cotton.Tillage methods significantly influenced residue breakdown, with approximately 50-60% of breakdown occurring within the first 30 days. Plough depth tillage showed a rapid initial decline from 100% to 50% in the first 30 days, followed by a slight increase to 25% at 75 days and then a decrease to 16.5% at 120 days. Shallow tillage exhibited a similar

Table 1: Initial biochemical composition of plant residues used in the study.

Type of Residue	Total N (%)	Total C (%)	Total P (%)	C:N Ratio	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Cotton	1.22	45.63	0.34	37.4	38.13	26.76	13.21
Maize	0.86	41.32	0.21	48.0	41.21	29.12	15.18
Cowpea	2.15	43.21	0.43	20.1	35.74	20.67	11.56

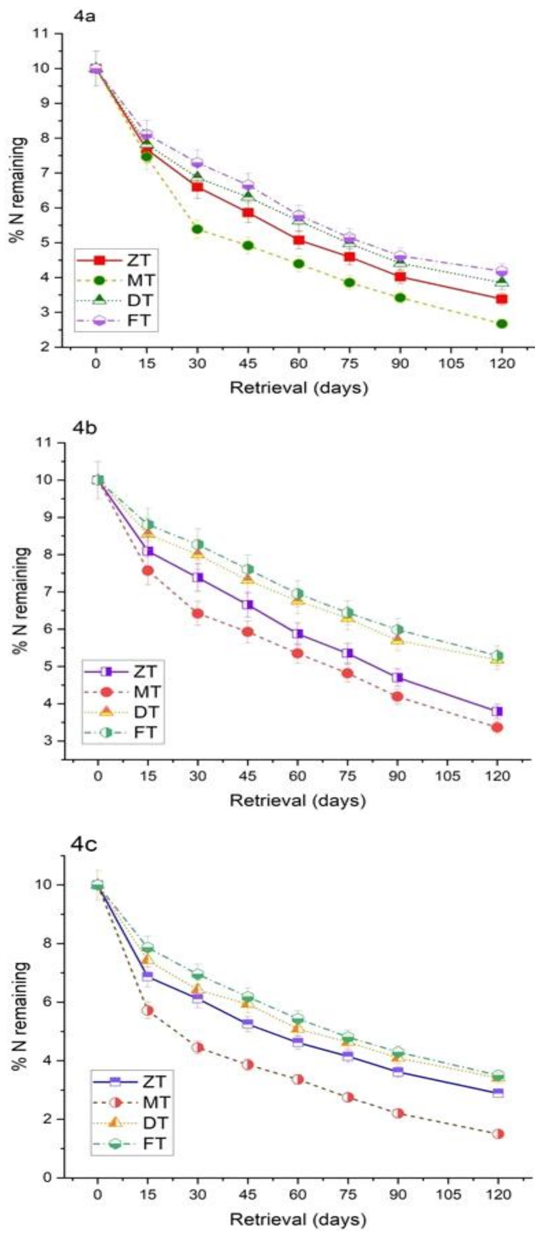
*Nutrient content expressed in % with mean of n=3 replication values.



3a- Cotton, 3b- Maize, 3c- Cowpea. (ZT- Zero tillage, MT- Medium tillage, DT- Deep tillage, FT- Full inversion tillage.

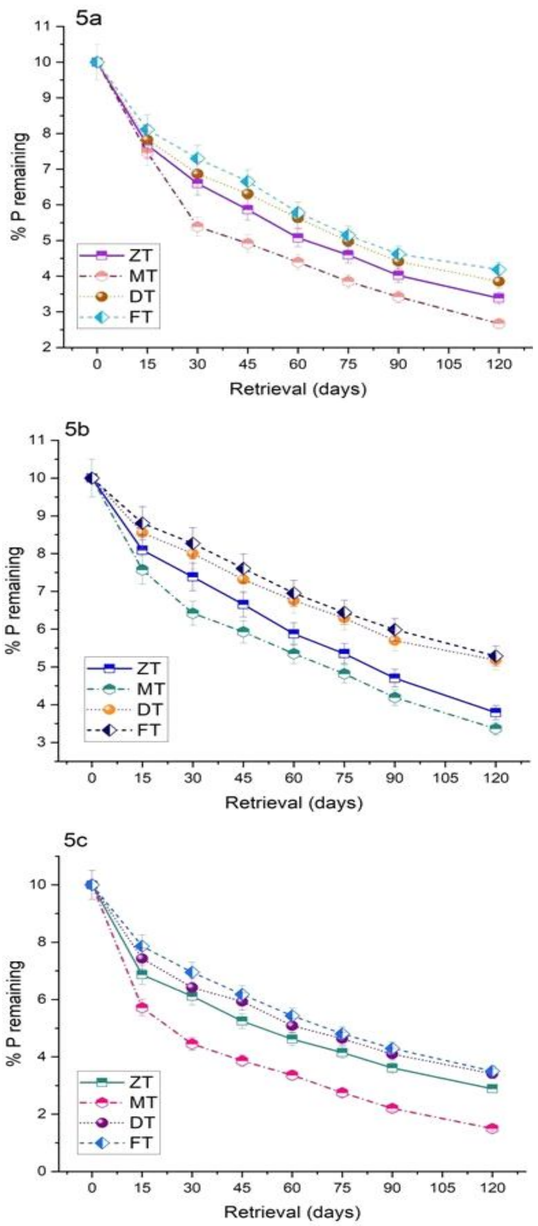
Fig 2: Percentage of C remaining under different tillage methods.

pattern but with higher mass loss values compared to deep and inversion tillage at each litter bag retrieval time. Full inversion and deep tillage had the slowest decomposition rates for all crop residues compared to plough depth and shallow tillage. On the 120th day, the percentage of remaining mass varied among the tillage methods, with full inversion tillage slowing and steadying the decomposition process, while full plough depth tillage hastened it.The rate of cowpea and cotton residue decomposition was higher at plough depth of soil (0-15 cm) than at shallow tillage (surface). This may be because the buried residue was in close contact with the soil and had optimal moisture content, which created a conducive environment for decomposition (Uwamahoro *et al*., 2023). The drier environment also increased soil temperature (Thongjoo *et al*., 2005), which can increase the rate of decomposition Hood (2001). In contrast, deep and full inversion tillage had a slow and steady decline of mass loss due to lower temperature, poor aeration and fewer microbial communities (Cassani *et al*., 2021).



4a- Cotton, 4b- Maize, 4c- Cowpea. (ZT- Shallow tillage, MT- Medium tillage, DT- Deep tillage, FT- Full inversion tillage).

Fig 3: Percentage of N remaining under different tillage methods.



5a- Cotton, 5b- Maize, 5c- Cowpea. (ZT- Shallow tillage, MT- Medium tillage, DT- Deep tillage, FT- Full inversion tillage).

Fig 4: Percentage of P remaining under different tillage methods.

Xue *et al*. (2011) discovered that surface-placed residues decomposed slowly than buried samples. Plough depth tillage developed surplus moist and humid environment and left more of the soil surface covered (Lupwayi *et al*., 2007), which helped to trap moisture, ideal for decomposers to decompose (Lutz *et al*., 2019). However, in conventional tillage, due to exposed soil surface, rapid moisture evaporation rapidly and a drier environment (Dietrich *et al*., 2019), pose less ideal for decomposers.

Crop residue type and tillage method on C, N and P release

Cotton had the highest carbon content, while cowpea had the highest nitrogen content compared to maize residues (Table 1). At the beginning of the study (day 0), the initial carbon contents were 45.65% for cotton, 41.32% for maize and 43.21% for cowpea residues. Over time, the mineralization rate increased, reaching a constant level for cotton and maize residues after day 30.Tillage methods also played a significant role, with plough depth tillage resulting in the maximum nutrient release, followed by shallow tillage. Cowpea residues having C, N and P content of 43.21%, 2.15% and 0.43%, decreased to 8.21%, 0.28% and 0.17% on day 120, with nearly all nutrients being mineralized (Fig 2,3,4). The C,N,P content decreased to 12.50%, 0.30% and 0.19% for cotton and 20.88%, 0.19% and 0.11% for maize on day 120 over their initial contents. In black calcareous soils, the rate of nitrogen loss from cotton residues is typically faster than in other types of soils because of high pH.

Deeper placement of crop residues, in deep and full inversion tillage, resulted in slower mineralization of nutrients. The remaining C and N content at day 120 was 23.41%, 0.59% and 26.18% for cotton, 0.36% and 18.49% for maize and 0.69% for cowpea residues (Fig 2, 3 and 4). Shallow tillage mineralized a significant amount of nitrogen overall during the study period. This is because the exposed soil surface caused moisture to evaporate more quickly, creating a drier environment that was less ideal for decomposers (Lizana *et al*., 2010). The slower and steady release of nutrients and carbon could enhance and maintain soil fertility over the long term, reducing carbon and nutrient loss and promoting organic carbon sequestration in deeper soil layers. However, some anaerobic decomposing organisms are present, they lead to a slower mineralization process (Ye *et al*., 2019). Nevertheless, the slow and constant release of nutrients and carbon will enhance and maintain the fertility of the soil under long term conditions (Li *et al*., 2013).

CONCLUSION

This study indicated that Cowpea and cotton residues decomposed faster than maize, with plough depth placement and shallow tillage promoting quicker decomposition than deep placement and conventional tillage. Nutrient mineralization was highest in cowpea, followed by cotton and maize residues and favoured by plough depth placement and shallow tillage. Over 50% of residue breakdown and nutrient release occurs within the first 30 days, emphasizing the need selecting low C:N ratio residues, plough depth placement and reduced tillage. Future research should explore the long-term impacts of these management systems on soil quality and crop productivity in tropical agriculture.

Conflict of interest

The authors declare no competing interests.

REFERENCES

Bremner, J.M., Mulvaney, C.S. (1982). Nitrogen Total. In: Methods of Soil Analysis. Agron. [Page, A.L. (ed)]. No. 9. Part 2: Chemical and Microbiological Properties, 2nd edn edn. Am Soc Agron, Madison. pp 595-624.

Cassani, M.T., Sabatte, M.L., Rubin, M.R., Sfeir, A.J., Massobrio, M.J. (2021). Litter decomposition by soil fauna: Effect of land use in agroecosystems. Heliyon. 7(10): https://doi.org/10.1016/j.heliyon.2021.e08127.

Chapman, H.D. and Pratt, P.F. (1961). Methods of analysis for soil, plant and water. University of California Riverside.

Dietrich, G., Recous, S., Pinheiro, P.L., Weiler, D.A., Schu, A.L., Rambo, M.R.L., Giacomini, S.J. (2019). Gradient of decomposition in sugarcane mulches of various thicknesses. Soil and Tillage Research. 192: 66-75. https://doi.org/10.1016/j.still.2019.04.022.

Dorissant, L., Brym, Z.T., Swartz, S. (2022). Residue decomposition dynamics in mixed ratios of two warm season cover crops. Agrosystems, Geosciences and Environment. 5(4): e20311. https://doi.org/10.1002/agg2.20311.

Faust, S., Koch, H.J., Dyckmans, J., Joergensen, R.G. (2019). Response of maize leaf decomposition in litterbags and soil bags to different tillage intensities in a long-term field trial. Applied Soil Ecology. 141: 38-44. https://doi.org/10.1016/j.apsoil.2019.05.006.

Grzyb, A., Wolna-Maruwka, A., Niewiadomska, A. (2020). Environmental factors affecting the mineralization of crop residues. Agronomy. 10(12): 1951. https://doi.org/10.3390/agronomy 10121951.

Hood, R.C. (2001). The effect of soil temperature and moisture on organic matter decomposition and plant growth. Isotopes in Environmental and Health Studies. 37(1): 25-41.

Kumawat, A., Meena, R.S., Rashmi, I., Kumar, A., Bamboriya, S.D., Yadav, D., Jhariya, M.K. (2021). Crop residue management: A novel technique for restoring soil health and sustainable intensification in India. Sustainable Intensification for Agroecosystem Services and Management. 229-265. https://doi.org/10.1007/978-981-16-3207-5_8.

Li, L.J., Han, X.Z., You, M.Y., Yuan, Y.R., Ding, X.L., Qiao, Y.F. (2013). Carbon and nitrogen mineralization patterns of two contrasting crop residues in a Mollisol: Effects of residue type and placement in soils. European Journal of Soil Biology. 54: 1-6. https://doi.org/10.1186/s40064-016-2651-1.

Lizana, A., Carbonell, R., Gonzalez, P., Ordonez, R. (2010). N, P and K released by the field decomposition of residues of a pea-wheat-sunflower rotation. Nutrient Cycling in Agroecosystems. 87: 199-208. https://doi.org/10.1007/s10705-009-9328-x.

Lupwayi, N.Z., Clayton, G.W., Donovan, J.T., Harker, K.N., Turkington, T.K., Soon, Y.K. (2007). Phosphorus release during decomposition of crop residues under conventional and zero tillage. Soil and Tillage Research. 95(1-2): 231-239. https://doi.org/10.1016/j.still.2007.01.007.

Lutz, F., Herzfeld, T., Heinke, J., Rolinski, S., Schaphoff, S., Von Bloh, W., Muller, C. (2019). Simulating the effect of tillage practices with the global ecosystem model LPJmL (version 5.0-tillage). Geoscientific Model Development. 12(6): 2419-2440. https://doi.org/10.5194/gmd-12-2419-2019.

Murungu, F.S., Chiduza, C., Muchaonyerwa, P., Mnkeni, P.N.S. (2011). Decomposition, nitrogen and phosphorus mineralization from winter-grown cover crop residues and suitability for a smallholder farming system in South Africa. Nutrient Cycling in Agroecosystems. 89: 115-123. https://doi.org/10.1007/s10705-010-9381-5.

Rezig, F.A., Elhadi, E.A., Abdalla, M.R. (2014). Decomposition and nutrient release pattern of wheat (*Triticum aestivum*) residues under different treatments in desert field conditions of Sudan. International Journal of Recycling of Organic Waste in Agriculture. 3: 1-9. https://doi.org/10.1007/s40093-014-0069-8.

Singh, R., Sherawat, M., Singh, A. (2018). Effect of tillage and crop residue management on soil physical properties. Journal of Soil Salinity and Water Quality. 10(2): 200-206.

Bocock, K.L., Gilbert, O. (1957). The disappearance of leaf litter under different woodland conditions. Plant Soil. 9: 179-185.

Thongjoo, C., Miyagawa, S., Kawakubo, N. (2005). Effects of soil moisture and temperature on decomposition rates of some waste materials from agriculture and agro-industry. Plant Production Science. 8(4): 475-481. DOI: 10.1626/pps.8.475.

Uwamahoro, H., Kpomblekou, A.K., Mortley, D., Quarcoo, F. (2023). Organic vegetable crop residue decomposition in soils. Heliyon. 9(3): https://doi.org/10.1016/j.heliyon.2023.e14529.

Xue, K., Serohijos, R.C., Devare, M., Thies, J.E. (2011). Decomposition rates and residue-colonizing microbial communities of Bacillus thuringiensis insecticidal protein Cry3Bb-expressing (Bt) and non-Bt corn hybrids in the field. Applied and Environmental Microbiology. 77(3): 839-846. DOI: 10.1128/AEM.01954-10.

Ye, X., Ye, Y., Chai, R., Li, J., Ma, C., Li, H., Gao, H. (2019). The influence of a year-round tillage and residue management model on soil N fractions in a wheat-maize cropping system in central China. Scientific Reports. 9(1): 4767. https://doi.org/10.1038/s41598-019-41409-5.