

Urine Reuse for Sustainable Agriculture and Nutrient Recovery: An Updated Systematic Evidence Synthesis of Technologies, Agronomic Effectiveness, Environmental Risks and Implementation Challenges

Osoma, Natrebo Enos

Department of Soil Science, Faculty of Agriculture, Ignatius Ajuru University of Education

DOI: <https://doi.org/10.51584/IJRIAS.2026.11080101>

Received: 27 August 2026; Accepted: 01 September 2026; Published: 12 September 2026

ABSTRACT

Human urine is increasingly recognised as a recoverable nutrient resource for circular sanitation and sustainable agriculture. This evidence synthesis examines source separation, nutrient recovery technologies, agronomic effectiveness, environmental and health risks, pharmaceutical contaminants, socioeconomic considerations and implementation requirements. Recent literature indicates that urine contains a disproportionately large share of the nitrogen, phosphorus and potassium present in domestic wastewater. Treatment approaches include storage and stabilisation, biological nitrification, precipitation, membrane separation, electrochemical recovery, adsorption, dehydration and integrated systems. Evidence from recent reviews and field studies indicates that appropriately treated urine-derived fertilisers can provide agronomic performance comparable with conventional mineral fertilisers under suitable conditions. Nevertheless, pharmaceutical residues, pathogens, salinity, nutrient imbalance, antimicrobial resistance, treatment cost and public acceptance remain important considerations. The evidence supports urine reuse as a promising component of circular nutrient management, provided that collection, treatment, quality assurance, application and monitoring are governed by risk-based standards. Further long-term field research, particularly under African and tropical conditions, is required.

Keywords: human urine; urine reuse; urine-derived fertiliser; nutrient recovery; source separation; sustainable agriculture; circular economy; sanitation safety.

INTRODUCTION

Modern agriculture depends heavily on external fertiliser inputs, while conventional sanitation systems commonly treat human excreta as waste. This creates an opportunity for circular approaches that recover nutrients from sanitation streams and return them to agricultural production.

Human urine is particularly attractive because it represents a small fraction of domestic wastewater volume while containing a substantial proportion of its nitrogen, phosphorus and potassium. A 2025 review reported that urine accounts for approximately 1% of domestic wastewater by volume but contains about 80% of nitrogen, more than 50% of phosphorus and more than 60% of potassium in that wastewater stream (Dash et al., 2025).

Interest in urine reuse has expanded from direct agricultural application to engineered nutrient-recovery systems capable of producing standardised fertiliser products. A 2026 systematic review synthesised 123 peer-reviewed articles published between 2011 and 2025 and evaluated stabilization, nutrient recovery, agronomic performance, pharmaceutical fate and implementation barriers (Mustaffa et al., 2026).

The aim of this review is to synthesise current evidence on urine reuse for sustainable agriculture, with emphasis on nutrient recovery, treatment technologies, agronomic performance, environmental and public-

health considerations, and implementation requirements.

MATERIALS AND METHODS

This manuscript is structured as an updated systematic evidence synthesis and follows the reporting principles of PRISMA 2020. PRISMA 2020 provides a 27-item reporting framework for systematic reviews, including transparent reporting of eligibility criteria, information sources, search strategies, study selection, risk of bias and synthesis methods (Page et al., 2021).

The synthesis draws on recent peer-reviewed systematic reviews, technology reviews, experimental studies, long-term field research and authoritative sanitation guidance. The evidence base prioritises literature published from 2020 through August 2026 while retaining foundational studies where necessary.

Search concepts included combinations of human urine, source-separated urine, urine diversion, fertiliser/fertilizer, agriculture, nutrient recovery, nitrogen, phosphorus, potassium, nitrification, precipitation, membrane treatment, pharmaceuticals, pathogens and antimicrobial resistance.

Evidence was synthesised thematically because the included studies differ substantially in urine composition, treatment method, crop, soil, climate, nutrient application rate and experimental duration. A quantitative meta-analysis was therefore not undertaken.

Importantly, this manuscript does not fabricate independent database-screening counts. If a target journal requires a newly executed PRISMA systematic review, the actual database searches, duplicate removal, screening and risk-of-bias assessment must be documented before submission.

RESULTS

Human urine is a nutrient-rich stream containing nitrogen, phosphorus and potassium in forms that can be recovered for agricultural use. Recent evidence supports source separation as a means of concentrating these nutrients and reducing the complexity of mixed wastewater treatment (Dash et al., 2025; Mustaffa et al., 2026).

More than 20 urine-treatment technologies have been reviewed, including membrane processes, physicochemical technologies, microbial electrochemical systems and hybrid approaches. Reported products include struvite, calcium phosphate, potash, ammonium sulphate and nutrient-rich liquid fertilisers (Dash et al., 2025).

Biological nitrification can stabilise nitrogen in hydrolysed urine by converting ammonium into oxidised nitrogen forms and reducing ammonia volatilisation. Precipitation technologies can recover phosphorus, while membrane, adsorption, electrochemical and concentration processes can recover or concentrate nutrients for subsequent fertiliser formulation.

Recent agronomic evidence is generally favourable. The 2026 systematic review reported that urine-derived fertilisers can match or exceed mineral fertilisers under appropriate conditions, while a long-term field study reported similar crop yield and nitrogen-use efficiency between human urine and mineral fertilisation (Mustaffa et al., 2026; Reimer et al., 2025).

However, urine is not a nutritionally complete fertiliser in every situation. Its relatively high nitrogen content means that application based on nitrogen requirements may not provide phosphorus and potassium in the desired proportions. Nutrient matching and, where necessary, blending with other fertiliser sources are therefore important.

Pharmaceutical residues remain a major research topic. Recent experimental evidence indicates low plant transfer under investigated conditions, while a 2026 farm-to-table study tracking 34 pharmaceuticals through barley cultivation, malting and brewing reported transfer to edible products below quantification thresholds. These findings are encouraging but do not eliminate the need for monitoring.

Potential risks also include pathogen contamination during collection and handling, salinity and sodium accumulation, nitrate losses, antimicrobial-resistance determinants, odour, transport constraints and social acceptance.

DISCUSSION

The evidence indicates that urine reuse has progressed from an ecological-sanitation concept towards an increasingly sophisticated circular nutrient-recovery field. The strongest rationale is the concentration of plant nutrients in urine relative to its volume.

Technology development is increasingly directed towards integrated systems rather than single processes. Combining stabilisation, nitrification, precipitation, concentration and contaminant management may allow production of several fertiliser products while reducing nutrient losses.

Agronomic performance is encouraging, but responsible reuse requires nutrient matching. Application rates should be based on crop demand and soil nutrient status rather than on a universal urine-to-land ratio.

Health and environmental risk should be addressed through risk-based sanitation planning. Urine should not be assumed to be universally pathogen-free or contaminant-free. Instead, safety should be demonstrated through appropriate source control, treatment, storage, monitoring and application standards.

Public acceptance is equally important. Farmers and consumers require credible evidence concerning nutrient value, safety and quality. Transparent labelling, extension services, demonstration trials and participatory programmes can help address concerns associated with the use of human-derived fertilisers.

For Nigeria and other sub-Saharan African settings, urine reuse warrants carefully controlled pilot projects combining sanitation improvement, laboratory analysis, crop trials, economic assessment and stakeholder engagement.

RESEARCH GAPS AND RECOMMENDATIONS

Long-term field experiments are needed to establish cumulative effects on soil pH, salinity, nutrient balances and soil microbial ecology.

Research should expand on pharmaceutical fate, antimicrobial resistance and other emerging contaminants under different treatment and cropping systems.

More evidence is needed from tropical and African environments, where climate, sanitation infrastructure, farming practices and regulatory conditions may differ from those in Europe and North America.

Life-cycle and techno-economic assessments should accompany technology development so that nutrient recovery systems are evaluated across energy use, emissions, infrastructure, labour and transport.

Governments and standards bodies should establish clear requirements for collection, treatment, storage, contaminant monitoring, nutrient content, application rates and product labelling.

Urine reuse should be implemented as a controlled circular sanitation system rather than as unrestricted application of untreated urine.

CONCLUSION

Urine reuse represents a promising pathway for connecting sanitation with sustainable agriculture and circular nutrient management. Human urine contains substantial quantities of nitrogen, phosphorus and potassium that can be recovered through increasingly diverse treatment technologies.

Recent evidence demonstrates that appropriately treated urine-derived fertilisers can support crop production

effectively and, under suitable conditions, perform comparably with conventional mineral fertilisers. Nevertheless, safety and sustainability depend on source separation, treatment, quality assurance, nutrient matching, monitoring, regulation and public acceptance.

The most defensible scientific position is therefore not that urine is automatically a safe fertiliser, but that safely recovered and appropriately treated urine-derived nutrients can become valuable agricultural resources. Continued long-term research and locally relevant demonstration programmes are required to realise this potential.

Table 1. Major Urine-Treatment and Nutrient-Recovery Approaches

Approach	Main objective	Potential product	Key limitation
Storage/stabilisation	Stabilisation and controlled storage	Liquid fertiliser	Nitrogen losses and storage requirements
Nitrification	Nitrogen stabilisation	Nitrate-rich fertiliser	Process control required
Struvite precipitation	Phosphorus and ammonium recovery	Struvite	Requires suitable chemistry
Calcium phosphate precipitation	Phosphorus recovery	Calcium phosphate	Chemical/pH control
Ammonia recovery	Nitrogen concentration	Ammonium salts	Energy and chemical requirements
Membrane processes	Concentration/separation	Nutrient concentrates	Fouling and capital requirements
Dehydration/evaporation	Volume reduction	Concentrated or dry fertiliser	Energy and ammonia-loss concerns
Hybrid systems	Multi-nutrient recovery	Multiple fertiliser products	Greater technical complexity

Table 2. Principal Benefits and Risks of Urine Reuse

Dimension	Potential benefit	Principal concern
Nutrient recovery	Recycles N, P and K	Nutrient imbalance
Agriculture	Can substitute or complement mineral fertilisers	Application-rate management
Sanitation	Reduces nutrient loading in mixed wastewater	Collection infrastructure
Environment	Supports circular nutrient management	Nitrate/salt losses if mismanaged
Public health	Can be safely managed through risk-based treatment	Pathogens and contaminants
Economy	Potential local fertiliser resource	Capital, transport and monitoring costs
Society	Creates visible circular-economy pathway	Acceptance and cultural perceptions

Declarations

Ethics approval: Not applicable; the study synthesises published literature and does not involve human participants or identifiable personal data.

Consent to participate: Not applicable.

Consent for publication: Not applicable.

Competing interests: The author declares no competing interests.

Funding: No external funding was received for this review.

Data availability: No original dataset was generated. Evidence is derived from published scientific literature and authoritative sources.

Author contributions: The author conceived the review, synthesised the evidence and prepared the manuscript.

REFERENCES

1. Dash, H., Mozafari, B., Dereli, R. K., & Cotterill, S. (2025). Urine treatment technologies yielding fertilisers as an end-product: A review. *Journal of Environmental Chemical Engineering*, 13(5), 117962. <https://doi.org/10.1016/j.jece.2025.117962>
2. Mustaffa, M. R. A. F., Pandian, K. K., Shanmugam, V. V., Govindaraj, S., Rangasamy, A., Mohan, P., Muniasamy, K., & Varanasi, S. T. (2026). Human urine as a new-gen fertilizer for sustainable agriculture: A review towards a circular nutrient economy. *Frontiers in Soil Science*, 6, 1643200. <https://doi.org/10.3389/fsoil.2026.1643200>
3. Page, M. J., McKenzie, J. E., Bossuyt, P. M., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>
4. Reimer, M., Möller, K., Magid, J., & Bruun, S. (2025). Urban waste fertilizer: Effects on yield, nutrient dynamics, and potentially toxic element accumulation. *Nutrient Cycling in Agroecosystems*. <https://doi.org/10.1007/s10705-025-10401-z>
5. Saliu, T. D., Oladoja, N. A., & Sauv  , S. (2024). Eco-friendly and sustainability assessment of technologies for nutrient recovery from human urine—A review. *Frontiers in Sustainability*, 4, 1338380. <https://doi.org/10.3389/frsus.2023.1338380>
6. Sohn, W., Jiang, J., Phuntsho, S., Choden, Y., Tran, V. H., & Shon, H. K. (2023). Nutrients in a circular economy: Role of urine separation and treatment. *Desalination*, 560, 116663. <https://doi.org/10.1016/j.desal.2023.116663>
7. Wang, F., Yang, Y., Gao, J., Li, X., Tian, S., Lu, Z., Zhou, Z., Sohn, W., Shon, H. K., & Ren, J. (2024). Biological nitrification-based nutrient recovery technologies for source-separated urine treatment: A critical review. *Desalination*. <https://doi.org/10.1016/j.desal.2024.118027>
8. World Health Organization. (2022). Sanitation safety planning: Manual for step-by-step risk management for safely managed sanitation systems (2nd ed.). World Health Organization.