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Nutrient Release Behaviour of POME-Derived Organo-Mineral Fertilisers in Acidic Ultisol

Fadeila Mohamed Hashim Ali, Syaharudin Zaibon*, and Susilawati Kasim

Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia(UPM), 43400 Serdang, Selangor, Malaysia

ABSTRACT

This study investigated the nutrient release behaviour of organic and organo-mineral fertilisers made from palm oil mill effluent (POME) in an acidic Ultisol under regulated incubation. The experiment used a completely randomised design with eight treatments and 400 g of soil, incubated for 60 days at 25 °C. The treatments comprised soil only, mineral fertiliser, POME only (one formulation), and blends of POME and minerals (two formulations). The first Ultisol was strongly acidic (pH 4.46), low in cation exchange capacity (10.16 cmol (+) kg^{-1}), and severely deficient in available phosphorus (P), calcium (Ca), magnesium (Mg), and potassium (K), while POME sludge was indicative of nutrient contribution potential. The study showed that the fertilised treatments had significant improvement in the soil pH and nutrients. In terms of short-term nutrient release (particularly phosphorus and several base cations), treatment T3 (120% POME) produced the best results, suggesting that POME sludge has a high nutrient-supply capacity. However, T5 (80% POME + 20% mineral fertiliser) exhibited the most balanced, slow nutrient-release pattern throughout the incubation. Further, T5 also managed to moderate soil pH better than the single-source treatment. The results show that organo-mineral fertiliser based on POME could improve nutrient availability in acidic tropical soil. It could reduce the reliance on synthetic fertiliser. Furthermore, it offers a more sustainable nutrient management strategy in low-fertility Ultisol systems with practical value for sustainable recycling of agro-waste.

Keywords: Agricultural waste, incubation, palm oil mill effluent, sustainable agriculture, weathered soil

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E-mail addresses:
alifadeila69@gmail.com (Fadeila Mohamed Hashim Ali)
syaharudin@upm.edu.my (Syaharudin Zaibon)
susilawati@upm.edu.my (Susilawati Kasim)
*Corresponding author

INTRODUCTION

Nutrient management is a critical issue in tropical agriculture. Indeed, in highly weathered soils, crop productivity depends not just on fertiliser input, but importantly

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on the efficiency of nutrient retention and release in the soil system. According to the Natural Resources Conservation Service (NRCS) of the U.S. Department of Agriculture (USDA) (n.d.) and the University of Idaho (n.d.), Ultisols are strongly weathered soils that are usually acidic, low in base saturation, and naturally limited in nutrient availability. According to Burbano et al. (2022), acidic tropical soils that occur in Malaysia, such as Ultisols and Oxisols, often need amendments to enhance their fertility and sustain crop production. It is vital to note that low pH, weak nutrient-holding capacity, and limited exchangeable bases reduce fertiliser efficiency and can limit the response, even when nutrients are added.

The problem that arises is not only low fertility but also low nutrient use efficiency. In Ultisols, which have an acidic nature, phosphorus is fixed easily, while nitrogen and potassium are less efficiently absorbed because the soil is not able to hold nutrients strongly enough. The works of Dermiyati et al. (2016) and Fahrunsyah et al. (2019) can be used to identify several soil components in Ultisols that can improve plant growth and phosphorus uptake. Various improvements with fertilisers and other nutrients can improve Ultisol growth factors. The findings imply that fertiliser strategies in acidic soils should focus not only on application rate but also on nutrient release behaviour, nutrient retention, and improvements in soil chemistry.

However, excessive use of mineral fertilisers raises agronomic and environmental problems at this time. According to Ditta and Arshad (2016), modern fertiliser management should transform into efficient and sustainable nutrient delivery systems. Further, Nongbet et al. (2022) highlighted that modern agricultural research is emphasising intelligent fertilisers that reduce losses and optimise synchrony between nutrient release and crop demand. Uddin et al. (2025) mentioned that organo-mineral fertilisers are gaining importance these days as their use can maintain soil health and yield, besides having a lesser environmental burden than the use of chemical fertilisers. For this reason, there is strong justification for the search for alternative fertiliser systems that can perform better in acidic tropical soils.

One possible resource is palm oil mill effluent or POME. This is produced in large quantities while palm oil is produced and is considered to be a waste management problem. However, recent studies have shifted views on POME sludge as a viable agrochemical. As reported by Mohd Nizar et al. (2018), application of treated POME sludge enhanced growth performance and gas exchange of maize. This indicated that POME sludge contributes useful nutrients to the crop system. According to Mutar et al. (2025), POME sludge could be used as a reusable source of micronutrients and other beneficial elements. Furthermore, palm oil mill waste could be better converted into useful products instead of being left as waste (Nagime et al., 2025).

POME's role in sustainable agriculture is further accentuated when used as organo-mineral fertilisers. Organo-mineral fertilisers involve adding organic material to a mineral

nutrient source to provide a high initial nutrient supply and gradual nutrient release. According to Moreira et al. (2021), the chemical soil properties can be modified with the use of pelletized organo-mineral fertilisers, while Gonçalves et al. (2021) state that the use of organo-mineral fertilisers based on waste-derived organic sources improved important chemical and technological properties in agricultural crop production systems.

According to Hawrot-Paw et al. (2022), the organo-mineral fertiliser derived from sewage sludge affects both soil biological quality and crops' physiological performance. All in all, these studies suggest that waste-derived organo-mineral fertilisers may become useful instruments for nutrient recycling, enhancing soil quality, and sustainable crop production.

Despite the growing interest, little is known about the nutrient release behaviour of POME-derived fertiliser in acidic Ultisol. Many studies have focused on crop response, soil improvement or the overall promise of organic amendments. But pure mineral fertiliser, pure POME-based fertiliser and blended organo-mineral formulations and their differences in releasing nutrients over time under controlled acidic soils are less explored. The possibility of a deficient or excess supply of a needed nutrient in soil can also arise due to fertilisers and their marginal efficiency. According to Uddin et al. (2025), organo-minerals offer practical value in aiding the fast availability of nutrients with a slow release and lower environmental losses.

Soils that have high acidity and limited nutrient-holding capacity face a problem of serious concern. Nutrients being released too fast means that part of the fertiliser you applied may either get lost or become less available. When release is too slow, crops may miss out on sufficient nutrients at the time they need to be at their maximum. POME sludge cannot be utilised directly to provide nutrients for the plants. However, its mineral and organic nutrients can be made available through formulations. Pure mineral, pure organic, or blended organo-mineral formulations need to be directly compared to determine which formulation provides the best nutrient release pattern in the soil, which is acidic and tropical. The comparison is necessary to progress from blanket statements about organic recycling to more specific fertiliser design evidence.

Consequently, this study assessed the nutrient-release behaviour of mineral-, organic-, and organo-mineral POME-based fertiliser formulations in an acidic Ultisol under incubation-controlled conditions. It examined changes in soil pH and the release of major nutrients from the three fertiliser formulations over time to identify formulations that release nutrients more balanced and sustainably.

This research will contribute to the development of sustainable fertiliser for acidic tropical soils. The study has focused on nutrient release behaviour rather than total nutrient composition. It helps formulate a more realistic basis for the design of fertilisers related to soil constraints and nutrient release behaviour. This aligns with the general trend of sustainable nutrient management identified by Ditta and Arshad (2016), Nongbet et al.

(2022), and Uddin et al. (2025), all of whom emphasise the need for fertiliser systems that would enhance efficiency and minimise environmental footprint.

Furthermore, the findings lend support to the transformation of POME from an agricultural waste nuisance into a fertiliser resource. Given that the palm oil businesses produce a lot of waste streams, the addition of POME sludge will give a more circular and sustainable alternative to dependence on completely synthetic fertilisers. In this sense, the study is relevant not only to soil fertility management but also to waste reutilisation and sustainable agricultural production. For the acidic Ultisols that have persistently low pH, poor phosphorus availability and weak base status as limitations, successful POME-based organo-mineral fertiliser application may help improve phosphate availability and reduce dependence on conventional mineral fertiliser. This research paper is organised with a thoughtful structure. First, the introduction is covered in Section 1. Then, Section 2 discusses the materials and methods. After that, Section 3 covers results and discussion. Finally, Section 4 is the conclusion.

MATERIALS AND METHODS

This study used the laboratory incubation method to determine the nutrient release behaviour of POME organic and organo-mineral fertilisers in acidic Ultisol. First, relevant materials were collected at the local level and standardized for laboratory evaluation. The Ultisol used in the study was collected from the Farm of University Putra Malaysia (UPM), while the organic material used was POME sludge obtained from the open treatment ponds at a palm oil mill. Table 1 summarises the main materials, sampling sources, and scope of preparation.

Table 1
Study materials

Item	Description
Soil material	Bungor series soil (Ultisol) collected from UPM faculty farm. Ladang 16 at 16°58′48.1″ N, 10°43′45.7″ E
POME material	POME sludge collected from Palm Oil Mill at Felda Jengka 8, Bandar Tun Abdul Razak Jengka, 26400 Jengka, Pahang, Malaysia
Soil sampling depth	0-20 cm topsoil
Soil sampling tools	Stainless-steel auger; stainless-steel core ring (7.6 cm x 4 cm); hammer
POME source	Open treatment ponds
Initial sample handling	Samples placed in clean containers, labelled, and transported to the laboratory
Standard preparation	Air-drying, grinding/milling, and sieving to 2 mm
Purpose of preparation	To obtain uniform laboratory material for physical, chemical, and formulation analyses

Soil samples were collected from the 0-20 cm layer using a stainless-steel auger and undisturbed core samples using a stainless-steel core ring (7.6 cm × 4 cm) with a hammer wherever required for physical analysis. Once collected, all samples were placed in clean containers, labelled appropriately, and delivered to the laboratory. After that, the soil and POME sludge were air-dried, milled, and sieved through a 2 mm sieve for analysis and formulation. The incubation medium, an acidic Ultisol, initially had a pH of approximately 4.8. To determine nutrient contribution potential and major fertility constraints after fertiliser formulation, baseline characterisation was undertaken to measure the main physical and chemical properties of the soil and the chemical properties of the POME sludge. The analytical methods applied in this stage are stated in Table 2.

Table 2
Analytical methods

Parameter	Method / Instrument	Purpose
Particle-size distribution	Pipette method	Baseline physical characterisation
Bulk density	Core ring method	Baseline physical characterisation
Moisture retention	Pressure Plate Chamber method	Water retention-related indices
Soil pH	pH meter	Soil acidity assessment
Electrical conductivity (EC)	EC meter	Salinity / soluble ion status
Total N	Kjeldahl digestion block	Nitrogen determination
Available nutrients	Spectrophotometer	Colorimetric nutrient determination
K, Ca, Mg	Atomic Absorption Spectrometer (AAS)	Cation concentration measurement
CEC	Ammonium acetate at pH 7(1945).	Soil fertility and nutrient-holding capacity
POME sludge chemistry	Dry ashing	Nutrient contribution for OMF formulation

An analysis of various soil characteristics from the respective sites was undertaken. Physical analysis included soil texture, bulk density, and moisture retention. Chemical analysis included soil pH, electrical conductivity, total nitrogen, selected available nutrients, cation concentrations and cation exchange capacity. Soil pH was measured using a pH meter. Electrical conductivity was determined using an EC meter, and total nitrogen was analysed by Kjeldahl digestion block. Using a spectrophotometer, available nutrients were determined. K, Ca, and Mg cations were determined by Atomic Absorption Spectrophotometer (AAS). The cation exchange capacity (CEC) was determined using ammonium acetate at pH 7. For the POME sludge, the dry ashing method was used to analyse calcium, magnesium, phosphorus, and potassium. Nitrogen was analysed using the Kjeldahl method.

The fertiliser materials underwent preparation for formulation after baseline characterisation. According to a target formulation of 15:15:15:3:2. T2 mineral fertiliser made out of ammonium sulphate, phosphate rock, muriate of potash (MOP) and dolomite, with a nutrient rate basis of 120:60:90 kg ha^{-1} at 400 kg ha^{-1}, was used. The organic component was air-dried POME sludge, which was milled and sieved with 2 mm mesh to enhance uniformity during mixing. The binder was clay at a controlled rate of 10%, resulting in a base organic mixture of 90% POME sludge and 10% clay. According to the incubation study, this ratio was chosen to optimise pellet integrity and handling. Prior to mixing, all materials were checked for sufficient dryness and clumping. Each batch of raw materials and prepared materials was labelled properly.



Figure 1. Mixing and batching procedure for the preparation of mineral and POME-based organo-mineral fertiliser

As depicted in Figure 1, mixing and batching of the POME and clay binder were carried out according to the fixed 90:10 base ratio as shown in Table 3. The required quantity of both the POME sludge and clay binder was weighed for each formulation first. This was followed by weighing the calculated amounts of ammonium sulphate, phosphate rock, MOP and dolomite. Distilled water was then added little by little and blended on an electric mixer until a homogeneous colour and texture were formed with no visible dry pockets and adequate binding capacity for the formation of pellets. To reduce cross-treatment contamination, each batch was prepared separately and labelled upon mixing. Weighing in at one-half to three-quarters of an inch in diameter, the finished materials can either be pelletised or granulated for ease in fertilizer handling and application.

The completely randomised design of the incubation experiment had eight treatments, each applied to 400 g of acidic Ultisol and incubated for 60 days at 25 °C. Table 3 provides information on the treatment structure, which consisted of T1: soil only (control), T2: 100% mineral fertiliser (Recommendation fertiliser), T3: 120% POME, T4: 100% POME, T5: 80% POME + 20% mineral fertiliser, T6: 60% POME + 40% mineral fertiliser, T7: 40% POME + 60% mineral fertiliser, and T8: 20% POME + 80% mineral fertiliser. Following wet mixing, the homogenised materials were fed into a mill to produce pellets, and the pellets obtained for each treatment were separately collected and labelled. The pellets were oven-dried at 56 °C and then kept at room temperature for 48 hours to improve stability. All pellets were dried under the same conditions and checked to ensure they remained dry and

Table 3
Treatment layout

Treatment	Composition	Description
T1	Soil	Control 1
T2	100% mineral fertiliser	Control 2
T3	120% POME	Organic treatment
T4	100% POME	Organic treatment
T5	80% POME + 20% mineral fertiliser	Organo-mineral treatment
T6	60% POME + 40% mineral fertiliser	Organo-mineral treatment
T7	40% POME + 60% mineral fertiliser	Organo-mineral treatment
T8	20% POME + 80% mineral fertiliser	Organo-mineral treatment

stable without cracking or softening during handling. The final pellets were standardised to a diameter of about 0.5 cm and a length of 2.5 cm for application.

All treatments were maintained under similar laboratory conditions during incubation. The same acidic Ultisol source was used with the same application basis for comparability. According to the 15:15:15 fertiliser reference, the application rate for all treatments in the experiment was 400 kg ha^{-1}, or approximately 2 g per container. Each week, soil or leachate extracts were collected, filtered before instrumental analysis, and analysed for NH_4+ (ammonium), NO_3 − (nitrate), available P, available K, available Ca, and available Mg. To allow comparisons of trends in nutrient release from week to week across T1-T8, all data were systematically recorded by treatment, replicate, and week. This dataset was subsequently used to assess the nutrient-release behaviour of mineral, organic, and organo-mineral fertilisers, and to identify formulations with greater potential for sustained nutrient availability.

RESULTS AND DISCUSSION

It is well known that palm oil mill effluent can alleviate nutrient deficiencies in poor Ultisols. As shown in Table 4, it has a very high potential to contribute nutrients. As far as the Ultisol condition is considered, it is strongly acidic with a pH of 4.46. Furthermore, it has extremely low available P of 0.057% (Bray-1), a cation exchange capacity of 10.16 cmol(+) kg^{-1}, as well as very low exchangeable Ca, Mg and K. Moreover, it is noted that the Ultisol is very low in nutrient content.

Similarly, it is strongly acidic but less so than Ultisol, with a pH of 5.6. Above all, it is very high in nutrient content, which is extremely beneficial in minimising deficiencies in Ultisol. Here is the tabulation of the contents of the study. In view of this, the fertilised treatments clearly affected soil acidity and nutrient release more than the control.

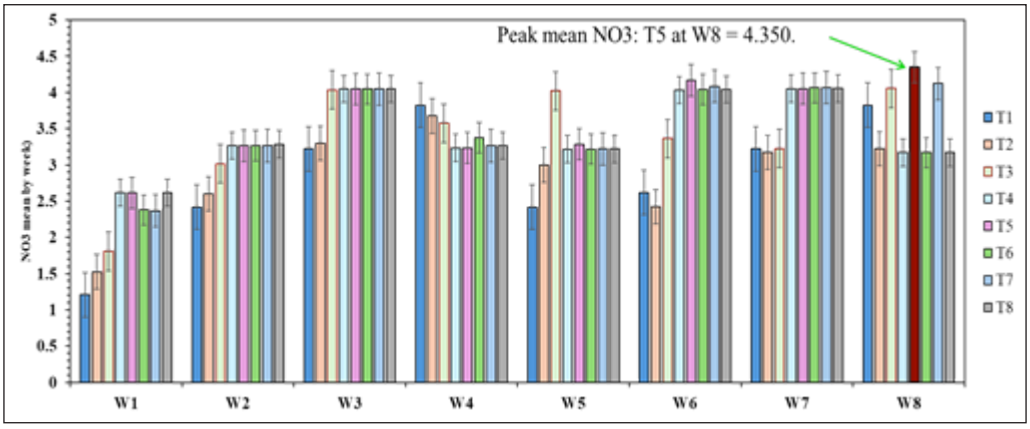
Table 4
Baseline properties of the acidic Ultisol and nutrient composition of POME sludge

Material	Parameter	Unit	Value	Interpretation
Acidic Ultisol	pH (H_2O, 1:2.5)	-	4.46	Strongly acidic soil condition
Acidic Ultisol	Organic carbon	%	1.79	Low organic-C signal in the baseline sample
Acidic Ultisol	Total N	%	0.24	Medium N status
Acidic Ultisol	Total P	%	0.057	Very low and limiting
Acidic Ultisol	CEC	cmol(+) kg^{-1}	10.16	Low nutrient-holding capacity
Acidic Ultisol	Exchangeable Ca^{2+}	cmol(+) kg^{-1}	0.075	Very low
Acidic Ultisol	Exchangeable Mg^{2+}	cmol(+) kg^{-1}	0.082	Low
Acidic Ultisol	Exchangeable K^{+}	cmol(+) kg^{-1}	0.1435	Very low
Acidic Ultisol	Texture	-	Clayey	High clay fraction affecting water and nutrient dynamics
POME sludge	pH	-	5.6	Mildly acidic and less acidic than the soil
POME sludge	Total N	%	2.30	High N contribution potential
POME sludge	Total P	%	0.46	Strong P reserve for nutrient balancing
POME sludge	Organic carbon	%	9.40	High organic-C. signal in the POME sample
POME sludge	K	%	0.64	Meaningful K contribution
POME sludge	Mg	%	0.65	Supports Mg supplementation
POME sludge	Ca	%	3.09	Strong Ca input for low-Ca Ultisol
POME sludge	Humic acid	%	0.64	

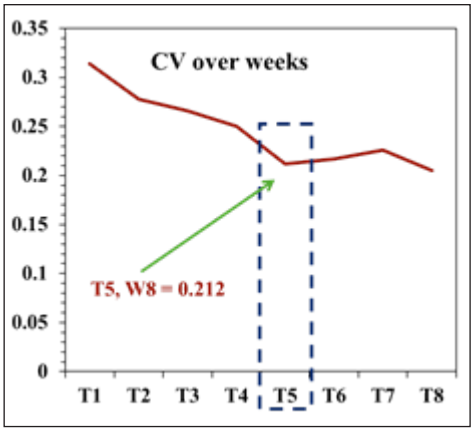
Nitrate (NO_3) Release Behaviour

The nitrate release pattern of the treatment was clearly different over the incubation period (see Figure 2). Generally, fertilised treatments released higher NO_3 than the control. This observation confirms that both mineral and POME-based inputs enhanced N availability in acidic Ultisol. The weekly bars show that during the first to middle of incubation, nitrate release increased progressively across the various treatments, then became more constant in the later weeks. According to this response, nitrate formation was influenced by both the immediately available mineral N fraction and the delayed mineralisation of the organic component.

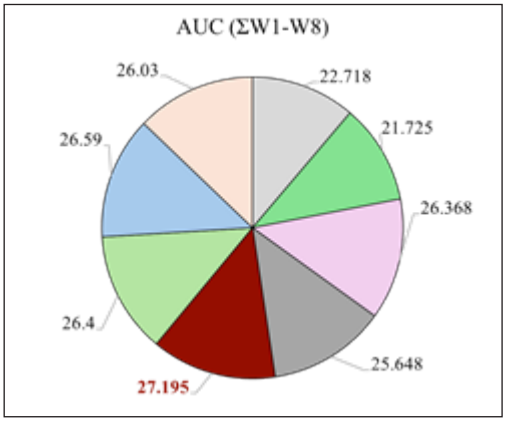
Of all treatments, the organo-mineral and POME-containing formulations exhibited a more prolonged nitrate profile than the unfertilised soil. The treatment response showed variability, suggesting that the organic-to-inorganic ratio influenced the rate and continuity of NO_3 formation. The variability trend presented in Figure 2b reached a lower endpoint at T5 (0.212) at week 8, indicative of more stable nitrate release compared to other treatments at the end of incubation. Such a steadier nitrate supply is often more desirable than a transient release pulse, especially in low-CEC acidic soils, where N loss may occur easily.



(a)



(b)



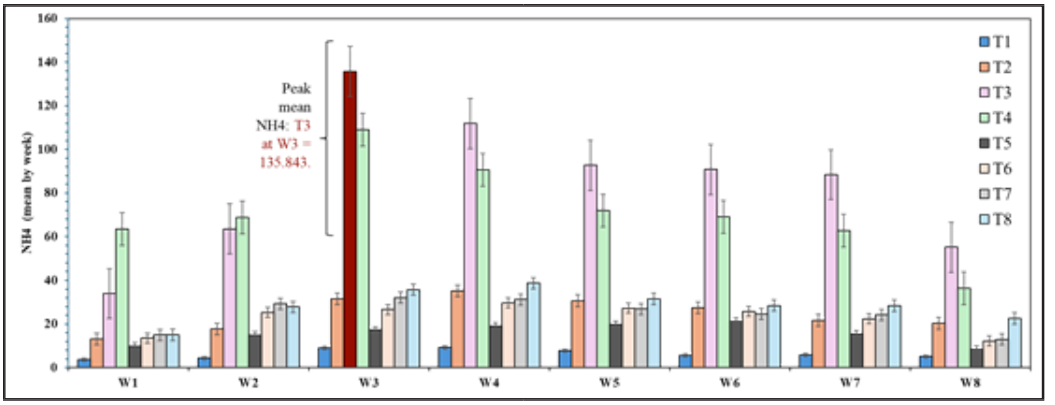
(c)

Figure 2 (a) response trend over weeks of incubation; (b) trend of the parameter measured; (c) relative contribution of treatments in percentage

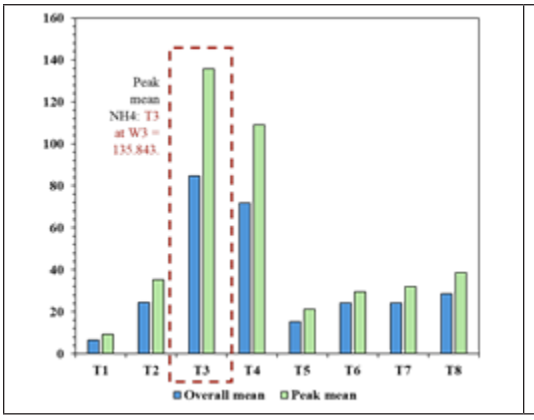
The cumulative distribution in Figure 2c suggests that nitrate release differed among treatments, as certain formulations were more influential than others in total NO_3 release. Considering the findings, it can be said that the blended POME-mineral treatments were more effective than control treatments in sustaining nitrate availability and were also more agronomically balanced than treatments based on a single nutrient (i.e., potassium, magnesium, or sulphate).

Ammonium (NH_4) Release Behaviour

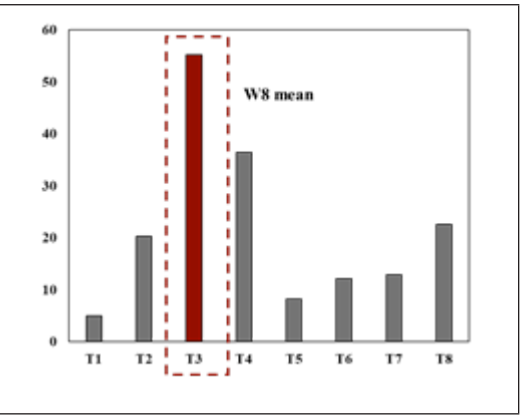
The ammonium response shown in Figure 3 differs noticeably between fast-release and moderate-release treatments. The baseline soil only had a total N content of 0.24%, while the POME sludge had 2.30% N. Hence, when all treatments were fertilised, NH_4 availability increased relative to the control. As can be seen in Figure 3c, the strongest NH_4



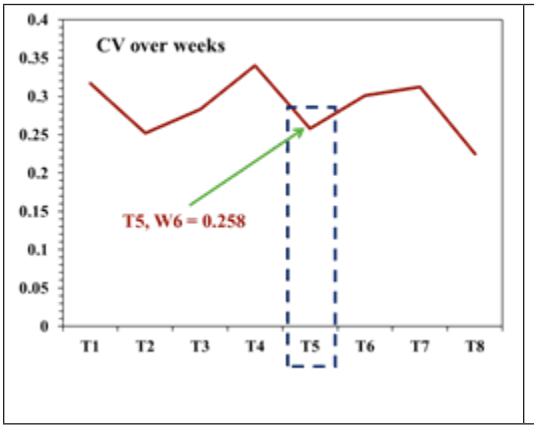
(a)



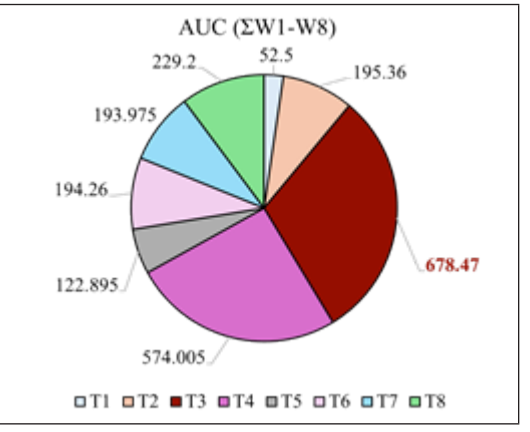
(b)



(c)



(d)



(e)

Figure 3 (a) Ammonium release per treatment per week; (b)Ammonium release comparison of selected treatments; (c) cumulative NH_4 response by treatment; (d) coefficient of variation trend; (e) cumulative NH_4 contribution of treatments

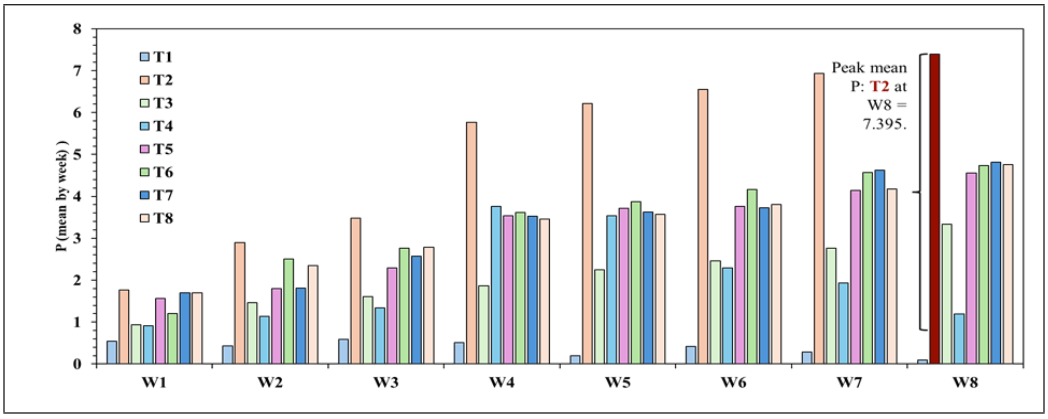
accumulation from all treatments is observed in T3, where POME is dominant, reaching values of 41.0. Hence, in terms of cumulative distribution, it reflects that POME sludge makes a big contribution towards NH_4. Agronomically speaking, the mineral fertiliser treatment probably released NH_4 more rapidly at the early stage, because ammonium sulfate supplies NH_4 in a directly available form. In comparison, the NH_4 from other treatments mineralised more quickly. In other words, the mineral-based treatment provided an immediate supply of NH_4 compared to other treatments. However, treatments that contained POME were better for extended supply. The NH_4 data indicate that the best practical option is not necessarily the treatment with the quickest initial release, but rather the one that maintains NH_4 for longer in low-CEC acidic soil where losses can potentially occur more easily.

Phosphorus Release Behaviour

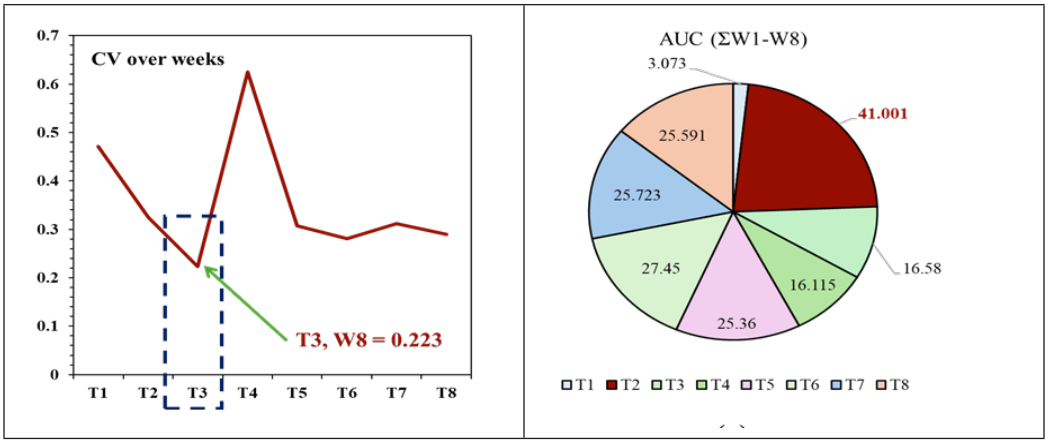
The phosphorus response in Figure 4 was one of the most important findings, as P was the most limiting nutrient in the starting soil. The most obvious evidence is the very sharp early release under the POME-dominant treatment, whereby T3 reached 135.843 at week 3 (Figure 4a). This is consistent with the sludge composition, which had both a strong total P reserve and a high fraction of immediately available P. Essentially, the POME sludge is a genuine P source and not merely an organic carrier. Nonetheless, the conversation ought to go beyond the highest peak value, as the study objective was sustained nutrient availability, not just rapid release. In an acidic Ultisol, this very rapid P release can still be followed by losses due to fixation. So, agronomically, these organo-mineral blends are more meaningful than the peak value alone because immediate P supply is combined with a more relaxed release environment. In the short term, T3 was the best treatment for maximum P release, while the combinations were best suited for sustained usable P over time.

Potassium, Calcium, and Magnesium Release

The release patterns for K, Ca, and Mg, as shown in Figure 5, confirm that the POME sludge contains multiple nutrients and that the base-cation values were very high. According to the cumulative plots, the highest marked value was allocated to the POME treatment dominance, with its cumulative plot values of 479.5 for K in Figure 5c, 895.6 for Ca in Figure 5f and 219.1 for Mg in Figure 5i. These findings are coherent with the sludge chemistry in Table 4, especially its strong Ca content and meaningful K and Mg contents. The relevance of this farming system is extremely high, as the starting Ultisol was extremely low in exchangeable Ca and K and low in Mg.



(a)



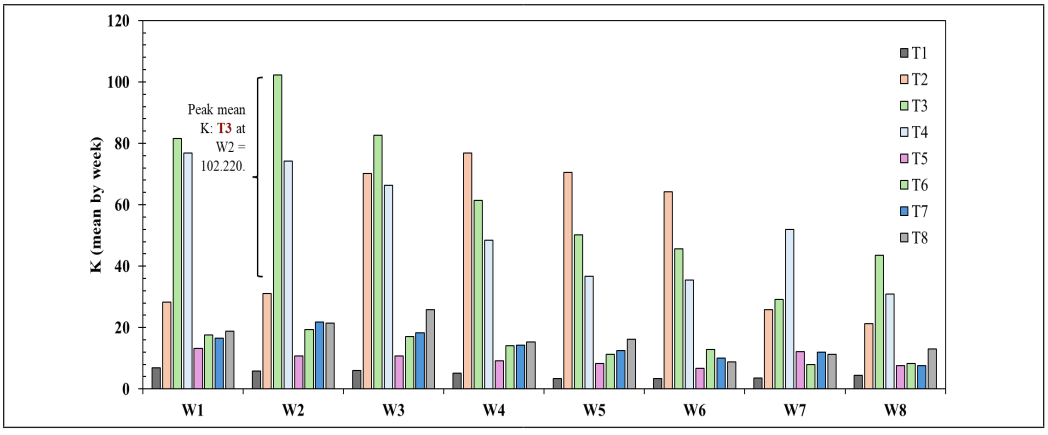
(b) (c)

Figure 4 (a) Weekly phosphorus release across treatments; (b) coefficient of variation trend; (c) phosphorus proportions among treatments

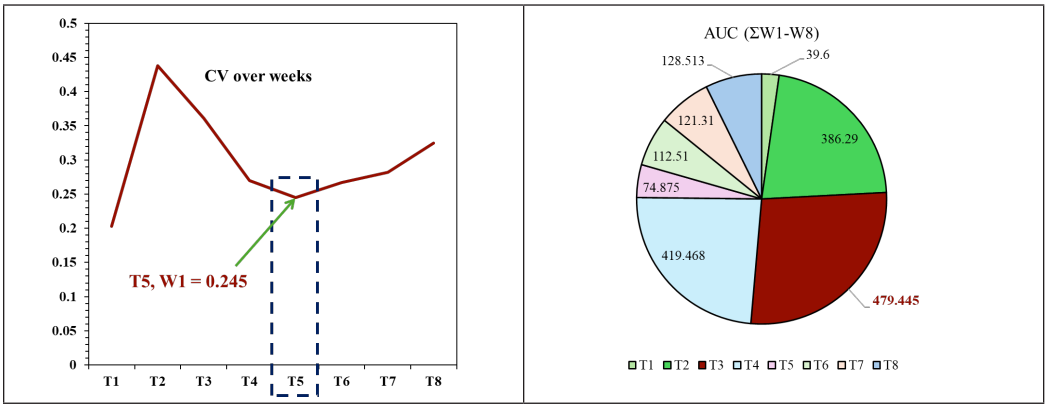
The mineral fertiliser improved these nutrients better, especially dolomite, while the POME-based treatments were more beneficial for total cation contribution. Nonetheless, the most beneficial interpretation is that organo-mineral blends could apply these cations more evenly than a single-source treatment. In soils that are acidic and have low buffering capacity, a balanced pattern is more beneficial than a single sharp pulse, as it helps in reducing the likelihood of nutrient loss and does so over a longer period of time.

Comparison Between Organic, Mineral, And Organo-Mineral Fertilisers

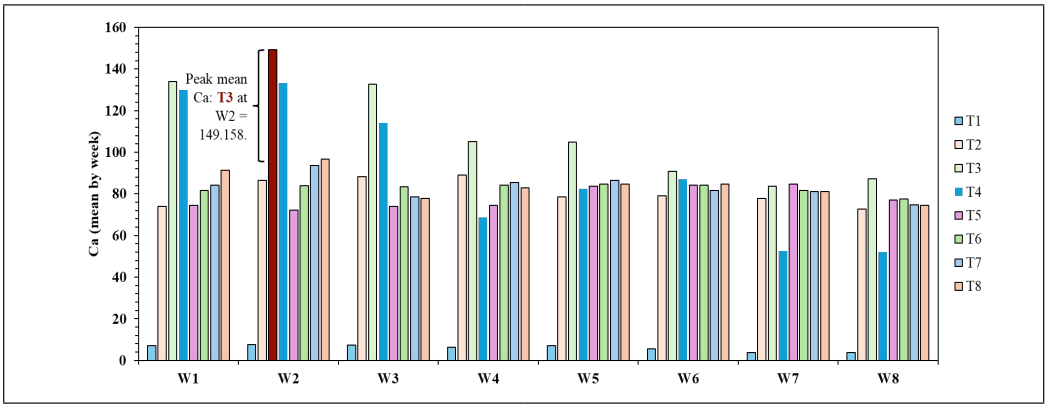
The three fertiliser groups behaved differently; taken together, the results show. The mineral fertiliser was the best option to attain fast release of nutrients that are readily solubilized.



(a)

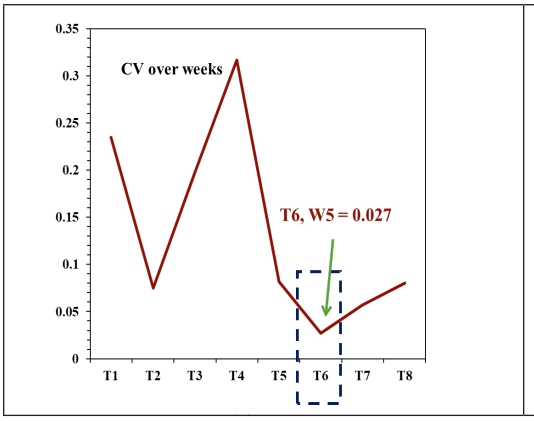


(b) (c)

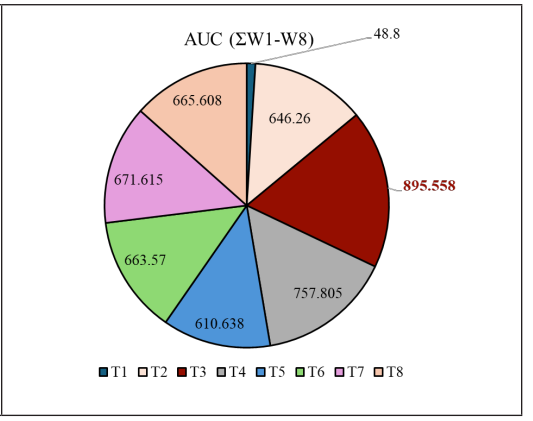


(d)

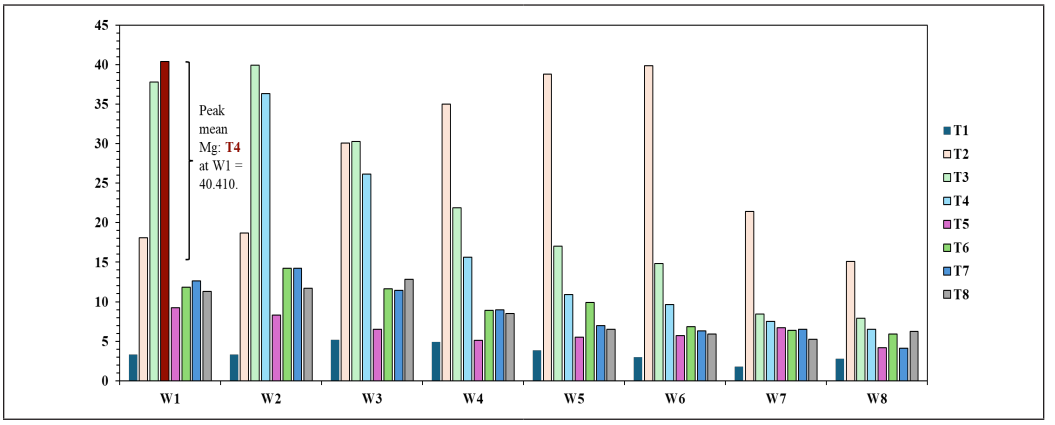
Figure 5. (a) weekly potassium released from treatments; (b) variation coefficient trend for potassium; (c) cumulative contribution of treatments of potassium; (d) weekly calcium released from treatments



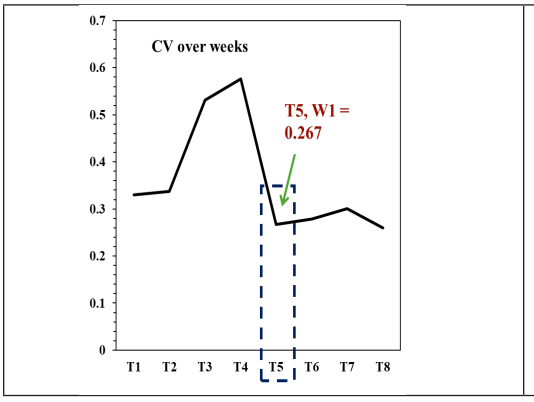
(e)



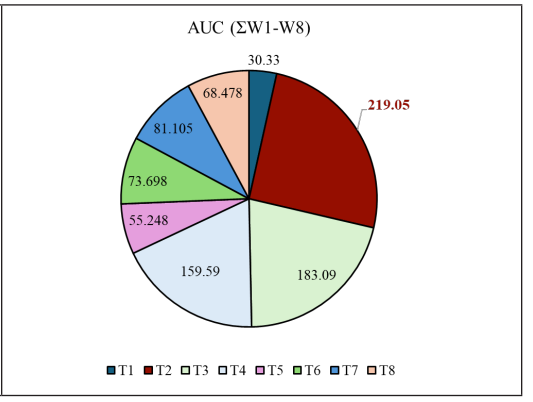
(f)



(g)



(h)



(i)

Figure 5 (*continued*). (e) Variation coefficient trend for calcium; (f) cumulative contribution of treatments for calcium; (g) weekly magnesium released from treatments; (h) variation coefficient trend for magnesium; (i) cumulative contribution of treatments for magnesium

The treatment with the highest nutrient peak and cumulative value for several parameters was POME-only dominant, particularly T3, which makes this treatment the best sample for optimum nutrient supply. Maximum release does not mean best agronomic performance. That means it won't perform well in acidic soils. The organo-mineral mixes were superior for balanced and sustained release, as they involved the immediate beneficial nutrient effect of mineral fertiliser with the buffering and supplementary nutrient effect of POME sludge. According to the results, the most favorable treatment in this study was T5 (80% POME + 20% mineral fertiliser). This means that T3 was best for maximum release, but T5 was best for sustained and practical nutrient management.

Implications For Sustainable Fertiliser Management

The outcomes from this investigation bear practical implications for fertiliser management of acidic tropical soils. The initial soil condition indicated that fertilisers should not only add nutrients to the soil but also improve its buffer capacity, exchangeable base status, and available P for the planted crop. The soil chemical environment must also be enhanced to improve nutrient availability. POME-based formulations can effectively accomplish this; the results indicate. The mineral fertiliser alone can supply nutrients efficiently; however, the POME sludge contributes nutrient reserves, base cations, humic substances and some buffering of acidity. For this reason, the blended formulations performed better as a management strategy. Treatment T5 had the best sustainability performance because it was based on a high proportion of recycled POME material while still providing sufficient mineral input for reliable nutrient release. The practical implication of this research is that the use of organo-mineral blends, especially T5, will be better and more efficient than single-source fertilisers on acidic Ultisols due to a more balanced, sustained and soil-improving nutrient response.

CONCLUSION

In conclusion, this study has demonstrated the nutrient release behaviour of mineral fertiliser, POME-based organic fertiliser, and blended organo-mineral formulations in acidic Ultisols under controlled incubation conditions. The results indicate that the initial soil was severely constrained by strong acidity, very low available P, low CEC and exchangeable base status, while POME sludge offered an important nutrient reserve, particularly for N, P, Ca, Mg and K. Among the tested treatments, it was T3 (120% POME) that produced the strongest nutrient peaks in the short term, particularly for phosphorus and several base cations. This finding indicates that the POME sludge has a high potential for the release of nutrients. Nevertheless, the overall findings suggested that T5, which consisted of 80% POME + 20% mineral fertiliser, gave a more balanced and sustained release pattern, improved soil reaction, and combined the instant benefit of mineral nutrients with the buffering and

nutrient-retention advantage of the organic fraction. Hence, T5 was the best treatment for practical fertiliser management. Due to the possible loss of nutrients from fertilisers and the short durability of fertilisers, T5 is a more appropriate option than either the purely mineral or purely organic treatment in an acidic tropical soil context. Consequently, this research contributes directly to the evidence on POME-derived formulations in acidic Ultisol. In addition, our results indicate that a blended organo-mineral approach is more effective than single-source fertiliser strategies for sustained nutrient availability, less dependency on synthetic fertiliser, and better management of low-fertility tropical soils.

IMPLICATION OF THE STUDY

This study shows that POME-based organo-mineral fertiliser improves acidic Ultisol and supports nutrient availability. T5 gives the best overall performance and provides a more sustainable fertiliser option.

LIMITATION AND RECOMMENDATION FOR FUTURE RESEARCH

This study uses one soil type under laboratory conditions. Future research should test the fertiliser in different soils and field conditions and examine its long-term effects on soil and crop performance.

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REFERENCES

Burbano, D. F. M., Theodoro, S. H., de Carvalho, A. M. X., & Ramos, C. G. (2022). Crushed volcanic rock as soil remineralizer: A strategy to overcome the global fertilizer crisis. *Natural Resources Research, 31*, 2197-2210. https://doi.org/10.1007/s11053-022-10107-x

Dermiyati, Utomo, S. D., Hidayat, K. F., Lumbanraja, J., Triyono, S., Ismono, H., Ratna, N. E., Putri, N. T., & Taisa, R. (2016). Effectiveness of Organonitrofos Plus fertilizer on sweet corn and soil chemical properties of Ultisols. *Journal of Tropical Soils, 21*(1), 9-17. https://doi.org/10.5400/jts.2016.v21i1.9-17

Ditta, A., & Arshad, M. (2016). Applications and perspectives of using nanomaterials for sustainable plant nutrition. *Nanotechnology Reviews, 5*(2), 209-229. https://doi.org/10.1515/ntrev-2015-0060

Fahrunsyah, F., Kusuma, Z., Prasetya, B., & Handayanto, E. (2019). Utilization of coal fly ash and oil palm empty fruit bunch compost to improve the uptake of soil phosphorus and yield of maize grown on an Ultisol. *Journal of Ecological Engineering, 20*(6), 36-43. https://doi.org/10.12911/22998993/108635

Gonçalves, C. A., de Camargo, R., de Sousa, R. T. X., Soares, N. S., de Oliveira, R. C., Stanger, M. C., Lana, R. M. Q., & Lemes, E. M. (2021). Chemical and technological attributes of sugarcane as functions of organomineral fertilizer based on filter cake or sewage sludge as organic matter sources. *PLOS ONE, 16*(12), Article e0236852. https://doi.org/10.1371/journal.pone.0236852

Hawrot-Paw, M., Mikiciuk, M., Koniuszy, A., & Meller, E. (2022). Influence of organomineral fertiliser from sewage sludge on soil microbiome and physiological parameters of maize (*Zea mays* L.). *Agronomy, 12*(5), Article 1114. https://doi.org/10.3390/agronomy12051114

Mohd Nizar, K., Isharudin, M. I., Abd Jamil, Z., & Hazandy, A. H. (2018). Influence of treated palm oil mill effluent sludge on maize (*Zea mays*) growth performance and gas exchange. *Sains Malaysiana, 47*(5), 961-969. https://doi.org/10.17576/jsm-2018-4705-11

Moreira, J. G., Delvaux, J. C., Magela, M. L. M., Pereira, V. J., de Camargo, R., & Lana, R. M. Q. (2021). Chemical changes in soil with use of pelletized organomineral fertilizer made from biosolids and sugarcane filter cake. *Australian Journal of Crop Science, 15*(1), 67-72. https://doi.org/10.21475/ajcs.21.15.01.2645

Mutar, Z. H., Al-Baldawi, I. A., & Sheikh Abdullah, S. R. (2025). Sustainable treatment of palm oil mill effluent and repurposing of sludge as a micronutrient resource. *Journal of King Saud University—Science, 37*, Article 9862025. https://doi.org/10.25259/JKSUS_986_2025

Nagime, P. V., Chidrawar, V. R., Singh, S., Shafi, S., & Singh, S. (2025). Palm oil mill waste: A review on ecological improvement goals advancement and prospects. *Food and Humanity, 5*, Article 100816. https://doi.org/10.1016/j.foohum.2025.100816

Nongbet, A., Mishra, A. K., Mohanta, Y. K., Mahanta, S., Ray, M. K., Khan, M., Baek, K.-H., & Chakrabartty, I. (2022). Nanofertilizers: A smart and sustainable attribute to modern agriculture. *Plants, 11*(19), Article 2587. https://doi.org/10.3390/plants11192587

Uddin, M. K., Saha, B. K., Wong, V. N. L., & Patti, A. F. (2025). Organo-mineral fertilizer to sustain soil health and crop yield for reducing environmental impact: A comprehensive review. *European Journal of Agronomy, 162*, Article 127433. https://doi.org/10.1016/j.eja.2024.127433

U.S. Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS). (n.d.). *Ultisols*. https://www.nrcs.usda.gov/conservation-basics/soil/ultisols

University of Idaho. (n.d.). *Ultisols*. https://www.uidaho.edu/agricultural-life-sciences/soil-orders/ultisols