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IMPACT OF STRUVITE (ORGANIC), NPK, AND UREA (INORGANIC) FERTILIZERS ON PHYSICOCHEMICAL PROPERTIES OF SOIL SAMPLES

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ABSTRACT

This study assessed the effects of struvite, NPK, and urea fertilizers on selected soil physicochemical properties. A randomized complete block design (RCBD) was employed with four treatments: struvite, NPK (20:10:10), urea, and an unfertilized control, each replicated four times. Struvite was synthesized from human urine using standard procedures. All fertilizers were analysed for nitrogen (N), phosphorus (P), and potassium (K) content prior to application. Soil parameters evaluated included pH, organic and inorganic matter, carbon content, trace elements (K, Zn, Fe, Mn, Cu, and B), and soluble salts (NO_3^-, PO_4^{3-}, SO_4^{2-}, and Cl^-). Measurements were taken before planting and three weeks after cultivating Cucurbita maxima in soils treated at a rate of 0.004 g/cm². Comparative analysis showed that urea contained the highest nitrogen concentration, while struvite had significantly greater phosphorus (15.00±0.06%) and potassium (3.70±0.07%) levels. Although soil pH increased with all fertilizer applications, the changes were not statistically significant. Organic carbon improved across treatments, with struvite producing the greatest increases in both organic and inorganic carbon. Struvite-treated soils also showed the highest levels of K, Zn, and Fe across both sampling periods, along with notable reductions in Mn and Cu. Nitrate depletion was greatest in NPK-treated soils, whereas struvite showed the least reduction (61.64±5.17ug/g). Urea-treated soils exhibited the highest PO_4^{3-} levels (3.70±0.36ug/g). A marked rise in SO_4^{2-} was observed in the struvite group (546.11±41.92ug/g), while chloride increased in all treatments, especially with urea (1.69±0.39ug/g). Overall, large-scale production and agricultural application of struvite as a slow-release fertilizer should be promoted to enhance crop productivity and support environmental sustainability through waste reutilization.

Keywords: Fertilizers; Hectare ha; Physicochemical properties; Struvite; Urine.

1.0. Introduction

Soil health plays a pivotal role in determining crop productivity and overall ecosystem sustainability (Xing *et al.*, 2025). Soil physicochemical properties, including pH, electrical conductivity, organic matter content, and microbial activity, are essential indicators of soil

health (Xing *et al.,* 2025). According to Adeniya *et al*. (2011, the application of fertilizers is widely practised to improve soil fertility and, subsequently, crop yield. However, the choice of fertiliser type can significantly impact soil physicochemical properties and crop growth. Among the various types of fertilizers available, struvite, NPK (Nitrogen-Phosphorus-Potassium), and urea are commonly used. Struvite, a natural fertiliser, has become of interest for its ability to improve soil health while remaining environmentally friendly (Nqaba, 2013). Bouropoulos and Koutsoukos (2000) state that the following chemical process leads to the synthesis of struvite:

$$Mg^{\{2+\}} + NH_4^+ + PO_4^{\{3-\}} + 6H_2O \rightarrow MgNH_4PO_4.6H_2O$$

Struvite is composed of magnesium, ammonium, and phosphate ions, which can improve soil structure, increase nutrient availability, and promote microbial activity (Stanley and Siraje, 2020; Ahmad and Guputa, 2019; Alzamel *et al.,* 2022). According to Etter et al. (2011), the recovery of P from urine can reach 98% with a Mg dosage of 1.8 mol Mg per mol of P. In contrast, NPK fertilizers, a blend of nitrogen, phosphorus, and potassium, are widely used for their broad-spectrum benefits. Urea, a common nitrogen fertilizer, is a preferred choice due to its high nitrogen content and cost-effectiveness (Linden,1996). However, excessive application of urea can lead to soil degradation, environmental pollution, and reduced crop yields.

Understanding how different fertilizers impact soil properties is crucial for sustainable agriculture practices. Previous studies have investigated the effects of different fertilizer types on soil properties and crop yield (Zhang *et al.,* 2014; Bhuiyan *et al.,* 2008). Although several studies have examined individual fertilizer effects, comparative assessments of struvite, NPK, and urea under similar conditions remain limited. This study, therefore, aims to evaluate their respective impacts on soil physicochemical properties in order to provide insights into more sustainable fertilizer management practices. A review of the literature suggests that struvite can improve soil fertility, promote microbial activity, and increase crop yields (Popoola et al., 2015; Dania et al., 2022). This research will provide valuable insights into the effects of different fertilizer types on soil physicochemical properties, contributing to the development of sustainable agricultural practices that prioritize soil health and ecosystem sustainability.

2.0. Materials and Methods

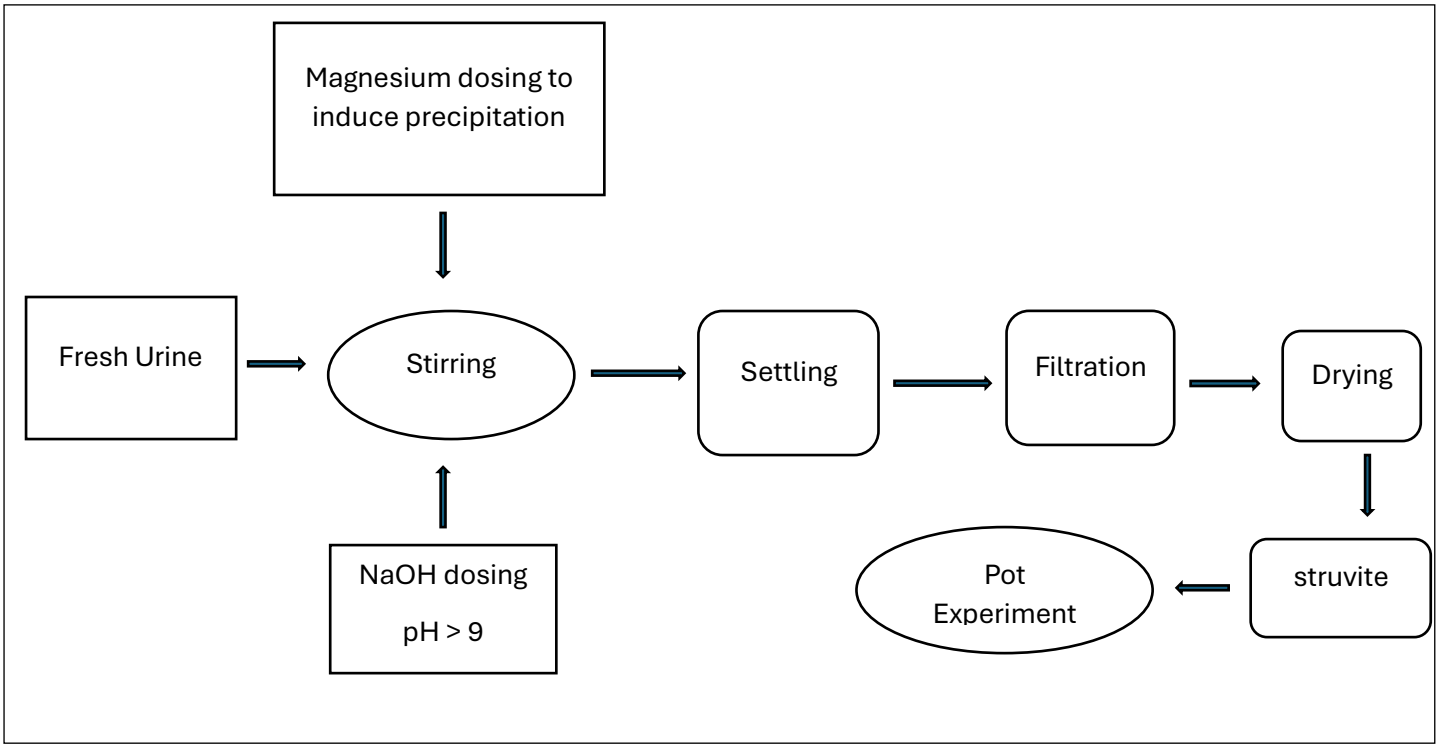


Figure 1: Schematic Process of the study

2.1. Sampling

2.1.1. Study Area

The study was conducted at the Department of Biochemistry, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria.

2.1.2. Struvite Preparation

Struvite was precipitated from human urine following standard methods (Etter et al., 2011). Twenty litres of urine were mixed with 64 g of magnesium sulphate ($MgSO_4$), and the pH was adjusted above 9 using sodium hydroxide (NaOH). The mixture was stirred for 30 minutes and allowed to settle for 48 hours. The precipitate was filtered and dried as illustrated in Figure 1 above.

2.1.3. Experimental Design

A randomized complete block design (RCBD) with four treatments and four replicates was used to minimize variability and ensure statistical robustness.: Struvite (200 kg/ha), NPK (200 kg/ha), Urea (200 kg/ha) and Control no fertilizer) (Gomez & Gomez, 1984). Cucurbita maxima seeds (4 seeds at a depth of 2cm) were sown uniformly across each bag with the fertilized soil. Standard agronomic practices were followed throughout the growing period. All fertilizer applications were incorporated into the soil 3 weeks after planting (3WAP) using the ring method.

2.1.4. Soil Sampling and Preparation

Soil samples (5 kg) were placed in 16 experimental bags. Samples were collected before planting and at 3 weeks after planting (3 WAP). Sixteen (16) soil samples were collected from the bags for analysis, thoroughly mixed, and divided into four (4) groups of four samples each (FAO, 2000).

2.2. Analytical Methods

The pH was measured using pH meter (1:2.5 soil-water ratio) using a calibrated glass electrode pH meter**.** Ammonium and nitrate concentrations were determined using colourimetric methods (Association of Analytical Chemistry (AOAC), 2005)**.** Phosphorus was extracted using Bray,

followed by colorimetric detection (e.g., molybdenum blue method) (Henryk, 2003). Potassium was extracted with ammonium acetate solution and quantified via flame photometry) (Henryk, 2003). Organic matter was analysed using the Walkley–Black method, and the micronutrients were determined using the standard AOAC methods (AOAC, 2005).

2.3. Statistical Analysis

The results were presented with the mean and standard deviation.

3.0.Results and Discussion

3.1. Nutrient Composition of Fertilizers

Table 1: Average Nitrogen, Phosphorus and Potassium levels in the struvite, NPK and Urea fertilizers.

Manure type	Nitrogen%	Phosphorus%	Potassium%
NPK	8.00±0.10	3.00±0.22	3.00±0.04
Urea	41.00±0.31	0.50±0.33	1.20±0.12
Struvite	9.30±0.11	15.00±0.06	3.70±0.07

Table 1 presents the nitrogen (N), phosphorus (P), and potassium (K) composition of the fertilizers used in this study. Urea recorded the highest nitrogen content (41.00±0.31 %), followed by struvite (9.30±0.11 %), while NPK fertilizer contained 8.00±0.10 %. Conversely, struvite exhibited the highest phosphorus concentration (15.00±0.06%), significantly exceeding both NPK (3.00±0.22%) and urea (0.50±0.33%). Potassium levels were also highest in struvite (3.70±0.07 %). The high nitrogen content of urea is expected due to its chemical composition ($CO(NH_2)_2$), which contains approximately 46% nitrogen (Linden, 1996). In contrast, struvite ($MgNH_4PO_4 \cdot 6H_2O$) is characterized by high phosphorus content, explaining its superior P levels (Ahmad and Gupta, 2019). The relatively balanced nutrient composition of NPK fertilizer reflects its formulation for general crop nutrition (Dania *et al*., 2022).

3.2. pH Levels

Table 2. Effect of Different Fertilizer types on Average pH levels

Treatments	Initial	3 WAP
Normal control	6.64±0.04	6.87±0.02
Struvite	6.47±0.04	7.01±0.10
Urea	6.46±0.04	7.09±0.27
NPK	6.46±0.03	6.79±0.03

Table 2 displays the impact of fertilizer treatments on soil pH. After three weeks, all treatments caused a modest rise in soil pH. The soil treated with urea experienced the greatest increase, from 6.46±0.04 to 7.09±0.27, followed by struvite, which rose from 6.47±0.04 to 7.01±0.10. NPK showed the smallest change.

The observed increase in pH may be attributed to ammonification processes, where nitrogen-containing fertilizers release ammonium ions that can temporarily increase soil alkalinity before nitrification occurs (Linden, 1996). In the

case of struvite, its buffering capacity is linked to the presence of magnesium and phosphate ions, which stabilise soil pH (Ahmad & Gupta, 2019). The relatively moderate pH change observed suggests that struvite may help maintain soil pH balance, which is beneficial for nutrient availability and microbial activity.

3.3. Organic Matter Content

Table 3. Effect of Different Fertilizer types on Average Organic Matter Content

Groups	Initial (ug/g)	After 3 weeks(ug/g)
Normal control	2.15±0.65	3.64±0.52
Struvite	2.14±0.77	8.91±2.47
Urea	2.15±0.66	3.90±1.01
NPK	2.15±0.69	6.57±1.66

Table 3 shows the changes in organic matter content following fertilizer application. The soil treated with struvite exhibited the largest increase, rising from 2.14±0.77 µg/g to 8.91±2.47 µg/g, followed by the NPK and urea treatments. This significant increase in organic matter in the struvite group may be attributed to enhanced microbial activity stimulated by the gradual release of nutrients. Slow-release fertilizers such as struvite provide sustained nutrient availability, which supports microbial decomposition processes and organic matter accumulation (Etter *et al.,* 2011). In contrast, urea provides rapid nitrogen release, which may not sustain long-term microbial activity, thereby resulting in lower organic matter accumulation.

3.4.Inorganic Matter Content

Table 4. Effect of Different Fertilizer types on Average Inorganic Matter Content

Groups	Initial (ug/g)	After 3 weeks(ug/g)
Normal control	39.75±1.55	37.75±1.89
Struvite	40.11±0.13	43.00±1.41
Urea	39.89±1.45	41.25±1.80
NPK	39.77±1.49	38.25±0.95

As shown in Table 4, the struvite-treated soil exhibited the highest inorganic matter content after 3 weeks (43.00±1.41ug/g). The increase in inorganic matter in the struvite group can be attributed to its mineral composition, particularly magnesium and phosphate ions, which contribute to soil mineral content. These minerals enhance soil cation exchange capacity and nutrient retention (Fraústo da Silva and Williams, 1997). The relatively stable inorganic matter levels across treatments indicate that all fertilizers contributed to mineral enrichment, but struvite provided a more sustained effect.

3.5.Organic carbon content

Table 5. Effect of Different Fertilizer types on organic carbon content

Treatments	Initial (ug/g)	3 WAP (ug/g)
Normal control	1.25±0.38	2.11±0.30
Struvite	1.25±0.33	5.18±1.44
Urea	1.24±0.41	2.27±0.59
NPK	1.25±0.37	3.82±0.97

Table 5 shows that all fertilizer treatments increased soil organic carbon content, with the highest increase observed in the struvite-treated soil (1.25±0.33ug/g to 5.18±1.44ug/g). This increase can be linked to improved microbial activity and carbon sequestration resulting from the gradual release of struvite nutrients. Organic carbon plays a critical role in soil fertility by enhancing water retention and microbial growth (Etter *et al.,* 2011). The relatively small increase observed in urea-treated soil may be due to the rapid release of nitrogen, which does not significantly contribute to long-term carbon accumulation.

3.6.Soil Nitrate Levels

Table 6. Effect of Different Fertilizer types on nitrate composition

Treatment	Initial (ug/g)	3 WAP(ug/g)
Normal control	73.50±9.70	60.43±8.83
Struvite	72.78±8.82	61.64±5.17
Urea	73.47±7.73	69.05±13.95
NPK	73.51±9.25	53.14±3.47

Table 6 shows a reduction in nitrate concentration across all treatments after 3 weeks. The greatest reduction was observed in NPK-treated soil (approximately 27%), whereas urea-treated soil showed the smallest reduction (6%). The rapid decline in nitrate levels in NPK-treated soil can be attributed to nitrate's high solubility, which makes it readily available for plant uptake and susceptible to leaching (Dania *et al.*, 2022). In contrast, struvite exhibited moderate nitrate reduction, supporting its classification as a slow-release fertilizer (Nqaba, 2013). Urea showed the least reduction due to the gradual conversion of urea into ammonium and subsequently nitrate through microbial processes (Linden, 1996).

3.7.Soil phosphate levels

Table 7. Effect of Different Fertilizer types on phosphate levels.

Treatment	Initial (mg/g)	3WAP (mg/g)
Normal control	1.78±0.09	1.91±0.11
Struvite	1.77±0.10	2.34±0.34

Urea	1.79±0.08	3.70±0.36
NPK	1.78±0.09	2.04±0.46

Table 7 indicates a significant increase in phosphate levels after fertilizer application ($p<0.05$), with the highest increase observed in the urea-treated soil (1.79±0.08mg/g to 3.70±0.36mg/g). Although urea does not directly supply phosphorus, its high nitrogen content enhances microbial activity, which promotes mineralization of organic phosphorus into available phosphate (Linden, 1996). The increase observed in the struvite-treated soil is directly linked to its phosphate-rich composition (Ahmad and Gupta, 2019).

3.8.Soil chloride levels

Table 8. Effect of Different Fertilizer types on chloride levels.

Groups	Initial (ug/g)	3WAP (ug/g)
Normal control	1.06±0.11	1.54±0.15
Struvite	1.05±0.12	1.47±0.08
Urea	1.06±0.13	1.69±0.39
NPK	1.06±0.10	1.30±0.10

Table 8 shows an increase in chloride levels across all treatments, with the highest increase observed in the urea-treated soil. This increase can be attributed to ion exchange processes in the soil. During nitrification, ammonium ions are converted to nitrate, releasing hydrogen ions that displace other ions such as chloride from soil exchange sites (Fraústo da Silva and Williams, 1997). This explains the increase in chloride concentration despite the fertilizers not being direct sources of chloride.

3.9. Potassium

Table 9. Effect of Fertilizer types on K levels

Treatment	Initial (ppm)	3WAP (ppm)
Normal control	0.55±0.03	0.48±0.07
Struvite	0.55±0.05	0.51±0.02
Urea	0.54±0.09	0.40±0.01
NPK	0.55±0.02	0.40±0.03

As shown in Table 9, the struvite-treated soil maintained the highest potassium levels at the end of the experimental period. Although struvite is not primarily a potassium fertilizer, its ability to improve soil structure and cation exchange capacity enhances potassium retention in the soil (Ahmad and Gupta, 2019). This suggests that struvite indirectly improves potassium availability, which is essential for plant growth and metabolic processes

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3.10. Zinc

Table 10: Effect of Fertilizer types on zinc levels

Groups	Initial (ppm)	3WAP (ppm)
Normal control	1.02±0.01	0.41±0.00
Struvite	1.02±0.03	0.56±0.03
Urea	1.01±0.12	0.59±0.03
NPK	1.02±0.01	0.40±0.05

Table 10 shows a decrease in zinc levels across all treatments, although the struvite- and urea-treated soils retained relatively higher levels. The reduction in zinc levels may be due to plant uptake during growth. However, the relatively higher zinc levels in struvite-treated soil may be attributed to improved nutrient availability and microbial activity (Stanley and Siraje, 2020). Additionally, changes in soil pH influence zinc solubility, with slightly acidic to neutral conditions favouring its availability.

3.11. Iron

Table 11. Average iron levels in the various soil groups

Groups	Initial (ppm)	3WAP (ppm)
Normal control	1.22±0.06	1.15±0.10
Struvite	1.21±0.10	2.09±0.05
Urea	1.22±0.05	1.30±0.10
NPK	1.22±0.08	1.74±0.30

Table 11 indicates that the struvite-treated soil had the highest iron concentration after 3 weeks (2.09±0.05 ppm). This increase may be linked to improved soil conditions that enhance iron solubility and availability. Struvite application may influence redox reactions and microbial activity, thereby increasing iron mobilization in the soil (Fraústo da Silva and Williams, 1997).

3.12. Manganese

Table 12. Average manganese levels in the various soil groups

Groups	Initial (ppm)	3WAP (ppm)
Normal control	4.58±0.43	3.10±0.12
Struvite	4.60±0.13	2.81±1.26
Urea	4.59±0.11	2.91±0.84
NPK	4.58±0.13	3.30±1.57

Table 12 shows a reduction in manganese levels across all treatments, with the highest reduction observed in the struvite-treated soil. The decrease in manganese concentration is likely due to plant uptake during growth. Manganese is essential for photosynthesis and enzyme activation, and its reduction suggests active utilization by plants (Fraústo da Silva and Williams, 1997).

3.13. Copper

Table 13. Average Cu levels in the various soil groups

Groups	Initial (ppm)	3 WAP (ppm)
Normal control	0.034±0.03	0.02±0.02
Struvite	0.033±0.00	0.04±0.01
Urea	0.032±0.01	0.02±0.01
NPK	0.034±0.01	0.02±0.02

As shown in Table 13, copper levels remained relatively stable across treatments. Copper availability in soil is strongly influenced by pH and organic matter content. The relatively stable levels observed suggest that fertilizer application did not significantly alter copper dynamics within the short experimental period (Fraústo da Silva and Williams, 1997).

4.0. Conclusions

The study compared the physicochemical properties of struvite, NPK and Urea on soil samples. It was found that struvite gave a better result when compared with other fertilizers. The findings from this study may contribute to the development of positive attitudes about the use of Struvite produced from urine as fertilizer, a way to retain soil physicochemical properties and increase crop yield. Struvite crystallization process is an effective, eco-friendly process which can result in reduced environmental pollution caused by inorganic fertilizer. In addition, findings may optimize the use of struvite produced from urine to fertilize crops, which will help to maintain crop quality, improve soil characteristics, and reduce the demand for inorganic fertilizers. Struvite is also a highly effective source of nitrogen, magnesium and phosphorus for plants and can be used as a slow-release fertilizer at high application rates without damaging plant roots.

4.1. Recommendation

The production of struvite and its use in agriculture should be engaged on a large scale and should be used as an organic fertilizer to improve plant yield and indirectly improve environmental well-being. Struvite is a slow-release, valuable fertilizer that can be used in agriculture. It is therefore necessary to develop optimal conditions for the production of struvite at both small and commercial scales. Struvite can be a good substitute for inorganic fertilizer, as urine has been certified as fertilizer and the raw material for struvite production. More research should be conducted to understand the full effects of struvite on a variety of crops and to assess its potential, limitations, and any possible drawbacks. Since only a few physicochemical properties were analysed, further work is recommended on other properties essential for bountiful yield.

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