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Mohan V
Department of Soil Science and
Agricultural Chemistry, S.V.
Agricultural College, ANGRAU,
Andhra Pradesh, India

P Kavitha
Department of Soil Science and
Agricultural Chemistry, RARS-
Nandyal, ANGRAU, Andhra
Pradesh, India

TNVKV Prasad
Nanotechnology laboratory, IFT,
RARS- Tirupati, ANGRAU,
Andhra Pradesh, India

A Malleswara Reddy
Department of Agronomy, RARS-
Nandyal, ANGRAU, Andhra
Pradesh, India

M Raghavendra
Department of Soil Science and
Agricultural Chemistry, S.V.
Agricultural College, ANGRAU,
Andhra Pradesh, India

BP Singh
Department of geology, BHU,
Uttar Pradesh, India

M Dhanunjaya Reddy
Department of Soil Science and
Agricultural Chemistry, S.V.
Agricultural College, ANGRAU,
Andhra Pradesh, India

MVS Naidu
Department of Soil Science and
Agricultural Chemistry, S.V.
Agricultural College, ANGRAU,
Andhra Pradesh, India

Corresponding Author:

P Kavitha
Department of Soil Science and
Agricultural Chemistry, RARS-
Nandyal, ANGRAU, Andhra
Pradesh, India

Comparative evaluation of indigenous glauconitic Nanopotassium and Muriate of potash on soil potassium availability: An incubation study

**Mohan V, P Kavitha, TNVKV Prasad, A Malleswara Reddy, M
Raghavendra, BP Singh, M Dhanunjaya Reddy and MVS Naidu**

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Abstract

The Indian subcontinent lacks high-grade K reserves like carnallite, langbeinite, and polyhalite, which has led India to meet 100% of its potash requirement through imports. This, alongside the continuous depletion of native soil K, necessitates the exploration of sustainable, indigenous alternatives. Glauconite is a widespread, potassium-rich mineral; by leveraging nanotechnology, these indigenous K sources can be used as highly effective alternate K fertilizers. This 90-day laboratory incubation study evaluated the potassium availability and release patterns of synthesized glauconitic nanopotassium (TEM 89 nm size) compared to conventional MOP in a sandy loam soil. Twelve treatments, comprising varying substitution ratios of MOP with nanopotassium, were tested in a Completely Randomized Design with three replications. The available K₂O revealed three distinct phases. In the initial phase (0-15 days), MOP-dominated treatments exhibited a rapid surge in available K₂O, peaking at 103.26 mg kg⁻¹ in the 100% MOP treatment, followed by a steady decline due to the likely irreversible fixation of unutilized K⁺ ions. During the intermediate phase (30-45 days), integrated treatments maintained optimal availability. By the final phase (60-90 days), the available K pool in conventional MOP treatments significantly depleted, whereas nanopotassium-enriched treatments demonstrated a controlled, sustained release. At 90 days, pure nano-based and highly integrated treatments recorded the highest sustained available K₂O (peaking at 98.78 mg kg⁻¹), significantly outperforming the 100% MOP treatment (85.64 mg kg⁻¹). The nanoscale reduction of glauconite exponentially increases its specific surface area, facilitating a continuous, gradual weathering of K into the soil solution. Ultimately, substituting 50% to 70% of conventional MOP with indigenous glauconitic nanopotassium acts as an efficient, slow-release fertilizer, presenting a sustainable soil management strategy to improve long-term nutrient-use efficiency and reduce import dependency.

Keywords: Glauconite, Nanopotassium, Muriate of Potash, Slow-release fertilizer, Soil incubation, Potassium availability

1. Introduction

Potassium (K) is a primary macronutrient essential for maintaining soil fertility and ensuring sustainable agricultural productivity. Within the soil ecosystem, K exists in four distinct pools: soil solution K, exchangeable K, interlayer K, and mineral or structural K. While structural K constitutes 90-98% of total soil potassium, the soil solution K the only form immediately available for plant uptake represents merely 0.1-0.2%. Continuous agricultural intensification combined with lack of K fertilization has led to excessive mining of native soil K reserves, resulting in a gradual decline in soil potassium fertility. Furthermore, the Indian fertilizer market is almost entirely dependent on imported soluble potassium salts, such as muriate of Potash (MOP), importing approximately 4 million tonnes annually due to a lack of high-grade domestic K reserves (Ministry of Chemicals and Fertilizers-GOI, 2022) ^[1]. Glauconite as an indigenous alternative considering the global demand and supply uncertainties, exploring locally available alternate resources is imperative. India possesses significant deposits of glauconite across various sedimentary basins, it was estimated that India has 3,149 million tonnes of glauconite reserves (Ministry of Mines-GOI, 2024) ^[2]. Glauconite is a naturally occurring, dioctahedral, potassium and iron-rich micaceous clay mineral with the generalized chemical formula: of (K,

Na, Ca) (Fe³⁺, Fe²⁺, Al, Mg)₂ (Al, Si)₄ O₁₀ (OH)₂. nH₂O Containing approximately 4-8% K₂O (Odin and Matter, 2003) [3]. Glaucinite represents a massive indigenous mineral resource (Chand and Swami, 2000) [4]. However, its historically poor structural organization and slow-release nature in its native granular form have limited its widespread adoption compared to highly soluble commercial K fertilizers (Annapurna *et al.*, 2017) [5]. Nanotechnological intervention might help in effective usage of glauconite and improve its nutrient release efficiency, nanotechnology offers a significant technical advantage. By manipulating materials at the atomic and molecular scale (typically 1-100 nm), nanomaterials exhibit drastically increased surface areas and enhanced physicochemical reactivity. Transforming bulk glauconite into glauconitic nanopotassium can fundamentally alter its dissolution kinetics, allowing for a controlled, highly efficient release of potassium that minimizes leaching losses and sustains the available soil K pool over time. However, the precise temporal availability of potassium within the soil matrix as influenced by glauconite nanopotassium are not yet fully documented. Therefore, an incubation study was conducted to evaluate the potassium availability patterns of glauconitic nanopotassium in comparison with commercial source MOP, therefore assessing its contribution towards a sustainable alternative to conventional K fertilizers.

2. Material and Methods

2.1. Soil collection and processing

The soil used for the laboratory incubation study was collected from the top 30 cm layer Upon collection, the soil was manually processed and passed through a 2-mm standard sieve to ensure uniform particle size prior to use in the incubation experiment. Prior to the imposition of treatments, the initial physicochemical properties of the revealed that soil was sandy loam in texture, neutral in reaction with a pH of 6.9, a low EC of 0.17 dS m⁻¹, a low OC of 0.27%. Low levels of available N (85.7 mg kg⁻¹) and low available P₂O₅ (17.0 mg kg⁻¹), whereas the available potassium K₂O (ammonium acetate extractable) was categorized as medium at 83.0 mg kg⁻¹.

2.2. Experimental design and incubation setup

The 90 days incubation experiment was aimed to compare conventional muriate of potash (MOP) with glauconite nano potassium and different combinations of these two fertilizers, therefore we have procured MOP (58% K₂O) from local market sources and Glaucinite nanopotassium was synthesized and procured from nanotechnology laboratory, RARS- ANGRAU, Tirupati (fig.1), the estimated K₂O content of glauconite nanopotassium was 6.95% using four acid digestion (Chao and Sanzalone 1992) [6]. And the size of the nano particle was around 89 nm (TEM image as presented in fig.2). The dosage of fertilizer was calculated as to supply 50 kg K₂O ha⁻¹ to the 250 g of the processed soil, 100% MOP require 9.6 mg of MOP and 100% glauconite NanoK require 79.7 mg, the treatments were designed in such a way that 10% replacement at every treatment interval along with an absolute control. The experiment was laid out in a Completely Randomized Design (CRD) comprising 12 treatments with three replications (total of 36 experimental units). For each unit, the processed soil was taken into a 500 ml capacity plastic container equipped with a basal drainage hole to allow for the leaching of excess water. staggered mixing protocol was employed. thoroughly mixed with the respective treatment dose using a glass rod. This moisture level was continuously monitored and maintained throughout the 90-day incubation period. The containers were incubated in a controlled

greenhouse environment, with ambient temperatures maintained between 27 °C and 30 °C and relative humidity ranging from 65% to 75%. Samples were collected and analysed for available potassium at scheduled intervals (0, 15, 30, 45,60, 90 days) over the 90-day duration.



Fig 1: Synthesised indeginous glauconite nanoK, Fig. 2. TEM image of glauconite nanopotassium

Treatment details:

T ₁	:	Control (No application)
T ₂	:	9.6 mg MOP
T ₃	:	79.7 mg glauconite nanoK
T ₄	:	0.96 mg MOP + 71.73 mg glauconite nanoK
T ₅	:	1.92 mg MOP + 63.76 mg through Nano K
T ₆	:	2.88 mg MOP + 55.79 mg glauconite nanoK
T ₇	:	3.84 mg MOP + 47.94 mg glauconite nanoK
T ₈	:	4.8 mg MOP + 39.85 mg glauconite nanoK
T ₉	:	5.76 mg MOP + 31.88 mg glauconite nanoK
T ₁₀	:	6.72 mg MOP + 23.99 mg glauconite nanoK
T ₁₁	:	7.68 mg MOP + 15.99 mg glauconite nanoK
T ₁₂	:	8.64 mg MOP + 7.99 mg glauconite nanoK

3. Results and Discussion

The 90-day incubation experiment revealed that conventional MOP provided a rapid increase in potassium availability during the initial stages, whereas treatments containing higher proportion of glauconite based nano potassium maintained greater potassium availability during the later stages of incubation. The data presented in table 1. and fig. 3.

Table 1: Available K₂O (mg kg⁻¹) at different days during incubation after the imposition of treatments

Treatments	0	15	30	45	60	75	90
T ₁	83.93	82.63	84.12	83.28	83.22	83.88	82.89
T ₂	96.03	103.26	99.94	98.65	88.71	86.33	85.64
T ₃	86.53	87.21	89.45	90.37	92.10	94.26	98.78
T ₄	86.88	87.59	89.84	91.23	91.93	93.74	96.80
T ₅	89.34	90.30	92.76	93.82	94.61	97.82	96.24
T ₆	89.42	90.45	92.51	93.94	96.24	96.60	95.83
T ₇	89.68	91.28	92.84	93.48	93.41	93.81	91.70
T ₈	92.22	94.81	95.90	95.52	96.23	93.25	90.02
T ₉	90.92	95.77	97.97	97.35	101.08	93.13	91.78
T ₁₀	91.91	98.35	101.93	102.13	95.17	91.47	90.13
T ₁₁	92.75	99.65	95.86	91.20	92.82	90.82	89.65
T ₁₂	93.18	100.46	96.23	91.82	88.92	89.66	86.64
SE(m) ±	1.12	1.45	1.46	1.13	1.15	1.18	1.22
CD (0.05)	3.25	4.23	4.26	3.30	3.36	3.45	3.55
CV (%)	2.13	2.76	2.70	2.11	2.13	2.16	2.27

The initial evaluation immediately following treatment imposition (0 days) established a clear baseline directly influenced by the solubility of the respective potassium sources. The available K₂O ranged from a minimum of 83.93 mg kg⁻¹ in

the absolute control (T_1) to a maximum of 96.03 mg kg^{-1} in the 100% conventional fertilizer treatment, T_2 (9.6 mg MOP). Treatments integrating high proportions of MOP also reflected this immediate solubility, with T_{10} ($6.72 \text{ mg MOP} + 23.99 \text{ mg glauconite nanoK}$), T_{11} ($7.68 \text{ mg MOP} + 15.99 \text{ mg glauconite nanoK}$), and T_{12} ($8.64 \text{ mg MOP} + 7.99 \text{ mg glauconite nanoK}$) recording comparatively high initial values of 91.91 , 92.75 , and 93.18 mg kg^{-1} , respectively. Conversely, treatments dominated by the nano-mineral source, such as the sole-nano T_3 ($79.7 \text{ mg glauconite nanoK}$) at 86.53 mg kg^{-1} and T_4 ($0.96 \text{ mg MOP} + 71.73 \text{ mg glauconite nanoK}$) at 86.88 mg kg^{-1} , remained statistically closer to the control. This initial variation is fundamentally rooted in the high water-solubility of chloride-based MOP, which dissociates instantly upon contact with soil moisture. In contrast, the potassium within glauconitic nanopotassium remains securely held within a silicate framework, preventing immediate nutrient dumping and demonstrating its inherent controlled-release capacity.

By 15 days of incubation, a substantial surge in available K_2O was observed, particularly in treatments dominated by conventional fertilizer. Treatment T_2 experienced a steep influx to peak at $103.26 \text{ mg kg}^{-1}$, the highest concentration recorded in the study. Similar surges occurred in T_{12} ($100.46 \text{ mg kg}^{-1}$) and T_{11} (99.65 mg kg^{-1}). While this sudden influx provides abundant K^+ ions, such a rapid concentration spike leaves the dissolved potassium highly susceptible to irreversible lattice fixation within soil clays or, under field conditions, leaching losses. Meanwhile, the integrated treatments began to show the gradual contribution of the nano-source. For example, T_8 ($4.8 \text{ mg MOP} + 39.85 \text{ mg glauconite nanoK}$) increased steadily to reach 94.81 mg kg^{-1} , while the pure nano-source T_3 showed a modest but steady rise to 87.21 mg kg^{-1} . This controlled release mechanism is highly advantageous, as it mitigates the risk of rapid fixation while initiating a steady replenishment of the soil solution pool. The results are conclusive with Bharti (2022) [7].

The 30-day interval marked a critical transitional phase in the potassium release pattern. While T_2 remained high, it exhibited its first notable decline from the day-15 peak, dropping to 99.94 mg kg^{-1} . Similar declines were noted in other high-MOP treatments, with T_{11} dropping to 95.86 mg kg^{-1} and T_{12} to 96.23 mg kg^{-1} . This reduction indicates the gradual depletion of the readily available potassium pool and the onset of fixation into non-exchangeable forms. In stark contrast, treatments containing higher proportions of glauconitic nanopotassium continued a steady upward trajectory. Treatment T_{10} peaked in this window at $101.93 \text{ mg kg}^{-1}$, while T_9 increased to 97.97 mg kg^{-1} , and T_5 rose to 92.76 mg kg^{-1} . This progressive increase highlights that the glauconite nanoparticles, vastly enhanced by their mechanically reduced size and increased surface area, were actively weathering and continuously replenishing the soil solution with K^+ ions, buffering the decline seen in purely soluble sources. Similar results were reported by Rakesh *et al.* (2020) [8].

At 45 days, the influence of conventional MOP continued to wane as the sustained release from the nano-fertilizer became increasingly prominent. The highest available K_2O content firmly shifted away from the 100% MOP treatment to the integrated applications, with T_{10} reaching its absolute peak at $102.13 \text{ mg kg}^{-1}$ and T_9 maintaining a high availability of 97.35

mg kg^{-1} . Meanwhile, T_2 declined further to 98.65 mg kg^{-1} . This stage illustrates the distinct agronomic advantage of partial substitution. Treatments successfully combined the immediate availability of a reduced MOP dose with the sustained, steady-state dissolution of the nanopotassium. As the initial MOP flush was fixed or depleted, the massive specific surface area and elevated reactive sites of the nano-glauconite ensured a continuous mineral weathering process, maintaining optimum potassium availability exactly when conventional sources began to falter, aligning with Bhattacharyya and Poonia (1996) [9].

The 60-day sampling reinforced the shifting dominance toward the integrated and nano-rich treatments. Treatment T_9 recorded the highest availability at $101.08 \text{ mg kg}^{-1}$, while T_6 ($2.88 \text{ mg MOP} + 55.79 \text{ mg glauconite nanoK}$) climbed steadily to 96.24 mg kg^{-1} . Conversely, the purely conventional T_2 suffered a dramatic drop to 88.71 mg kg^{-1} , representing a massive depletion from its earlier peaks. The accelerated decline of MOP treatments compared to the steady climb of the nanopotassium treatments clearly demonstrates that the high surface energy of the nano-sized particles facilitates a prolonged, steady equilibrium between the fixed, exchangeable, and solution pools of soil potassium.

By 75 days of incubation, the limitations of highly soluble, conventional fertilizers under prolonged conditions became glaringly evident. Treatment T_2 recorded only 86.33 mg kg^{-1} , nearly returning to its Day 0 baseline. In contrast, the heavily nano-reliant treatments surged to the forefront. Treatment T_5 secured the highest available K_2O at 97.82 mg kg^{-1} . Notably, other nano-heavy treatments remained highly elevated: T_6 reached 96.60 mg kg^{-1} , and the pure-nano T_3 climbed to 94.26 mg kg^{-1} . The severe decline in MOP-dominated treatments can be directly attributed to the irreversible fixation of unprotected potassium into clay lattices over time. The glauconitic nanopotassium, however, acts as a protective mineral reservoir; its structural potassium is slowly liberated only as the nanoparticle weathers, effectively bypassing the rapid fixation pathway and maintaining a higher net availability in the soil solution.

At the end of incubation (90-days), the sustained release capability of glauconitic nanopotassium was unequivocally established. The purely nano-based Treatment T_3 ($79.7 \text{ mg glauconite nanoK}$) recorded the highest available K_2O at an impressive 98.78 mg kg^{-1} , which was nearly 19% higher than the control (82.89 mg kg^{-1}). It remained statistically at par with a suite of highly nano-enriched treatments, including T_4 (96.80 mg kg^{-1}), T_5 (96.24 mg kg^{-1}), and T_6 (95.83 mg kg^{-1}). These treatments significantly outperformed the conventional T_2 , which had completely degraded down to 85.64 mg kg^{-1} , a value lower than its day 0 starting point. The 90-day trajectory confirms that mechanically reducing glauconite to the nanoscale fundamentally alters its dissolution profile. By exponentially increasing the specific surface area, the nanoparticles permit a slow, continuous release of K^+ that perfectly mirrors the concept of a "smart" slow-release fertilizer. This minimizes wasteful fixation and ensures a steady nutrient supply for extended durations, making partial or full substitution of MOP with glauconitic nanopotassium a highly efficient and sustainable soil management strategy. These results are in strong correlation with Praveen (2018) [10].

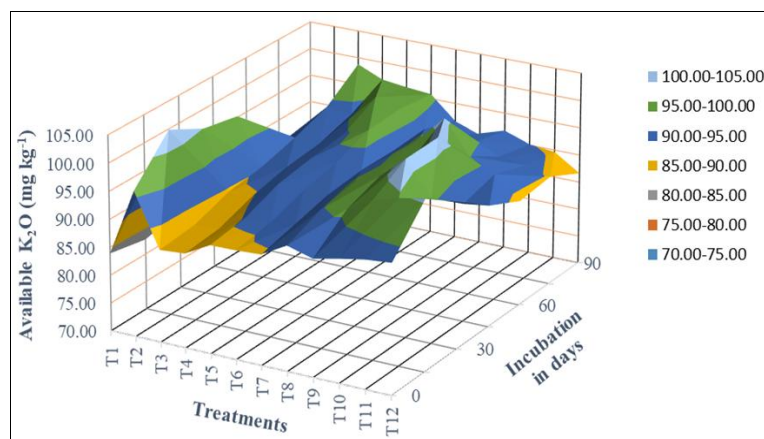


Fig 3: Available K₂O (mg kg⁻¹) at different days during incubation after the imposition of treatment

4. Conclusion

This 90-day laboratory incubation study in sandy loam soil unequivocally demonstrates the superior efficacy of indigenous glauconitic nanopotassium as a sustained-release, "smart" potassium (K) fertilizer. Temporal tracking of available K₂O revealed three distinct release phases. During the initial phase (0–15 days), conventional, highly soluble treatments like Muriate of Potash (MOP) exhibited a rapid dissolution surge, peaking significantly at 15 days (103.26 mg kg⁻¹ for T₂). However, this rapid spike was unsustainable; the abundant, unutilized K⁺ ions rapidly succumbed to irreversible fixation within soil clay lattices, resulting in a continuous and severe decline down to 85.64 mg kg⁻¹ by the study's end. The nanoscale fundamentally alters its dissolution profile, effectively overcoming the limitations of conventional sources. By exponentially increasing the mineral's specific surface area, the nano-sizing process facilitates continuous, gradual weathering. This mechanism bypasses rapid concentration spikes and potential leaching losses. During the intermediate phase (30–45 days) and the final phase (60–90 days), treatments reliant on nanopotassium demonstrated a highly controlled, sustained release mechanism. Ultimately, the pure nanopotassium treatment (T₃) steadily climbed to achieve the highest overall availability at 90 days (98.78 mg kg⁻¹). The study highlights the agronomic superiority of an integrated approach. Treatments substituting 50% to 70% of MOP with glauconitic nanopotassium proved highly effective, balancing the immediate K release from MOP with the steady, long-term mineral dissolution of the nano-source. Ultimately, the substitution of imported, highly soluble K salts with indigenous glauconitic nanopotassium presents a highly viable and ecologically sustainable soil management strategy.

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