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Research Article

EXPANDABLE SOIL PELLETS WITH ENHANCED NUTRIENT (NPK) RELEASE

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ABSTRACT

The present study aimed to develop expandable soil pellets with enhanced nutrient (NPK) release for sustainable agricultural and gardening applications. The pellets were prepared using locally available materials, such as soil, sawdust, and coconut fibres, along with biodegradable binders and essential nutrient sources, including urea, monoammonium phosphate, and potassium chloride. The formulated pellets exhibited desirable physical properties, including moderate bulk density (0.66 g/ml), high water absorption capacity (200%), and gradual disintegration behaviour, indicating good structural stability and suitability for soil fertility. As the pellets were tested in soil, NPK release was observed as a continuous, slow-release process. High nutrient retention percentages (97% for nitrogen and 100% for phosphorus and potassium) indicated minimal nutrient loss and efficient nutrient conservation within the pellets. It was confirmed by the methods Indophenol Blue, Molybdenum Blue, and Tetraphenylborate for NPK, respectively. This gradual release behaviour helps in reducing nutrient leaching and ensures continuous nutrient availability. The results indicate that expandable soil pellets are a viable, sustainable, and cost-effective substitute for traditional fertilisers for improving soil fertility.

Keywords: Biochar, Coconut fibre, Controlled release fertilizer, Expandable soil pellets, NPK release.

INTRODUCTION

Plants used in horticulture and ornamental gardening are gaining increasing importance due to their nutritional value, aesthetic appeal, and vital role in enhancing soil health and maintaining ecological stability. Household gardens serve as a direct source of fresh vegetables and herbs, reducing dependence on commercial supply chains and significantly enhancing food security in urban settings (Katwal *et al.,* 2025). Beyond food production, these plants improve soil fertility through root exudates, organic matter cycling, and complex biological interactions, thereby promoting long-term sustainability of terrestrial ecosystems (Farha *et al.,* 2023). Urban households face persistent challenges in managing organic waste, particularly fruit and vegetable peels, which when improperly discarded create breeding grounds for pathogens, attract pests, and emit greenhouse gases (Sung-inthara *et al.,* 2024). Repurposing such waste into structured expandable soil pellets offers dual benefits: mitigating microbial hazards while transforming waste into a valuable soil amendment. This approach embodies circular economy principles, converting household discards into resources that support localised food production and environmental health. Strategic incorporation of natural fibres such as coconut coir and sawdust significantly enhances the mechanical integrity and biological performance of soil pellets. Sawdust fibres improve soil shear strength, water retention capacity, and bearing ability, while coconut coir provides structural stability and controlled biodegradability (Medina-Martinez *et al.,* 2023). Balanced NPK nutrition forms the cornerstone of optimal plant growth, with nitrogen driving vegetative expansion and chlorophyll biosynthesis, phosphorus supporting root proliferation and energy metabolism, and potassium regulating osmotic balance, enzyme activation, and pathogen resistance (Farha *et al.,* 2023; Rohith *et al.,* 2023). Conventional fertilisers suffer from rapid nutrient leaching and inefficient delivery, leading to environmental pollution and economic waste. Controlled-release

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formulations embedded in expandable pellets synchronise nutrient availability with plant demand, maximising uptake efficiency while minimising ecological footprint (Cheng *et al.,* 2024). Soil amendment pellets show great promise in agriculture, with studies achieving high production rates and good density using simple flat-die mills. They enable slow release of NPK nutrients through biochar's adsorption properties, improving soil quality and water retention (Wang *et al.,* 2023; Rohith *et al.,* 2023). The present study aimed to produce expandable soil pellets from local materials, characterise their properties and nutrient-release patterns, and evaluate their effects on wheat (*Triticum aestivum*) and mustard (*Brassica juncea*) growth under home-gardening conditions. These model crops are well-suited for home gardening due to their rapid growth cycles, high nutritional value, and adaptability to local conditions in the semi-arid climate of Chhatrapati Sambhajinagar.

MATERIALS AND METHODS

Preparation of Raw Materials

Soil was air-dried, ground, and sieved to remove debris (≤2 mm). Biochar was added as a nutrient adsorbent at 10% (w/w) of total solid content. Cellulose or starch was added as a biodegradable binder at 5% (w/w), and soil constituted the remaining 85% (w/w) of the formulation. All components were mixed thoroughly to obtain a homogeneous mixture (Wang *et al.,* 2023; Sung-inthara *et al.,* 2024).

Formulation of Expandable Soil Pellets

Distilled water was added gradually to obtain a workable consistency. Pellets were formed by manual extrusion or hand rolling into a uniform size and air-dried at room temperature until constant weight (Rohith *et al.,* 2023). The pellet formulation used per batch is presented in Table 1.

Physical Characterisation

Pellet size measurement

The dimensions of the prepared soil pellets were measured using a ruler. The length, width, and thickness of each pellet were recorded.

Bulk density determination

Bulk density was calculated as the dry weight of the pellet divided by its volume, expressed in g/cm³.

Table 1. Pellet formulation ingredients and quantities.

Ingredient	Quantity (g)
Soil	35
Sawdust	15
Coconut fibre	15
Starch	8
Monoammonium Phosphate (MAP)	3.9
Urea	1.4
Potassium Chloride	2
Zinc Sulfate	0.7
Ferrous Sulphate	0.7

Water absorption test (24 hours)

The pellets were weighed before immersion in water, kept in water for 24 hours, removed, and excess surface water was blotted off. Water absorption was calculated from the increase in mass.

Disintegration time in water

Pellets were immersed in distilled water and observed at regular intervals. Partial disintegration was noted when cracks, softening, or breakage of the pellet structure became visible. Fifty percent disintegration was considered when approximately half of the pellet structure had broken down (Matkowski *et al.,* 2020).

Chemical and Nutrient Analysis: pH Measurement

Pellet leachate was prepared by soaking pellets in distilled water. pH was measured using a calibrated pH meter.

Nitrogen Estimation (Indophenol Blue Method - UV-Vis)

Pellet leachate was reacted with phenol and hypochlorite reagents. Indophenol blue colour was developed under alkaline conditions. Absorbance was measured using a UV-Visible spectrophotometer and nitrogen concentration was calculated using a standard curve (Wang *et al.,* 2023; Lu *et al.,* 2013).

Phosphorus Estimation (Molybdenum Blue Method - UV-Vis)

Pellet leachate was reacted with ammonium molybdate reagent to form a phosphomolybdenum blue complex. Absorbance was measured and phosphorus concentration was calculated using a standard curve (Ota and Kawano, 2017).

Potassium Estimation (Tetraphenylborate Method)

Pellet leachate was reacted with sodium tetraphenylborate (NaTPB) reagent to form a potassium-tetraphenylborate complex. Absorbance was measured and potassium concentration was calculated using a standard curve.

NPK Release Study

Pellets were hydrated for fixed time intervals (Day 1 and Day 3) and analysed for N, P, and K by UV-Vis spectrophotometric methods (Rohith *et al.,* 2023; Wang *et al.,* 2023).

Table 2. Percentage NPK retention from soil pellets on Day 1 and Day 3.

Nutrient	Day 1 (%)	Day 3 (%)
Nitrogen	97.8	97.0
Phosphorus	99.66	99.59
Potassium	99.981	99.954

Table 3. Percentage NPK released from soil pellets on Day 1 and Day 3.

Nutrient	Day 1 (%)	Day 3 (%)
Nitrogen	2.18	3.00
Phosphorus	0.34	0.41
Potassium	0.019	0.046

RESULTS AND DISCUSSION

Soil was sun-dried to reduce moisture and microbial load, then sterilised in a hot-air oven. Soil sterility was confirmed by spreading soil samples on nutrient agar plates and observing for microbial growth after incubation. Sawdust and coconut fibres were similarly sterilised using a hot-air oven to eliminate contaminants. Sterilised soil, sawdust, and powdered coconut fibres were then combined for pellet preparation. The physical properties of the prepared pellets were as follows: pellet size: 10 × 5 × 5 cm; bulk density: 0.66 g/ml; water absorption rate after 24 hrs: 200%; partial disintegration time: 2 hours; 50% disintegration time: 10-12 hours. On Day 1, the nitrogen concentration in the solution was recorded as 9.43 mg N/L. By Day 3, the concentration increased to 12.92 mg N/L. The gradual increase suggests that the pellets do not release nitrogen instantaneously but instead follow a sustained-release mechanism. On Day 1, the phosphorus concentration was recorded as 2.79 mg P/L. By Day 3, the concentration increased to 3.40 mg P/L, indicating a gradual and sustained release from the pellets. On Day 1, the potassium concentration in the solution was recorded as 0.381 mg K/L. By Day 3, the concentration increased to 0.925 mg K/L, confirming a controlled release pattern. The percentages of NPK retention and release on Day 1 and Day 3 are presented in Tables 2 and 3, respectively.

The results indicate that the prepared soil pellets exhibit very high retention of essential nutrients (nitrogen, phosphorus, and potassium) with only a small percentage being released into water over the observed period. From Day 1 to Day 3, there is a slight decrease in retention and a corresponding small increase in release for all three nutrients. This trend suggests that nutrients are gradually diffusing from the soil pellets into the surrounding medium rather than being released rapidly, demonstrating controlled slow-release characteristics. The results of the present study demonstrate the successful fabrication of soil pellets with desirable physical properties and controlled nutrient release. Sterilisation of soil, sawdust, and coconut fibres was performed to remove microbial contaminants, ensuring consistency and avoiding unwanted biological interference during storage and use. Coconut fibres were converted to a powdered form, facilitating homogenisation and enhancing the structural integrity of the pellets, supporting findings on the use of natural fibres to improve material performance (Medina-Martinez *et al.,* 2023). The prepared pellets exhibited an intermediate bulk density of 0.66 g/ml, indicating sufficient compactness and porosity to allow aeration and water retention. The high-water absorption capacity (200%) indicates suitability for water-restricted conditions, consistent with research showing enhanced moisture retention in biochar and fibrous materials (Wang *et al.,* 2023). Gradual disintegration behaviour, with partial disintegration observed within 2 hours and 50% disintegration within 10-12 hours, confirms that the pellets are structurally stable and capable of delivering nutrients over an extended period (Rohith *et al.,* 2023). The progressive increase in concentrations of nitrogen, phosphorus, and potassium from Day 1 to Day 3 indicates a diffusion-based release process rather than leaching, consistent with prior results showing that pelletised formulations provide nutrients in a delayed and prolonged manner (Sung-inthara *et al.,* 2024). High nutrient retention levels (more than 97% for nitrogen and nearly 100% for phosphorus and potassium) and the low but rising release rates are clear indicators of the pellets' efficiency in conserving nutrients and providing gradual availability. Such controlled nutrient-release systems minimise nutrient loss, increase nutrient use efficiency, and provide plants with a continuous supply of nutrients (Cheng *et al.,* 2024), which is especially relevant in semi-arid regions where traditional fertilisers can lead to rapid nutrient depletion due to erratic rainfall (Farha *et al.,* 2023). Overall, the produced soil pellets exhibit appropriate physical stability, high nutrient retention, and slow-release characteristics. These properties qualify them as a promising and sustainable option for enhanced soil fertility and environmentally friendly agricultural practices (Katwal *et al.,* 2025).

CONCLUSION

This study successfully developed expandable soil pellets from soil, natural fibres, and sources of nitrogen, phosphorus, and potassium. The prepared pellets were physically stable, exhibited high water-absorbing capacity, and showed low disintegration in water. Nutrient analysis demonstrated a steady and gradual release rate of NPK over time, high nutrient retention, and minimal rapid loss. These findings confirm that the developed pellets can effectively enhance nutrient availability and reduce nutrient leaching. Expandable soil pellets manufactured from locally available materials have great potential as sustainable soil additives for home gardening and small-scale agriculture.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declare that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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