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B Bhanukiran Reddy
 Department of Soil Science
 and Agricultural Chemistry,
 Agricultural College, PJTSAU,
 Polasa, Jagtial, Telangana,
 India

K Chandrashaker
 Department of Soil Science
 and Agricultural Chemistry,
 Agricultural College, PJTSAU,
 Polasa, Jagtial, Telangana,
 India

B Raju
 Department of Soil Science
 and Agricultural Chemistry,
 Agricultural College, PJTSAU,
 Polasa, Jagtial, Telangana,
 India

KB Suneetha Devi
 Department of Soil Science
 and Agricultural Chemistry,
 Agricultural College, PJTSAU,
 Polasa, Jagtial, Telangana,
 India

Changes in nutrient status (N, P, K, and S) during bio-conservation of diverse crop residues as influenced by microbial inoculants

B Bhanukiran Reddy¹, K Chandrashaker², B Raju³, KB Suneetha Devi⁴

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ABSTRACT

Efficient management of crop residues is essential for sustaining soil fertility and minimizing environmental degradation in intensive agricultural systems. The present study investigated the changes in nutrient status, specifically nitrogen (N), phosphorus (P), potassium (K), and sulphur (S), during the bio-conservation of selected crop residues as influenced by microbial inoculants. A field experiment was conducted during kharif 2019 at Agricultural College Farm, Jagtial, Telangana, using a factorial randomized block design with three replications. Four crop residues, namely paddy (*Oryza sativa*), sesamum (*Sesamum indicum*), redgram (*Cajanus cajan*), and cotton (*Gossypium hirsutum*), were composted under three treatments comprising control, Decomposer-1, and Decomposer-2. The results revealed a progressive increase in nutrient concentrations over the 120-day composting period. Among the residues, redgram recorded the highest nitrogen (1.32%) and phosphorus (0.49%) content, paddy exhibited maximum potassium (2.04%), and sesamum showed the highest sulphur concentration (1.48%). The application of microbial inoculants significantly enhanced nutrient enrichment, with Decomposer-1 consistently outperforming Decomposer-2 and control treatments. The increase in nutrient content was primarily attributed to microbial decomposition, mineralization processes, and the concentration effect resulting from carbon loss as CO₂ (Tiquia and Tam, 2000; Bhattacharjya *et al.*, 2021). The study demonstrates that microbial-assisted composting improves the quality of compost and provides a sustainable approach for recycling crop residues and enhancing soil fertility.

Keywords: Crop residues, Microbial inoculants, Nutrient status, Bio-conservation, Composting

Introduction

The maintenance of soil health is fundamental to sustainable agricultural intensification and long-term food security. In recent decades, declining soil organic matter and depletion of essential plant nutrients have emerged as critical constraints to crop productivity, particularly under intensive farming systems (Mandal *et al.*, 2004; Meena *et al.*, 2020) [1, 2]. In India, the annual generation of agricultural residues exceeds 500 million tonnes, a substantial portion of which remains either underutilized or is disposed of through open-field burning (NPMCR, 2014) [3]. This practice not only contributes to environmental pollution through greenhouse gas emissions but also results in significant loss of valuable plant nutrients. It has been reported that burning leads to the volatilization of nearly 80 per cent of nitrogen and 50–60 per cent of sulphur, while also reducing the availability of phosphorus and potassium (Bhuvaneshwari *et al.*, 2019; Dube, 2022) [4, 5].

In the Northern Telangana Zone, large quantities of residues from crops such as paddy (*Oryza sativa*), cotton (*Gossypium hirsutum*), sesamum (*Sesamum indicum*), and redgram (*Cajanus cajan*) accumulate annually, posing both environmental and management challenges. Direct incorporation of these residues into soil is often constrained by their high carbon-to-nitrogen (C:N) ratio and the presence of recalcitrant compounds such as lignin and cellulose, which slow down decomposition and may lead to temporary nutrient immobilization (Gaind *et al.*, 2007) [6]. Composting or bio-conservation of crop residues offers a viable alternative, enabling the conversion of bulky organic waste into stable, nutrient-enriched organic manure.

Composting is a microbially mediated process in which complex organic materials are decomposed into simpler forms. During this process, carbon is lost as carbon dioxide, resulting in a reduction in mass and a corresponding increase in the concentration of nutrients such as nitrogen, phosphorus, potassium, and sulphur, a phenomenon often referred to as the “concentration effect” (Tiquia *et al.*, 2000; Bhattacharjya *et al.*, 2021) [8, 7]. The efficiency of this process is greatly influenced by the microbial community involved. The use of microbial inoculants, including fungi such as *Trichoderma* spp. and ligninolytic organisms, along with bacteria capable of solubilizing phosphorus and zinc, has been shown to accelerate decomposition and enhance nutrient availability (Kumar *et al.*, 2020; Sood *et al.*, 2022) [9, 10].

While nitrogen dynamics during composting have been extensively studied, comparatively less attention has been given to the transformation of phosphorus, potassium, and sulphur, which are equally important for balanced plant nutrition. Therefore, the present investigation was undertaken to study the changes in the con

Corresponding Author:

B Bhanukiran Reddy
 Department of Soil Science
 and Agricultural
 Chemistry, Agricultural
 College, PJTSAU, Polasa,
 Jagtial, Telangana, India

centration of these major nutrients during composting of different crop residues and to evaluate the effectiveness of microbial inoculants in enhancing nutrient enrichment under the agro-climatic conditions of Northern Telangana.

Materials and methods

The experiment entitled “Performance of Selected Decomposer Inoculations on Bio-conservation of Crop Residues” was conducted during the kharif season of 2019 at the College Farm, Agricultural College, Polasa, Jagtial, Telangana. The experimental site is situated at an altitude of 243.4 m above mean sea level, with geographical coordinates of 18°49'40" N latitude and 78°56'45" E longitude, representing the Northern Telangana agro-climatic zone.

The study was laid out in a randomized block design with a factorial concept and replicated three times. Four types of crop residues, namely paddy straw, sesamum stalks, redgram stalks, and cotton stalks, were used as the primary substrates. These residues were collected from the Regional Agricultural Research Station, Jagtial, and were chopped into pieces of 10–15 cm length prior to composting. Initial samples were oven-dried, powdered, and analyzed for their chemical composition, including carbon, nitrogen, phosphorus, potassium, and sulphur content, following standard procedures.

Two microbial inoculants along with a control were used for composting. The control consisted of the conventional heap method with periodic turning as described by FAO (1980) [11]. Decomposer-1 comprised a consortium of *Trichoderma reesei*, xylan-degrading bacteria, phosphorus-solubilizing bacteria (PSB), and zinc-solubilizing bacteria, whereas Decomposer-2 included *Aspergillus nidulans*, *Trichoderma viride*, and *Phanerochaete chrysosporium*. Microbial cultures were prepared using jaggery as a substrate and incubated for appropriate durations prior to application (Krishan, 2015) [12].

Each compost heap measured 2 m in length and 1 m in width, containing 10 kg of crop residue. The residues were layered and inoculated with microbial consortia, and moisture content was maintained at approximately 60 per cent throughout the composting period. The heaps were turned at regular intervals to ensure proper aeration.

Samples were collected at periodic intervals up to 120 days after decomposition. Nitrogen content was determined at 10-day intervals using the micro-Kjeldahl method (Jackson, 1973) [13], while phosphorus, potassium, and sulphur were analyzed at 30-day intervals using standard spectrophotometric and flame photometric techniques (Bhargava *et al.*, 1993; Muhr *et al.*, 1963; Cottin *et al.*, 1979) [14, 15, 16]. The experimental data were subjected to statistical analysis using the analysis of variance (ANOVA) technique as described by Gomez *et al.* (1984) [17].

Results and discussion

The initial chemical composition of the crop residues revealed significant variability among substrates. Paddy straw exhibited the highest carbon content (48.2%) and C:N ratio (71.9), indicating a slower rate of decomposition. In contrast, redgram residues recorded the highest nitrogen (1.15%) and phosphorus (0.31%) content, while sesamum residues were particularly rich in sulphur (1.21%). These inherent differences in chemical composition played a crucial role in determining the rate of decomposition and nutrient transformation during composting.

The nitrogen content of composting materials increased progressively over the decomposition period, irrespective of the residue type and treatment. Among the crop residues, redgram consistently recorded the highest nitrogen content at all stages, reaching a maximum of 1.32 per cent at 120 days after decomposition. Paddy straw, on the other hand, recorded the lowest nitrogen values, which can be attributed to its high C:N ratio and slower microbial degradation. The application of microbial inoculants significantly influenced nitrogen dynamics, with Decomposer-1 recording higher nitrogen content compared to Decomposer-2 and control treatments.

The observed increase in nitrogen content during composting can be explained by several mechanisms. The loss of carbon as carbon diox-

ide during microbial respiration leads to a reduction in total mass, thereby increasing the relative concentration of nitrogen (Viel *et al.*, 1987) [18]. Additionally, microbial synthesis of cellular components and enzymes contributes to the accumulation of nitrogen in the compost matrix (Zhu, 2007; Choudhary *et al.*, 2016) [20, 19]. Similar findings have been reported by Rajabanshi *et al.* (1998) [21] and Balakrishna *et al.* (2007) [22], who attributed the increase in nitrogen content to enhanced microbial activity and organic matter decomposition.

Phosphorus content also showed a consistent increase throughout the composting period. Redgram residues recorded the highest phosphorus concentration, reaching 0.49 per cent at 120 days. The application of Decomposer-1 significantly enhanced phosphorus content compared to other treatments. This increase can be attributed to the mineralization of organic phosphorus compounds and the solubilization of insoluble phosphates by phosphorus-solubilizing microorganisms present in the inoculant (Sharma *et al.*, 2012). The reduction in carbon content during decomposition further contributes to the concentration of phosphorus in the compost (Summerell *et al.*, 1989) [23].

Potassium content exhibited a similar increasing trend during composting. Paddy straw recorded the highest potassium content, increasing from 1.72 per cent initially to 2.00 per cent at 120 days. Unlike nitrogen and phosphorus, potassium is not structurally bound in organic compounds and is present in ionic form within plant tissues. Therefore, its increase during composting is primarily due to the release from decomposing plant material and the concentration effect resulting from mass loss (Kayikcioglu *et al.*, 2011) [24]. The application of microbial inoculants further facilitated the release of potassium by accelerating decomposition.

Sulphur dynamics followed a comparable pattern, with sesamum residues recording the highest sulphur content throughout the composting period. The sulphur content increased due to the mineralization of organic sulphur compounds and microbial oxidation processes. Decomposer-1 significantly enhanced sulphur availability, likely due to increased microbial activity and enzymatic breakdown of sulphur-containing compounds. Similar observations have been reported in earlier studies, where microbial decomposition was found to increase sulphur content in compost through mineralization processes.

Overall, the results clearly demonstrate that both crop residue type and microbial inoculation significantly influence nutrient dynamics during composting. Decomposer-1 consistently outperformed Decomposer-2 and control treatments in enhancing the concentration of nitrogen, phosphorus, potassium, and sulphur. This can be attributed to the presence of a diverse microbial consortium capable of degrading complex organic materials and transforming nutrients into more stable and available forms.

Conclusion

The present study highlights the effectiveness of microbial inoculation in enhancing nutrient dynamics during composting of crop residues. The concentration of nitrogen, phosphorus, potassium, and sulphur increased significantly over the decomposition period, with the magnitude of increase varying among different crop residues. Redgram residues were found to be superior in terms of nitrogen and phosphorus content, while paddy straw and sesamum residues were rich in potassium and sulphur, respectively. Among the treatments, Decomposer-1 proved to be the most effective in improving nutrient content, owing to its diverse microbial composition and functional capabilities. The increase in nutrient concentration during composting was primarily attributed to microbial degradation of organic matter, loss of carbon as carbon dioxide, and subsequent concentration and mineralization of nutrients. The findings of this study suggest that microbial-assisted composting of crop residues can serve as a sustainable and environmentally friendly approach for improving soil fertility and managing agricultural waste. Adoption of such practices can reduce dependence on chemical fertilizers, enhance nutrient recycling, and contribute to sustainable agricultural systems in the Northern Telangana region and similar agro-ecological zones.

Table 1. Effect of crop residues and decomposers on total nitrogen content (%) during composting

Crop Residues	Period of composting (days)												
	0	10	20	30	40	50	60	70	80	90	100	110	120
S ₁	0.67	0.69	0.71	0.74	0.75	0.81	0.86	0.89	0.90	0.92	0.96	1.02	1.06
S ₂	1.07	1.08	1.09	1.10	1.12	1.13	1.14	1.15	1.17	1.18	1.19	1.20	1.21
S ₃	1.15	1.15	1.16	1.17	1.17	1.19	1.19	1.20	1.21	1.21	1.24	1.24	1.26
S ₄	0.91	0.92	0.92	0.93	0.93	0.94	0.94	0.95	0.96	0.97	0.97	0.99	1.00
SE _m ±	0.012	0.012	0.013	0.013	0.013	0.013	0.014	0.013	0.013	0.013	0.015	0.015	0.014
CD(P = 0.05)	0.035	0.036	0.039	0.039	0.037	0.037	0.041	0.038	0.038	0.039	0.043	0.044	0.042
Decomposer													
D ₁	0.95	0.96	0.96	0.97	0.98	0.99	1.02	1.03	1.04	1.05	1.06	1.08	1.09
D ₂	0.95	0.97	0.98	1.01	1.02	1.04	1.05	1.06	1.07	1.09	1.12	1.15	1.18
D ₃	0.95	0.96	0.97	0.98	1.00	1.02	1.03	1.05	1.06	1.07	1.09	1.11	1.13
SE _m ±	0.010	0.011	0.011	0.011	0.011	0.011	0.012	0.011	0.011	0.012	0.013	0.013	0.012
CD(P = 0.05)	NS	NS	NS	0.034	0.032	0.032	NS	NS	NS	0.034	0.037	0.038	0.036
Interactions													
S ₁ D ₁	0.67	0.68	0.69	0.70	0.71	0.73	0.83	0.85	0.85	0.87	0.89	0.94	0.95
S ₁ D ₂	0.67	0.70	0.72	0.79	0.81	0.89	0.90	0.92	0.94	0.96	1.01	1.09	1.15
S ₁ D ₃	0.67	0.69	0.71	0.72	0.74	0.82	0.84	0.90	0.92	0.93	0.98	1.02	1.07
S ₂ D ₁	1.07	1.08	1.08	1.09	1.09	1.11	1.14	1.15	1.16	1.17	1.18	1.18	1.19
S ₂ D ₂	1.07	1.09	1.09	1.13	1.14	1.15	1.15	1.16	1.17	1.19	1.20	1.22	1.23
S ₂ D ₃	1.07	1.08	1.09	1.09	1.13	1.14	1.14	1.13	1.17	1.17	1.19	1.19	1.21
S ₃ D ₁	1.15	1.15	1.16	1.16	1.17	1.17	1.18	1.19	1.19	1.20	1.20	1.21	1.22
S ₃ D ₂	1.15	1.16	1.17	1.18	1.18	1.20	1.20	1.21	1.22	1.22	1.29	1.29	1.32
S ₃ D ₃	1.15	1.16	1.16	1.17	1.18	1.19	1.20	1.20	1.21	1.22	1.22	1.23	1.24
S ₄ D ₁	0.91	0.92	0.92	0.92	0.93	0.94	0.94	0.95	0.95	0.96	0.96	0.98	0.99
S ₄ D ₂	0.91	0.92	0.92	0.93	0.94	0.95	0.95	0.96	0.96	0.98	0.99	0.99	1.01
S ₄ D ₃	0.91	0.92	0.92	0.93	0.93	0.94	0.95	0.95	0.96	0.96	0.97	0.99	1.00
SE _m ±	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02
CD(P = 0.05)	0.06	0.06	0.07	0.07	0.06	0.06	0.07	0.07	0.07	0.07	0.07	0.08	0.07
S ₁ : Paddy straw	3.79	3.79	4.09	4.04	3.80	3.72	4.03	3.71	3.72	3.77	4.06	4.03	3.79
S ₂ : Sesum stalks													
S ₃ : Radgram stalks													
S ₄ : Cotton Stalks													
D ₁ : Control													
D ₂ : decomposer-1													
D ₃ : decomposer-2													
CV (%)													

Table 2. Effect of crop residues and decomposers on Phosphorous content (%) during composting

Crop Residues	Period of composting (days)				
	0	30	60	90	120
S ₁	0.16	0.23	0.29	0.32	0.34
S ₂	0.15	0.20	0.25	0.29	0.33
S ₃	0.31	0.33	0.37	0.42	0.44
S ₄	0.18	0.22	0.25	0.29	0.34
SE _m ±	0.001	0.003	0.004	0.004	0.005
CD(P = 0.05)	NS	0.009	0.011	0.012	0.014
Decomposer					
D ₁	0.20	0.22	0.26	0.29	0.32
D ₂	0.20	0.27	0.31	0.37	0.40
D ₃	0.20	0.24	0.30	0.33	0.37
SE _m ±	0.001	0.003	0.003	0.004	0.004
CD(P = 0.05)	NS	0.008	0.009	0.011	0.012
Interactions					
S ₁ D ₁	0.16	0.20	0.25	0.28	0.30
S ₁ D ₂	0.16	0.26	0.32	0.35	0.38
S ₁ D ₃	0.16	0.22	0.30	0.34	0.35
S ₂ D ₁	0.15	0.17	0.24	0.27	0.31
S ₂ D ₂	0.15	0.24	0.27	0.32	0.35
S ₂ D ₃	0.15	0.18	0.25	0.27	0.34
S ₃ D ₁	0.31	0.32	0.34	0.36	0.38

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Crop Residues	Period of composting (days)				
	0	30	60	90	120
S ₃ D ₂	0.31	0.34	0.39	0.46	0.49
S ₃ D ₃	0.31	0.33	0.38	0.44	0.46
S ₄ D ₁	0.18	0.20	0.23	0.25	0.28
S ₄ D ₂	0.18	0.24	0.27	0.35	0.39
S ₄ D ₃	0.18	0.22	0.25	0.27	0.34
SE _m ±	0.002	0.005	0.006	0.007	0.008
CD(P = 0.05)	0.007	0.016	0.019	0.021	0.024
CV (%)	2.02	3.82	3.77	3.80	3.83

S₁: Paddy straw S₂: *Sesamum* stalks S₃: Redgram stalks S₄: Cotton Stalks

D₁: Control D₂: decomposer-1 D₃: decomposer-2

Table 3. Effect of crop residues and decomposers on Potassium content (%) during composting

Crop Residues	Period of composting (days)				
	0	30	60	90	120
S ₁	1.72	1.80	1.85	1.90	2.00
S ₂	0.29	0.35	0.45	0.55	0.66
S ₃	0.38	0.47	0.54	0.65	0.75
S ₄	0.68	0.77	0.93	1.03	1.08
SE _m ±	0.011	0.013	0.014	0.014	0.016
CD(P = 0.05)	0.033	0.039	0.040	0.041	0.048
Decomposer					
D ₁	0.77	0.81	0.89	0.95	1.04
D ₂	0.77	0.88	0.99	1.09	1.19
D ₃	0.77	0.85	0.95	1.05	1.14
SE _m ±	0.010	0.012	0.012	0.012	0.014
CD(P = 0.05)	NS	0.034	0.035	0.036	0.041
Interactions					
S ₁ D ₁	1.72	1.77	1.82	1.86	1.95
S ₁ D ₂	1.72	1.83	1.88	1.94	2.04
S ₁ D ₃	1.72	1.81	1.85	1.91	2.00
S ₂ D ₁	0.29	0.33	0.38	0.42	0.50
S ₂ D ₂	0.29	0.38	0.51	0.63	0.78
S ₂ D ₃	0.29	0.35	0.46	0.60	0.69
S ₃ D ₁	0.38	0.43	0.51	0.62	0.70
S ₃ D ₂	0.38	0.51	0.58	0.69	0.81
S ₃ D ₃	0.38	0.46	0.54	0.64	0.74
S ₄ D ₁	0.68	0.72	0.83	0.91	0.99
S ₄ D ₂	0.68	0.80	0.99	1.11	1.13
S ₄ D ₃	0.68	0.78	0.96	1.06	1.11
SE _m ±	0.019	0.023	0.024	0.024	0.028
CD(P = 0.05)	0.056	0.068	0.070	0.071	0.082
CV (%)	4.34	4.75	4.39	4.09	4.34

S₁: Paddy straw S₂: *Sesamum* stalks S₃: Redgram stalks S₄: Cotton Stalks

D₁: Control D₂: decomposer-1 D₃: decomposer-2

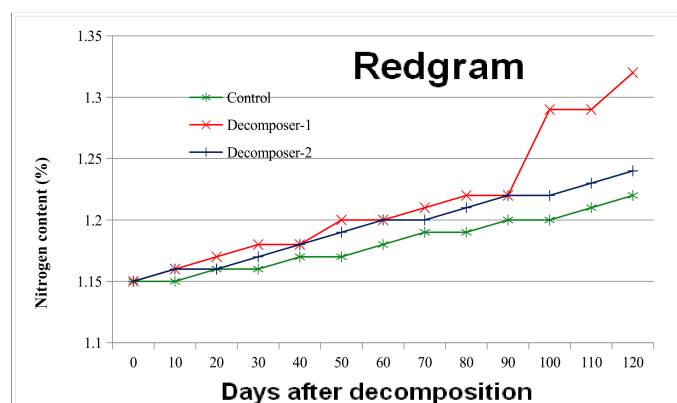
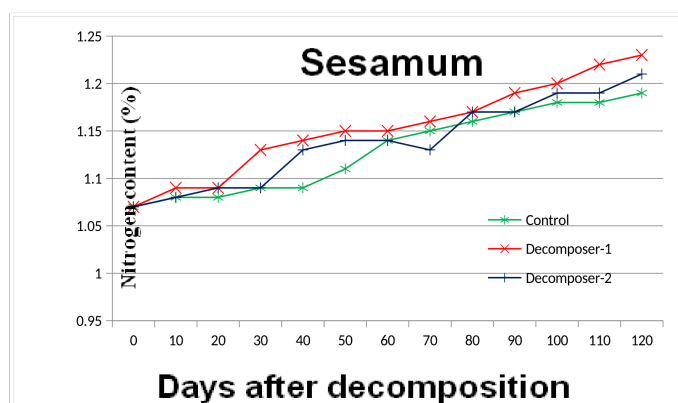
Table 4. Effect of crop residues and decomposers on Sulphur content (%) during composting

Crop Residues	Period of composting (days)				
	0	30	60	90	120
S ₁	0.16	0.19	0.25	0.28	0.30
S ₂	1.21	1.26	1.34	1.41	1.44
S ₃	0.23	0.26	0.32	0.38	0.41
S ₄	0.17	0.21	0.23	0.26	0.29
SE _m ±	0.004	0.004	0.004	0.005	0.005
CD(P = 0.05)	0.012	0.012	0.013	0.013	0.013

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Crop Residues	Period of composting (days)				
	0	30	60	90	120
Decomposer					
D ₁	0.44	0.46	0.51	0.55	0.57
D ₂	0.44	0.50	0.57	0.61	0.64
D ₃	0.44	0.49	0.54	0.59	0.62
SE _m ±	0.004	0.004	0.004	0.004	0.004
CD(P = 0.05)	NS	0.011	0.011	0.011	0.011
Interactions					
S ₁ D ₁	0.16	0.17	0.21	0.25	0.27
S ₁ D ₂	0.16	0.21	0.28	0.30	0.33
S ₁ D ₃	0.16	0.20	0.26	0.28	0.30
S ₂ D ₁	1.21	1.23	1.30	1.36	1.39
S ₂ D ₂	1.21	1.28	1.38	1.45	1.48
S ₂ D ₃	1.21	1.27	1.35	1.43	1.45
S ₃ D ₁	0.23	0.24	0.29	0.33	0.37
S ₃ D ₂	0.23	0.27	0.35	0.42	0.44
S ₃ D ₃	0.23	0.26	0.33	0.39	0.42
S ₄ D ₁	0.17	0.19	0.22	0.24	0.26
S ₄ D ₂	0.17	0.23	0.25	0.28	0.31
S ₄ D ₃	0.17	0.22	0.23	0.26	0.30
SE _m ±	0.007	0.007	0.007	0.008	0.008
CD(P = 0.05)	0.021	0.021	0.022	0.023	0.023
CV (%)	2.75	2.62	2.42	2.32	2.22

S₁: Paddy straw S₂: Sesamum stalks S₃: Redgram stalks S₄: Cotton Stalks



D₁: Control D₂: decomposer-1 D₃: decomposer-2

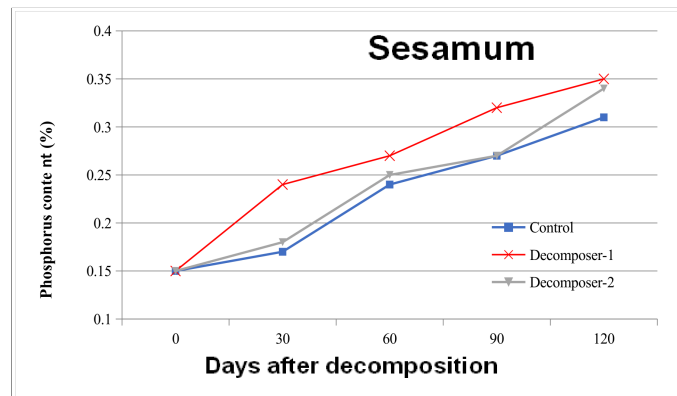
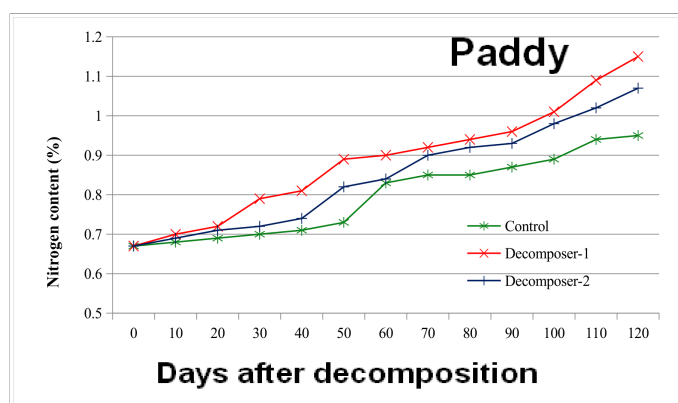


Figure 1. Total nitrogen content (%) of composting material as influenced by crop residues and decomposers

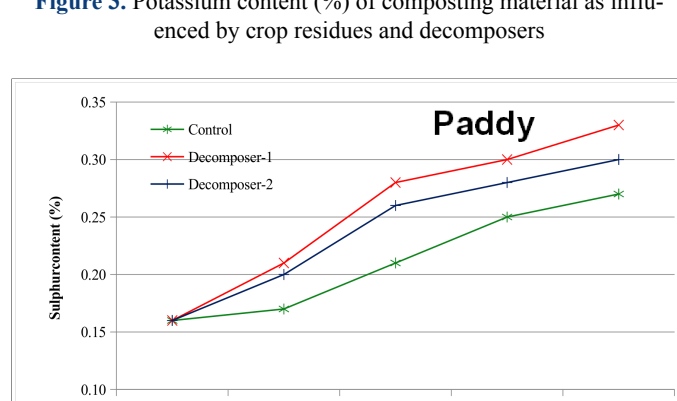
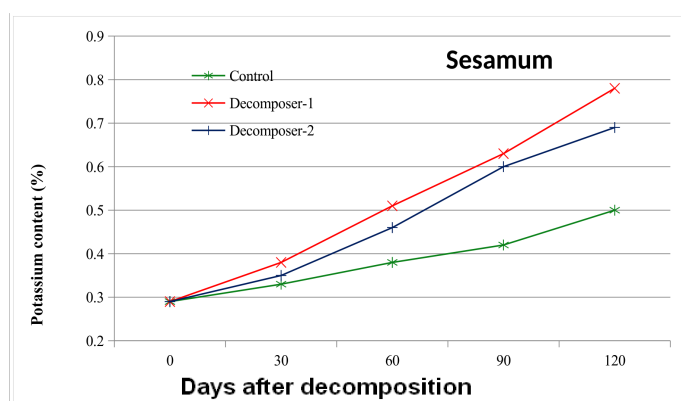
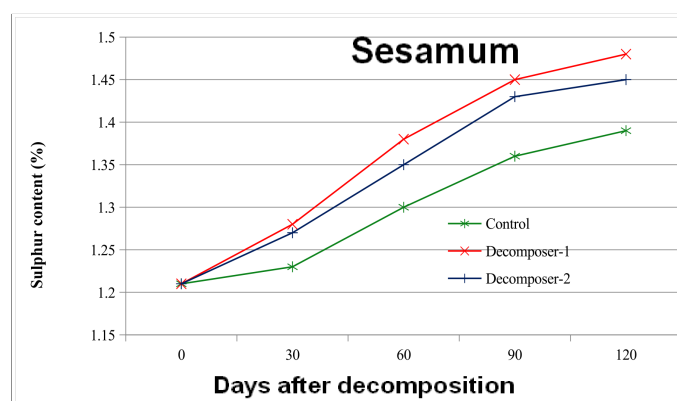
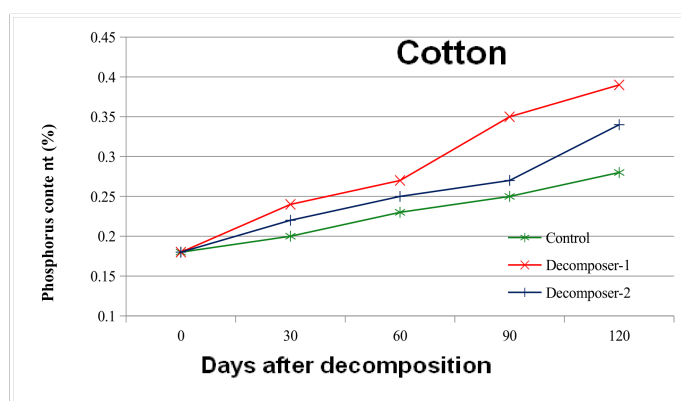
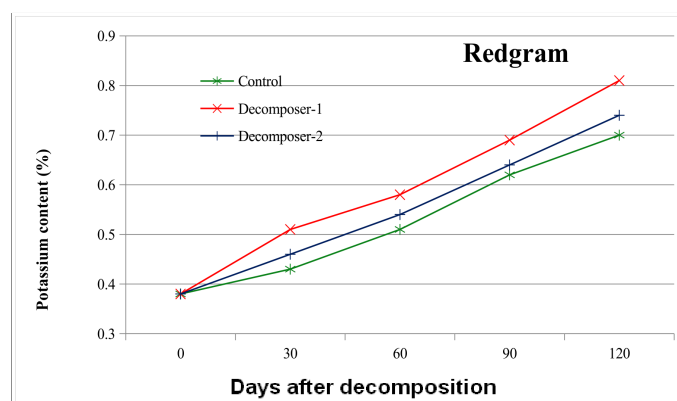
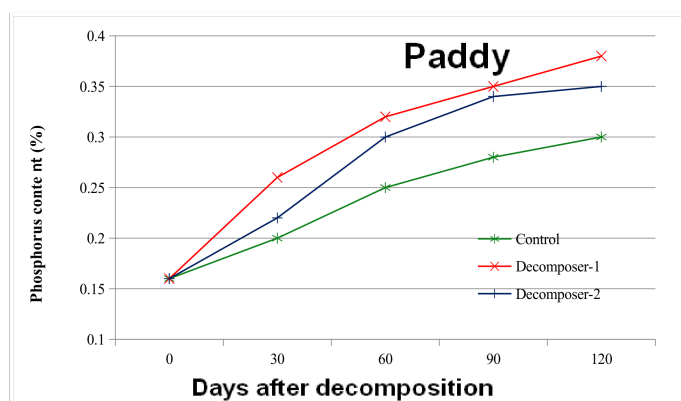
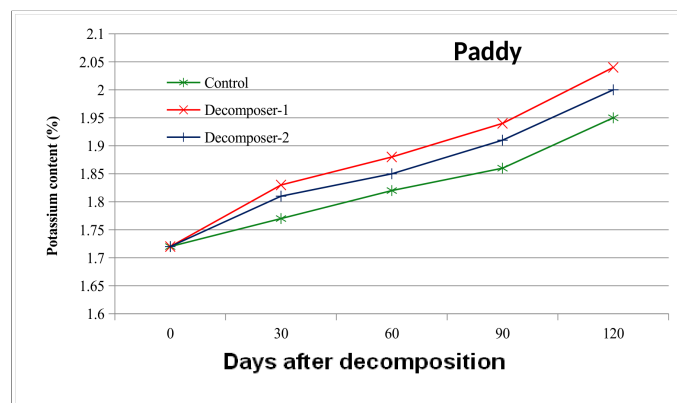
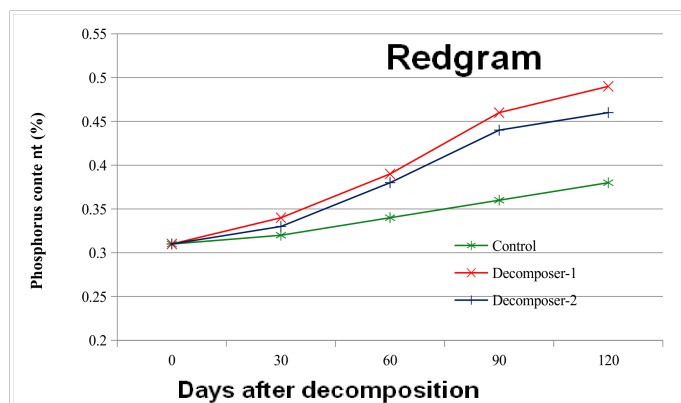
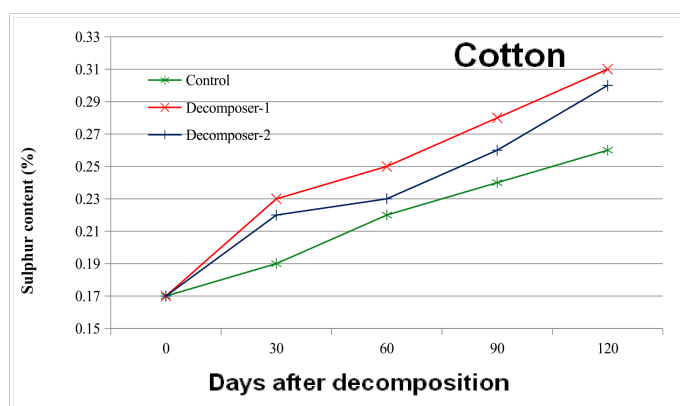


Figure 2. Phosphorous content (%) of composting material as influenced by crop residues and decomposers

Figure 3. Potassium content (%) of composting material as influenced by crop residues and decomposers

Figure 4. Sulphur content (%) of composting material as influenced by crop residues and decomposers



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