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Research article

Evaluating the role of pile geometric dimensions on the efficiency and maturity of agitated pile composting of aquatic weeds

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ABSTRACT

This study evaluates the impact of pile geometric dimensions (length × width × height) on the efficiency and maturity of agitated pile composting of invasive weeds, specifically water hyacinth (*Eichhornia crassipes*) and alligator weed (*Alternanthera philoxeroides*). Three trapezoidal compost piles with varying base and length but uniform height (0.35 m) were constructed and monitored over a 30-day composting period. Regular turning ensured adequate aeration and uniform decomposition. Temperature profiles indicated rapid microbial activity with pile 3 reaching the highest temperature over a 30-day composting period. Regular turning ensured adequate aeration and uniform decomposition of organic wastes. Temperature profiles of all trials indicated rapid microbial activity however temperature of pile 3 was reached the highest (50°C) on 5th Day of composting. Physio-chemical analysis of compost samples revealed that pH was found neural, significant moisture reduction, and decrease in volatile solids, which represent stabilization of organic matter. Nutrient concentration (Na, K, Ca, available phosphorous and total nitrogen) increased across all piles, reflecting nutrient enrichment. Fourier Transform Infrared (FTIR) spectroscopy confirmed substantial organic matter transformation and maturity. Among the piles, Pile 1, with optimized geometric configuration, demonstrated superior chemical stability and maturity, indicating enhanced compost quality. These results highlight the critical role of pile geometry in optimizing agitated pile composting performance for aquatic weed biomass valorisation.

1. Introduction:

An urgent worldwide problem, aquatic weeds bring serious ecological and financial difficulties. By lowering oxygen levels, blocking sunlight, and outcompeting native species, invasive species like water hyacinth (*Eichhornia crassipes*) and related plants damage aquatic ecosystems, lowering biodiversity and water quality (Abba and Sankarannair, 2024a). Communities that depend on agriculture, fishing, and navigation are burdened financially by the significant economic effects. In tropical and subtropical areas, these plants choke irrigation channels and hamper drainage, leading to environmental impact (Patnaik et al., 2021). Managing these weeds is difficult since the possible environmental effects of management methods, whether mechanical, chemical, or biological must be carefully studied (Abbas et al., 2017). Effective management techniques and creative solutions- like the profitable use of weed biomass are required to address these issues and transform them into opportunities (Bertrin et al., 2018). Water hyacinth and alligator weed are two invasive aquatic plants that seriously disrupt aquatic habitats. The dense mats that *Eichhornia crassipes* forms on the water's surface are well known for severely limiting sunlight penetration and lowering the dissolved oxygen level in the water bodies. As aquatic organisms depend on these essential components for their survival, this condition results in the displacement of native species and a decrease in biodiversity (Abba and Sankarannair, 2024b). Moreover, the spread of water hyacinth hinders water flow and interferes with local communities use of waterways, which impacts human livelihoods and economic activities (Su et al., 2018). On the other hand, *Alternanthera*

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philoxeroides has exceptional phenotypic plasticity, enabling it to flourish in a variety of environmental conditions, which further enhances its invasive potential (Wang et al., 2021). This species can have significant ecological and economic consequences, underscoring the need for effective management and control measures to preserve aquatic ecosystems (Wu and Ding, 2020).

Composting of aquatic weeds has tremendous potential for resource recovery, with major benefits for improving soil fertility, encouraging sustainable waste management and producing valuable agricultural products rich in nutrients like phosphate and nitrogen. Aquatic weeds contribute to the production of nutrient-dense compost which increases soil quality and boosts productivity (Thamarai et al., 2025). By transforming invasive aquatic weeds into a valuable resource and reducing their negative effects on ecosystems, composting is an effective method to manage their biomass. Composting also helps lower methane emissions, a major greenhouse gas, by diverting organic waste, such as aquatic weeds away from landfills (Orner et al., 2022). Additionally, aquatic weeds can be co-digested in anaerobic processes to produce biogas, which manages waste and offers an alternative energy source (Saha et al., 2020). Their high moisture content improves compost quality by increasing microbial activity. Composting initiatives can also promote a circular economy and create local economic opportunities in waste management (Singha and Singha, 2024).

In addition to improving soil fertility and organic matter content, composting aquatic weeds has great potential for sustainable waste management by effectively decreasing biomass volume and pathogen load. According to multiple research studies, this approach is in line with ecological sustainability and has many advantages like, an approach to sustainable waste management: Composting of aquatic weeds into nutrient-rich compost is an eco-friendly responsible way to manage the organic waste. This approach lessens the negative environmental effects of conventional waste disposal practices like landfilling and incineration, which can result in issues including an increased risk of leachate contaminating groundwater, also air pollution due to open burning of waste (Waqas et al., 2023).

Decrease in pathogen load and biomass Volume- A practical way to lessen the number of aquatic weeds, which multiply quickly and generate significant biomass, is managing through composting. This decrease is essential for reducing invasive species like water hyacinth, which are difficult to control, and managing excessive development that disturbs aquatic ecosystems.. By eliminating dangerous microorganisms, the heat produced during composting lowers pathogen burdens and ensures safe agricultural application (Gurtler et al., 2018). In areas where these invasive species are common, this has significant effects on the health of the soil and plants. Researches showing that volume reduction are approximately 50% during the process of composting.

Enhanced Soil fertility and Organic Matter Content: Composting increases the organic content of soils, which is essential for improving soil functions and preserving erosion. Composting also increases soil microbial activity, which improves soil biological quality, nitrogen cycling and soil structure. Better nutrient availability also results from high microbial activity (Picariello et al., 2021). Increased soil organic matter that stimulates soil biota is the primary way that a high nutrient content in compost improves soil fertility (Dhadse et al., 2021).

2. Materials and methods

2.1 Materials

Water hyacinth, alligator weed, cattle manure (buffalo), and rice husk were collected from nearby places and used for making windrow piles. Two distinct locations were used to collect aquatic weeds. *Alternanthera philoxeroides* was collected from Bijnor, Lucknow, India, and *Eichhornia crassipes* was collected from the pond in Telibagh, Lucknow. To guarantee grab sampling, aquatic weeds (shoot and root) were collected from four to five distinct locations at each sampling site. Cattle manure used in this study was sourced from a nearby dairy farm situated in the Piprauli village near BBA University and rice husk was purchased from a flour mill near Sanjay Gandhi Post Graduate Institute (SGPGI), Lucknow.

2.2 Agitated pile composting

Prior to composting procedure, all collected materials underwent laboratory processing. To improve aeration, the weed particle size was limited to less than 1 inch through chopping. Based on previous studies (Prasad et al., 2013; Singh et al., 2014), 90 kg of water hyacinth and Alligator weeds (in 1:1 ratio), 45 kg of cattle manure, and 15 kg of rice husk in 6:3:1 ratio were taken, respectively. Three composting piles with various dimensions (height, width, and height) were built. Table 1 lists the precise measurements of each. To guarantee comparability among treatments, a uniform height of 0.35 m was maintained for each pile. The trapezoidal shape of the compost piles maximizes surface area, improving aeration and moisture retention. The composting process lasted 30 days to complete. To maintain adequate aeration and ensure uniform decomposition, the compost piles were turned at specific time intervals during the 30-day composting period (day 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30). To record the temperature profile and assess the dynamics of microbial activity over the composting period, each pile's temperature was measured three times a day at an interval of 6 h. Compost samples were periodically collected to monitor decomposition and nutrient dynamics. At selected intervals (0, 6, 12, 18, 24, and 30 days), nearly 500 g of homogenized material was obtained from five representative areas of each pile. These samples were oven-dried for 24 h at 105°C. Oven dried samples were ground to a fine consistency. The powdered material was then sieved using a 0.2 mm mesh to maintain uniformity. The processed samples were stored in airtight polythene bags for subsequent physio-chemical analysis. Assessment of compost quality and maturity was carried out using samples collected in triplicate.

The initial characterization of each composting material is summarized individually in Table 2.

Table 1 Dimension of different piles

Name of Pile	Length (m)	Base width (m)	Top width (m)	Height (m)
Pile 1 (P_1)	3	0.5	0.15	0.35
Pile (P_2)	2.45	0.75	0.15	0.35
Pile (P_3)	2	1	0.15	0.35

Table 2 Initial characterization of each compost material

Parameters	***Eichhornia crassipes***	***Alternanthera philoxeroides***	**Cow dung**	**Rice husk**
Moisture content (%)	86.26±4.5	91.16±4.1	76±0.67	10±2
pH	6.3±0.15	6.1±0.2	7.05±0.35	6.25±0.5
EC (mS/cm)	3.32±0.17	4.18±0.12	3.8±0.15	2.7±0.2
Volatile Solids (%)	77.9±2.9	73.4±3.4	72.13±3.77	37.12±3.18
Ash content (%)	22.1±2.9	26.55±3.45	27±3.77	62.88±3.18

2.3 Physio-chemical analysis of compost samples

During the composting process, a digital thermometer was used to track the temperature changes. Using the gravimetric approach, moisture content (MC) was calculated by weighing the wet compost sample before and after it was dried at 105°C for 24 h. Estimation of pH and EC was carried out according to Mohee et al. (2005) using a pH meter and conductivity meter. For this purpose, 10 g of compost was suspended in 100 mL of distilled water and agitated using a horizontal shaker for two hours before analysis. Then kept it to settle for 30 min then filter it using Whatman filter paper 42. The ignition method, which entailed heating the sample at 550 °C for 2 hr. in a muffle furnace, was used to quantify the volatile solids (VS) and ash content in compost samples (Singh and Kalamdhad, 2015). Volatile solids data were used to estimate total organic carbon. For this calculation, the volatile solids were divided by a factor of 1.83 (Sharma et al., 2017). Total nitrogen was calculated using Kjeldahl method, while available phosphorous (acid digest) was calculated using the stannous chloride method (Tombesi and Calé, 1962). The macronutrients (Na, K and Ca) were analyzed according to Singh and Kalamdhad (2015) using flame photometer.

3. Results and discussion

The temperature profiles of three piles in the process of composting are shown in Fig. 1. A rapid rise in pile temperature was observed during the initial five days of the composting period. In pile 1, the highest temperature was reached up to 42-44°C on the fourth day, whereas the in pile 3 highest temperatures was 50° C on 5^{th} day of composting period. On same day, pile 2 showed maximum temperature of 42-45°C. Because of the heat released by microbial catabolism, the temperature increased in each pile.

Fig. 2 illustrates the changes observed in pH, MC, EC and VS. The pH of the compost piles showed characteristic changes throughout the 30-day of agitated pile composting. In Pile 1, the pH slightly increased from 7.6 initially to 7.9 between the 12^{th} and 18^{th} day and stabilized at 7.7 by the 30^{th} day. Pile 2 exhibited a more pronounced shift, rising from 6.3 at the start to 7.5 during the active phase, before settling at 7.0 at maturity. Similarly, pile 3 showed an initial acidic pH of 6.0 that increased to 7.5 in the mid-phase and stabilized at 7.2 in the final phase. An acidic pH was recorded in the initial stage of composting in piles 2 and 3. This condition can be associated with organic acid generation during the rapid decomposition of cellulose and hemicellulose rich aquatic weeds (Kumar et al., 2018). The subsequent rise in pH corresponds to the formation of ammonical compounds through microbial mineralization of proteins present in the weeds (Awasthi et al., 2016). As composting progress, the pH stabilized near neutrality due to volatilization of ammonia and the nitrification of ammonium to nitrate, accompanied by the formation of humic and fulvic acid during the maturation phase (Gajalakshmi and Abbasi, 2008). The final near-neutral pH (7.0-7.7) across all piles indicates adequate stabilization and maturity of the compost, consistent with the findings of (Bernal et al., 2009), who suggested that mature compost generally attains a pH close to neutrality. Adequate moisture in the initial composting mixture is essential to support microbial survival and activity. As composting progresses, MC gradually decreases due to heat generation and evaporation, which reflects the rate of organic matter decomposition (Kalamdhad et al., 2009). In the present study, the initial moisture levels of the piles were approximately 66.3%, 76.45%, and 75.45%, which declined to 53.9%, 46.86%, and 50.02%, respectively, during the composting of mixed weeds (Fig. 2b). The greatest reduction in moisture content was recorded in agitated pile 2 (29.59%), followed by pile 3 (25.33 %) and pile 1 (12.4%).

As shown in Fig. 2c, electrical conductivity (EC) initially increased in all composting trails, which can be attributed to the release of soluble mineral salts such as phosphates and ammonium ions during organic matter breakdown. With further compost stabilization, a decline in EC was observed in trail 1, 2 and 3, possibly due to ammonia volatilization and precipitation of mineral salts (Merhaut et al., 2006). At the end of the composting period, EC values of 3.34, 3.14, and 3.84 ds/m were recorded for trail 1, trail 2, and trail 3, respectively.

Volatile solids (VS), which indicate the organic matter content of compost, showed a decreasing trend throughout the process as microorganisms degraded organic components and carbon was lost in the form of CO_2. In this study, the most significant reduction in VS (16.7%) was observed in trail 2, followed by a reduction of 14.8% in trail 1, and 11.2% in trail 3 as shown in Fig. 2d and subsequent rise in the Ash content as shown in Fig.2

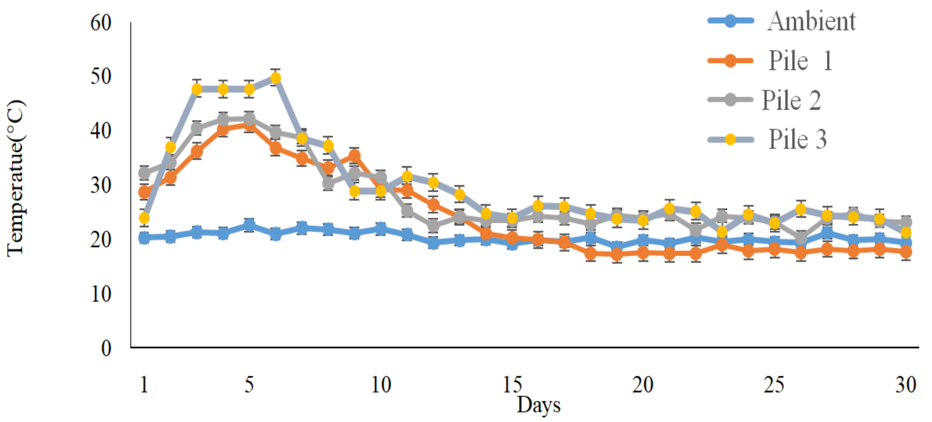

Fig. 1 Temperature profile of piles 1, 2 and 3

Figure 3 highlights the enrichment of Na, K, Ca concentration associated with organic matter degradation during the composting process (Huang et al., 2004). In the final compost of Pile 1, the nutrient concentrations rose to 3.04-7.53 g/kg for Na, 20.83-28.24 g/kg for K, and 16.83-29.8 g/kg for Ca. Similarly, for Pile 2, the concentration was 4.62-7.6 g/kg for Na, 21.03-28.55 g/kg for K, and 18.15-27.96 g/kg for Ca. For Pile 3, the values were 5.09-7.99 g/kg for Na, 22.92-28.57 g/kg for K and 19.88-26.15 g/kg for Ca. The enrichment of nutrients during composting is primarily due to the net loss of dry matter resulting from microbial degradation.

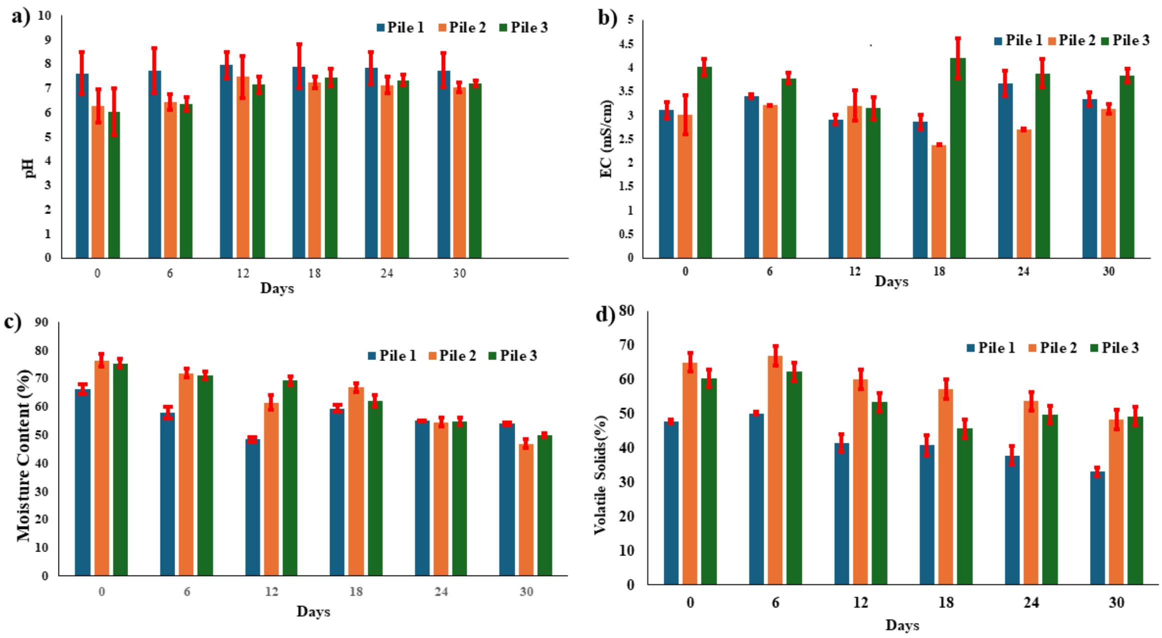

Fig. 2 Physio-chemical characters of Pile 1, 2 and 3: a) variation in pH, b) variation in electrical conductivity, c) changes in moisture content, and d) variation in volatile solids (%)

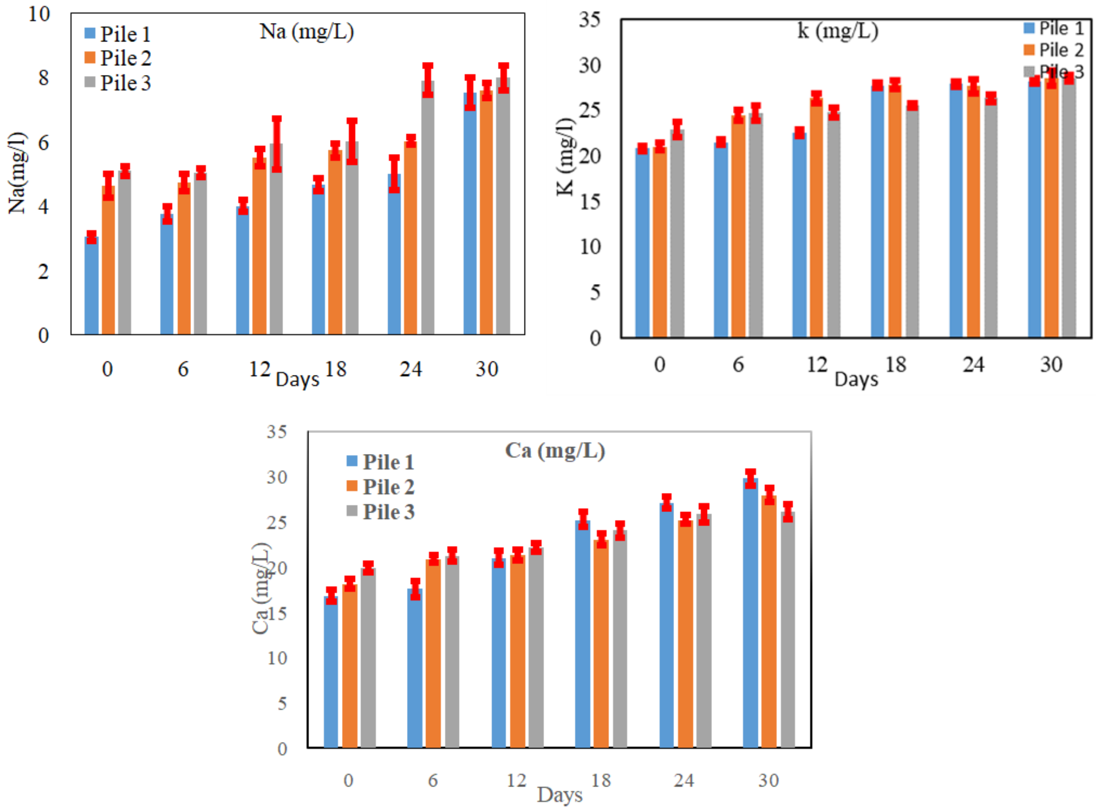

Fig. 3 Nutrient Concentration of Sodium (Na), Potassium (K), Calcium (Ca)

In Pile 1, Pile 2, and Pile 3, the available phosphorous concentration increased throughout the course of the 30-day composting process from 1.95 to 3.98 mg/kg, 2.33 to 4.33 mg/kg, and 2.3 to 4.9 mg/kg respectively (Fig. 4a). During the composting process, the quantities of accessible and total phosphorous were increased, which may have been caused by phosphorous released by microorganisms as organic waste mineralized. The current study's findings were in line with those of the previous investigation. Fig. 5b represents the variation in total nitrogen content during the composting period. The initial total nitrogen content across the compost piles were observed in the ranged from 1.13% to 1.96%, which was increased to 3.01-3.36% by the end of the composting process. Among the treatments, Pile 2 exhibited the greatest increase in total nitrogen (1.96%), followed by Pile 3 (1.81%) and Pile 1 (1.40%). The rising trend of total nitrogen observed in this study is consistent with the findings of Lim et al. (2010). The enhancement in total nitrogen content can be attributed to the decomposition of organic microbial respiration, and the activity of nitrogen-fixing microorganisms contributing to nitrogen enrichment (Salinas-Garcia et al., 1997)

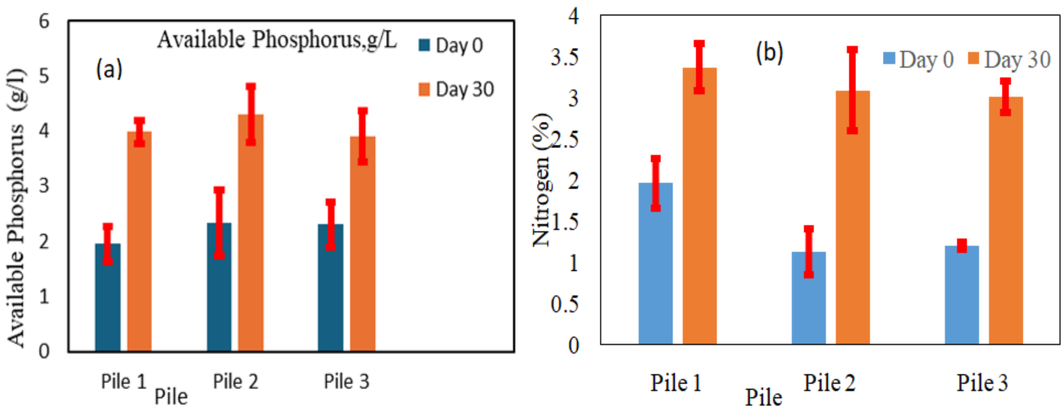

Fig. 4 a) Available Phosphorous b) Total Kjeldahl Nitrogen

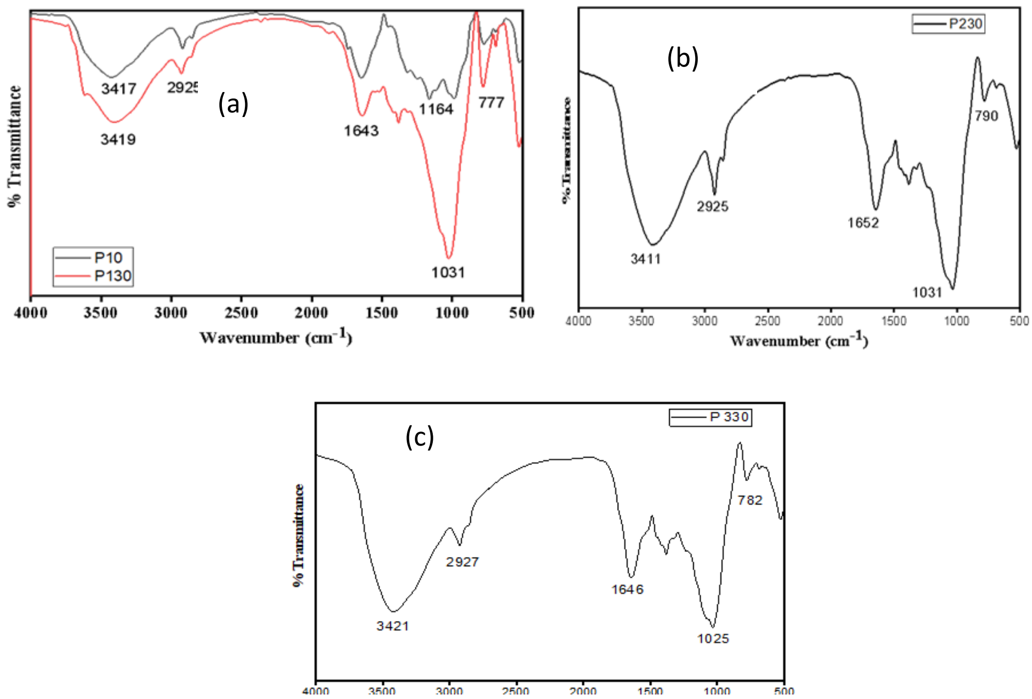

Fig.5 FTIR analysis of a) Pile1, 1st and 30th day, b) Pile 2, 30th day, c) Pile 3, 30th day

Fourier Transform Infrared (FTIR) spectroscopy as shown in Fig. 5, confirmed substantial organic matter transformation across all piles, characterized by the decomposition of readily degradable aliphatic compounds and the synthesis of stable humic substances. Image 1, comparing the initial ($P_1$0) and final ($P_1$30) material for Pile 1, demonstrates the intended molecular restructuring, showing a significant reduction in the aliphatic C-H stretching, band, alongside a relative increase in the aromatic/ carboxylate region confirming successful degradation. Crucially, the comparison of the final products (P_1 30, P_2 30, P_3 30) establish a performance gradient: the optimized geometric configuration of Pile 1 (P_1 30) achieved the highest chemical stability and maturity. However, Pile 3 (P_3 30) retained the highest residual intensity of suboptimal aeration or process control, leading to incomplete aerobic decomposition.

4. Conclusion

The study conclusively demonstrates that pile geometry significantly influences the efficiency and maturity of agitated pile composting of aquatic weeds. Among the three tested pile, Pile 1 (3 m length × 0.5 m base width × 0.35 m height) exhibits the best overall performance, achieving the highest chemical stability and compost maturity as evidenced by FTIR analysis. Although Pile 3 reached the highest temperature, its incomplete aerobic decomposition suggested suboptimal aeration or process control. Trapezoidal shape and dimensions of pile 1 shows maximized aeration and moisture retention, fostering uniform microbial activity and nutrient transformation. This resulted in stable pH values near neutrality, significant reduction in moisture content and volatile solids, enhanced nutrient concentrations, confirming superior compost quality. Therefore, geometric design of pile 1 is most effective for agitated pile composting of aquatic weeds, providing a practical guideline for optimizing composting operations to produce nutrient-rich, mature compost efficiently.

Author's contribution

Roshni Bajaj (Research scholar): Review literature, Writing and Format analysis. **Kuntal Sagra** (M.Sc. Student): assisted data collection and writing. **Jiwan Singh** (Asst. Professor): review, editing and validate the article.

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Conflict of interest

The authors have disclosed no conflict of interest

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