

CAMPUS GARDEN WASTE MANAGEMENT VIA MOBILE INCINERATION: CHARACTERIZATION AND EMISSION REDUCTION ASSESSMENT

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Abstract - Yard waste generated from landscape maintenance is commonly treated by open burning, causing localized air pollution and environmental concerns. This study evaluated yard waste characteristics and assessed the effectiveness of a mobile incineration system on the campus of The University of Danang-University of Science and Technology (UD-DUT). Yard waste was quantified and analyzed for its physical-chemical properties, while a survey of 150 participants assessed environmental perceptions. Field experiments compared air quality between open burning and controlled combustion using a mobile incinerator. Approximately 2.69 tons of yard waste were generated weekly, mainly consisting of lignocellulosic biomass. Open burning caused noticeable smoke and respiratory discomfort, whereas the mobile incinerator reduced PM_{2.5} emissions by about 80%. These findings demonstrate the potential of mobile incineration as an effective on-site yard waste management solution for university campuses.

Key words - Garden waste; mobile garden waste burning model; C/N ratio; PM_{2.5} dust concentration; model replication.

1. Introduction

The management of yard waste, including fallen leaves and pruning residues, represents an ongoing challenge in many urban landscapes and institutional campuses. In numerous countries, particularly in developing regions, open burning remains one of the most frequently used methods for treating this type of organic waste due to its simplicity, low operational cost, and minimal equipment requirements [1]. Despite these practical advantages, the open burning of garden residues has increasingly been recognized as an environmentally unsustainable practice that contributes to air pollution and potential public health risks. Environmental agencies and academic studies have reported that the combustion of yard waste releases a variety of harmful pollutants into the atmosphere. Smoke produced during the burning process contains fine particulate matter as well as several toxic and irritating gases. These fine particles are capable of penetrating deep into the respiratory system, where they may accumulate in lung tissue and remain for prolonged periods. Long-term exposure to such particles has been associated with respiratory irritation, reduced lung function, and an increased susceptibility to respiratory infections. Individuals with pre-existing respiratory conditions, such as asthma or chronic bronchitis, are particularly vulnerable to the effects of smoke generated from the burning of organic materials [2]. In addition to particulate emissions,

the combustion of garden waste generates several gaseous pollutants, including carbon dioxide (CO₂), methane (CH₄), carbon monoxide (CO), and sulfur dioxide (SO₂). These emissions contribute not only to local air quality deterioration but also to broader environmental concerns such as greenhouse gas accumulation and atmospheric pollution [3]. Consequently, many countries have introduced regulations limiting or prohibiting the open burning of yard waste in residential and public areas.

Despite the known environmental and health implications, open burning remains a common practice in Vietnam, largely because it provides a rapid and inexpensive solution for managing large volumes of fallen leaves and pruning residues [4 - 6]. Field observations conducted by the research team indicate that this method is currently the primary approach used to handle garden waste on the campus of The UD-DUT. Although the method is convenient and requires minimal labor and equipment, several disadvantages have been observed during its implementation. First, the combustion process produces smoke and gaseous emissions that negatively affect the surrounding environment. Second, smoke and dust generated during burning can disrupt the learning and working conditions of students, lecturers, and administrative staff within the campus area. Third, the residues generated from open burning, particularly ash scattered across the ground, reduce the aesthetic quality of the campus landscape. Furthermore, uncontrolled burning may generate excessive heat, which can damage nearby vegetation and potentially lead to leaf scorching or plant mortality in landscaped areas.

Although several studies have examined the environmental impacts of open biomass burning, limited research has focused on small-scale mobile incineration systems suitable for institutional landscapes such as university campuses [7 - 8]. Therefore, this study proposes the design and development of a mobile garden waste burning model that aims to improve the efficiency and controllability of the burning process while minimizing its negative environmental impacts. The proposed system is intended to provide a flexible and cost-effective waste treatment option suitable for institutional settings, thereby contributing to improved campus cleanliness, environmental protection, and operational convenience at UD-DUT.

2. Materials and Methods

2.1. Study area

The study was conducted at the campus of UD-DUT, located in Lien Chieu District, Da Nang City, Vietnam. The campus is characterized by a high proportion of green space, including mature trees, lawns, and landscaped areas distributed around lecture halls, administrative buildings, and pedestrian pathways. The presence of long-established vegetation provides shade and contributes to a favorable microclimate for academic activities. The relatively dense tree cover and routine landscape maintenance generate a continuous flow of garden waste, mainly consisting of fallen leaves, grass clippings, and pruned branches. These characteristics make the campus an appropriate case study for evaluating the generation of yard waste and exploring practical management solutions such as mobile incineration for on-site treatment.



Figure 1. Study area - UD-DUT campus

2.2. Yard Waste Generation and Characteristics

The generation of yard waste was assessed using the standard plot method. Square plots with an area of 25 m² (5 m × 5 m) were established within vegetated areas across the campus (green zones indicated in Figure 1). From the total number of standard plots, three plots for each location were randomly selected to determine the yard waste generation coefficient. Within each selected plot, accumulated garden residues—including fallen leaves, grass clippings, and small branches—were collected and weighed to estimate the mass of waste generated per unit area. The collected samples were then transported to the laboratory for further analysis.

Table 1. Chemical analysis parameters

No.	Parameter	Analysis method
1	Moisture content	TCVN 4048:2011
2	Ash content	TCVN 7038:2002
3	C	TCVN 9816 (ISO 29541)
4	H	TCVN 9816 (ISO 29541)
5	N	TCVN 6645:2000
6	O	TCVN 318:2009
7	S	TCVN 8622 (ISO 19579)
8	Cl	TCVN 12616:2019
9	K	TCVN 8660:2011
10	P	TCVN 8940:2011

Laboratory analyses were conducted to determine the physical and chemical characteristics of the yard waste. Physical parameters included moisture content, ash content, and combustible fraction, while chemical composition was analyzed in terms of elemental components such as carbon (C), hydrogen (H), oxygen (O), nitrogen (N), sulfur (S), potassium (K), phosphorus (P), and chlorine (Cl). All laboratory analyses were performed in accordance with the relevant Vietnamese Standards (TCVN) currently in force.

2.3. Environmental Awareness Survey

An environmental awareness survey was conducted to evaluate perceptions of garden waste burning and its impacts on the campus environment. The survey targeted students studying and spending time in lecture hall areas that are frequently affected by garden waste burning activities. In addition, in-depth interviews were carried out with campus sanitation workers to better understand current waste management practices, particularly the routine burning of collected yard waste.

A total of 150 respondents participated in the survey. Among them, 60 were female (40%), while 80 respondents were first-year students (53.3%). The questionnaire focused on participants' perceptions of environmental cleanliness, the frequency of encountering garden waste burning on campus, and the perceived impacts of smoke and emissions on daily activities.

The survey results indicated that most respondents expressed concern about environmental sanitation and acknowledged that air pollution and smoke from yard waste burning could negatively affect the learning environment and concentration during academic activities. These responses provided additional insights into the social and environmental implications of current yard waste management practices on campus.

2.4. Design and Development of the Mobile Incinerator

A mobile incinerator was designed to provide a controlled system for the on-site treatment of yard waste. The device mainly consists of four components: a combustion chamber, a gas exhaust system, a supporting frame, and a smoke treatment unit (Figure 2). The combustion chamber is constructed from a cylindrical double-layer stainless steel shell, with a narrow gap between the inner and outer layers to allow air circulation and improve combustion stability. A feeding door is installed on the chamber wall to load garden waste. Inside the chamber, a removable perforated tray supports the waste during combustion while allowing ash to fall into a conical ash collection hopper located at the bottom. The hopper is equipped with an ash discharge outlet and an air inlet connected to an air supply fan that enhances oxygen supply during the combustion process. The exhaust section includes a smoke collection funnel connected to a chimney through a joint connector, allowing combustion gases to be discharged upward. The incinerator is supported by a metal frame fitted with wheels, enabling convenient movement and flexible deployment within the campus area. To reduce particulate emissions, a smoke

treatment unit is installed inside the chamber. This device consists of several semi-circular trays made of iron or stainless steel, attached to the inner wall of the chamber and arranged alternately along a vertical axis. Each tray is fitted with a mesh screen of approximately 100 mesh size, depending on the dust removal requirements. The staggered configuration creates a spiral airflow path, increasing the residence time of the gas and promoting the deposition of particulate matter before the gas exits through the chimney.

During operation, garden waste is loaded into the chamber through the feeding door. Air supplied by the fan supports combustion, while ash is collected in the hopper for removal. The generated smoke passes through the internal tray system, which facilitates partial filtration of dust and particulate matter before the gases are released to the atmosphere. The overall operational procedure of the incinerator system is illustrated in Figure 3.

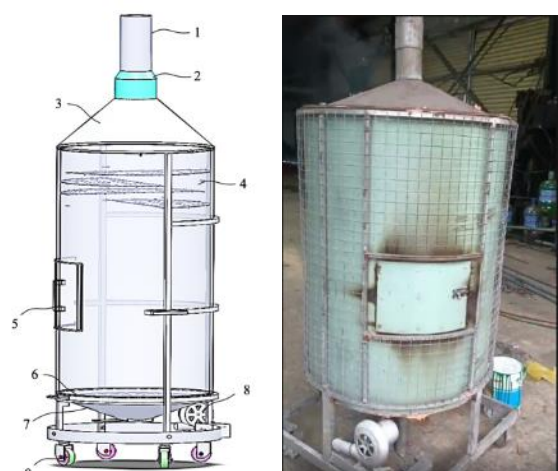


Figure 2. Design of mobile incinerator

In Figure 2, the specific components include: 1 - Chimney assembly, 2 - Joint connector, 3 - Smoke collection funnel, 4 - Smoke treatment unit, 5 - Fuel feeding door, 6 - Supporting tray, 7 - Ash collection hopper, 8 Air supply fan, 9 - Wheel.

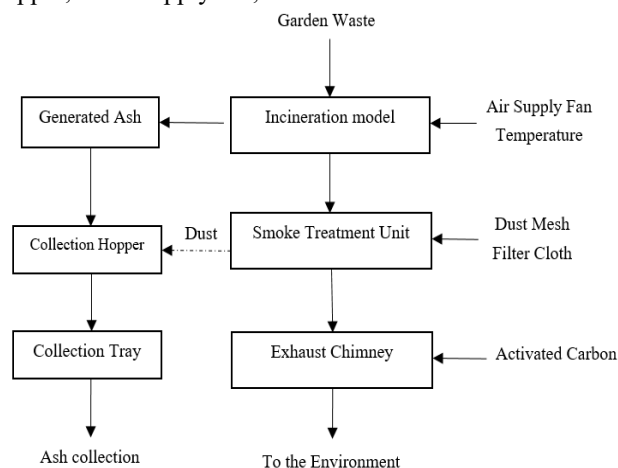


Figure 3. Operational Process of the Incineration Model

2.5. Air Quality Monitoring and Sampling Procedure

Rapid air quality measurements were conducted to assess the influence of garden waste burning on the surrounding atmospheric environment. The monitoring program was implemented in three stages to allow comparison between background conditions, open burning activities, and the operation of the mobile incinerator.

First, baseline air quality measurements were performed under conditions without any garden waste burning to determine the background environmental level. Monitoring was carried out during clear weather with low wind speeds ranging from 0 to 0.5 m/s. Second, air quality was measured during conventional open burning of garden waste conducted by campus sanitation workers. Sampling points were established 5 m (Point A) and 10 m (Point B) downwind from the burning source, following the prevailing wind direction as illustrated in Figure 4. Finally, the monitoring procedure was repeated at the same locations while operating the mobile garden waste incinerator. This allowed a direct comparison between open burning and controlled incineration conditions.

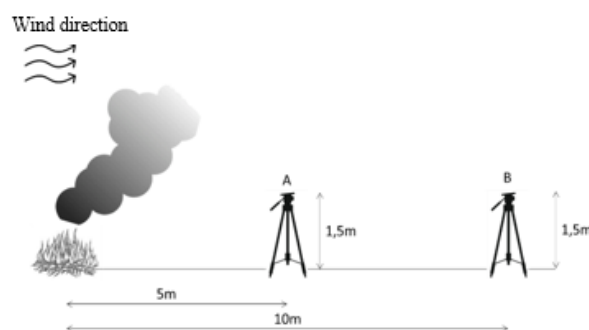


Figure 4. Simulation of the process air sampling

During all monitoring events, measurements were conducted under similar meteorological conditions (sunny weather and light wind of 0-0.5 m/s) to ensure data comparability. The monitoring equipment was installed at a height of 1.5 m above ground level, representing the typical human breathing zone. Air quality parameters were monitored using a DM509 multi-parameter portable air quality monitor, capable of simultaneously measuring particulate matter (PM_{10} and $PM_{2.5}$), carbon monoxide (CO), total volatile organic compounds (TVOC), and formaldehyde (HCHO). The device is suitable for rapid field assessments of ambient air quality under outdoor conditions. Among these indicators, $PM_{2.5}$ was selected as the primary parameter for analysis because fine particulate matter is widely recognized as a key indicator of air pollution associated with biomass combustion and has significant implications for human health.

2.6. Statistical and Data Analysis

The yard waste generation coefficient was calculated by dividing the mass of garden waste collected within each standard plot over one week by the plot area (25 m^2). The generation coefficient was expressed in units of $\text{kg/m}^2\text{-week}$. Based on this coefficient and the total area of vegetated land within the campus, the weekly quantity

of yard waste generated at UD-DUT was subsequently estimated.

For the air quality monitoring experiment, measurement values were recorded at 10-second intervals over a 5-minute period for each burning event. This time-series dataset allowed the evaluation of temporal variations in pollutant concentrations under different experimental conditions, including background air quality, open burning, and operation of the mobile incinerator.

All collected data were processed using Microsoft Excel for preliminary organization and visualization. Descriptive statistical analysis was performed to summarize the data and present trends through graphs and tables. In addition, independent sample t-tests were conducted using the R statistical software to examine differences in air quality parameters between open burning and incinerator operation. The results were reported as mean values with corresponding variability indicators.

3. Results and Discussions

3.1. Yard waste generation and characteristics

The generation rate of yard waste across different locations within the campus was determined using the standard plot method. The results are summarized in Table 2, showing the average generation coefficients of leaves, branches, and total yard waste expressed in g/m²·week.

Table 2. Yard waste generation rates

Location	Generation rates (g/m ² ·week)		
	Leaves	Branches	Total
Zone A	23 ± 2	11 ± 1	34 ± 3
Zone B	23 ± 4	17 ± 2	40 ± 4
Zone C	45 ± 8	15 ± 2	60 ± 7
Zone D	55 ± 5	15 ± 2	70 ± 12
Zone E	57 ± 6	16 ± 2	73 ± 7
Zone F	26 ± 3	16 ± 2	42 ± 4
Zone G	71 ± 7	13 ± 2	84 ± 9
Zone H	13 ± 1	10 ± 1	23 ± 3
Zone I	28 ± 4	13 ± 1	41 ± 4
Zone K	78 ± 9	10 ± 1	88 ± 7
Learning Center	16 ± 2	13 ± 1	29 ± 2
Parking lot	15 ± 2	15 ± 2	30 ± 3

Overall, the total yard waste generation rate varied considerably among different zones, ranging from 23 ± 3 g/m²·week (Zone H) to 88 ± 7 g/m²·week (Zone K). Leaves accounted for the largest fraction of the generated waste in most locations, while branches represented a smaller proportion. Higher generation rates were observed in Zone G and Zone K, where total generation coefficients reached 84 ± 9 g/m²·week and 88 ± 7 g/m²·week, respectively. These areas serve partly as temporary collection points for yard waste gathered from nearby zones, which explains the higher recorded values.

Based on the generation coefficients and the vegetated area of each zone, the weekly quantity of yard waste produced across the campus of UD-DUT was estimated. The total generation was approximately 2.69 tons per

week, with the highest contributions originating from Zone D (0.56 tons/week) and Zone K (0.55 tons/week). Together, these two zones accounted for more than 40% of the total yard waste generated on campus, followed by Zone A (13.3%), Zone F (11.8%), and Zone G (8.9%). The remaining areas contributed smaller proportions, ranging from 1.7% to 6.9% of the total weekly waste generation.

Variations in generation rates among the zones can be attributed to differences in vegetation density, tree species composition, and maintenance frequency. Areas with mature trees and dense vegetation tend to produce larger quantities of fallen leaves and pruning residues. In addition, seasonal factors such as weather conditions and wind events may also influence the accumulation of yard waste.

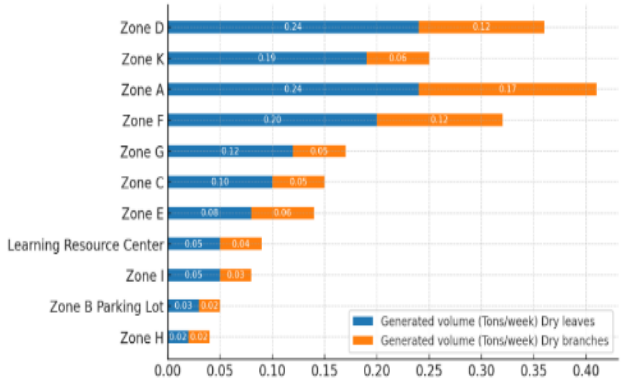


Figure 5. Total estimated amount of yard waste

The composition of yard waste varied slightly among campus zones but was generally dominated by dry leaves, small branches, and grass residues. In areas such as Zone D and Zone K, the waste stream consisted mainly of large fallen leaves and woody branches, whereas in zones such as A, F, and the library area, the waste was primarily composed of leaves mixed with grass clippings due to more frequent landscaping activities.

Physical and chemical properties of the collected yard waste samples were analyzed to better understand their characteristics and suitability for combustion. The bulk density of the mixed yard waste ranged from 6.25 to 7.4 kg/m³, indicating a relatively low-density biomass material typical of dried plant residues. The measured pH values ranged from 6.51 to 6.93, suggesting that the material was slightly acidic to nearly neutral. Elemental analysis revealed a relatively high carbon-to-nitrogen (C/N) ratio ranging from 48 to 50, reflecting the lignocellulosic nature of the waste dominated by dried leaves and woody components. Such high C/N ratios are commonly reported for yard waste materials because of their large proportion of structural carbon compounds. The measured characteristics are generally consistent with findings reported in previous studies. For example, Lopez et al. reported that yard trimmings used in biowaste composting typically exhibit high carbon content and C/N ratios ranging from 40 to 80, depending on the proportion of woody materials [9]. Similarly, Manu et al. documented that yard waste commonly has low bulk

density and relatively high organic carbon content, characteristics that influence both composting behavior and combustion performance [10 - 11]. The physical and chemical properties observed in the present study therefore fall within the typical ranges reported for landscape residues in urban environments.

Overall, the results indicate that yard waste generated on campus is primarily composed of dry lignocellulosic biomass, which can be effectively treated through thermal processes such as controlled incineration. Understanding these material characteristics is important for evaluating the performance and suitability of the proposed mobile incineration system.

Table 3. Physical and chemical characteristics of yard waste (leaves only)

Parameter	Unit	Result
Moisture content	%	18.74
Ash content	%	1.16
Volatite content	%	80.20
C	%	48.52
H	%	6.06
N	%	0.92
O	%	32.18
S	%	0.08
Cl	%	0.29

3.2. Environmental awareness on yard waste

After collection from landscaped areas, yard waste is typically gathered into piles with an approximate diameter of one meter, allowed to dry in open spaces, and subsequently burned on site. This practice is widely used because it is simple to perform and requires minimal equipment, labor, and financial resources. However, uncontrolled open burning can generate smoke, particulate matter, and unpleasant odors, which may degrade local air quality and negatively affect the surrounding learning environment. In addition, such practices may increase potential risks related to fire hazards and respiratory health.

Survey results indicate that most students rarely observe yard waste burning on campus, with reported frequencies ranging from 60.6% to 78.4%. This is largely because burning activities are typically conducted during periods with low student presence, such as lunch breaks or after 17:00. Nevertheless, a proportion of respondents reported occasionally encountering such activities, particularly in Zones B and F, where waste accumulation and maintenance operations occur more frequently.

Regarding campus environmental conditions, the majority of respondents assessed the sanitation quality around lecture halls as “moderate”, with percentages ranging from 70.9% to 85.4% depending on location. However, certain areas, including Zones G, H, and D, received higher proportions of “dirty” evaluations (up to 26.7%), reflecting the greater presence of accumulated vegetation residues. In contrast, Zone E received the most favorable evaluations, with 23.8% of respondents rating the area as clean and only 5.6% considering it dirty.

Perceptions of yard waste distribution across the

campus showed that most students considered the amount of garden waste to be moderate (41.5% - 54.7%). Areas such as Zones E, C, and A were perceived as having relatively lower levels of waste accumulation, while Zones G, H, and D were identified as locations with larger quantities of yard waste.

Students also reported several negative impacts associated with the open burning of yard waste. The most frequently identified effects included reduced aesthetic quality of the campus (89.7%), eye irritation (85.7%), respiratory discomfort (82.4%), and decreased concentration during study (80.2%). These findings suggest that although open burning remains a common waste management practice due to its convenience, it is perceived by campus users as having noticeable environmental and health implications. The results highlight the need for alternative yard waste treatment methods that minimize emissions and improve environmental quality within university campuses

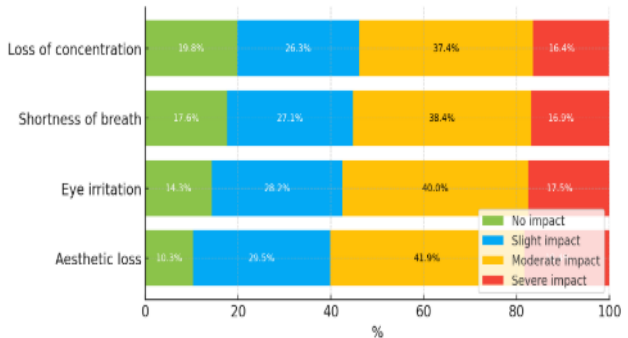


Figure 1. Assessing the impact of burning garden waste

3.3. Air pollution control by mobile incinerator

The results indicate substantial differences between the two treatment approaches. During open burning, the average PM_{2.5} concentration reached 934.5 µg/m³ at Location A and 276.4 µg/m³ at Location B, which significantly exceeded the national ambient air quality guideline specified in QCVN 05:2023/BTNMT (25 µg/m³). In contrast, when the mobile incinerator was used, the average PM_{2.5} concentrations decreased to 189.3 µg/m³ at Location A and 63.1 µg/m³ at Location B. These results correspond to emission reduction efficiencies of approximately 80% and 77%, respectively.

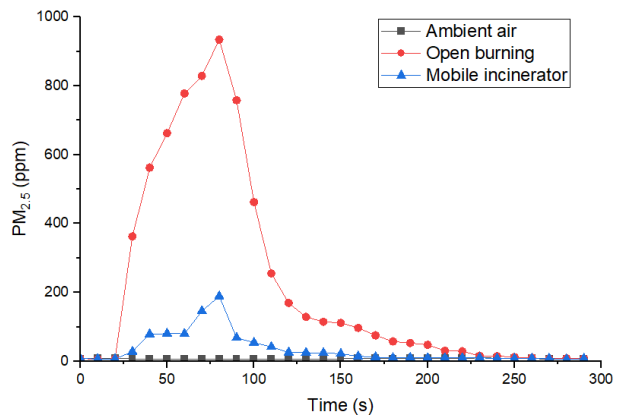


Figure 2. PM_{2.5} concentration at location A

Statistical comparison using an independent t-test further confirmed that the differences between the two combustion methods were statistically significant ($p < 0.001$). The mean $PM_{2.5}$ concentrations during open burning were $221 \pm 296 \mu\text{g}/\text{m}^3$ at Location A and $77 \pm 87 \mu\text{g}/\text{m}^3$ at Location B, while the corresponding values for the incinerator operation were $34 \pm 44 \mu\text{g}/\text{m}^3$ and $15 \pm 13 \mu\text{g}/\text{m}^3$. The calculated removal efficiencies were 84.6% at Location A and 80% at Location B, demonstrating that the mobile incinerator substantially reduced fine particulate emissions compared with uncontrolled burning.

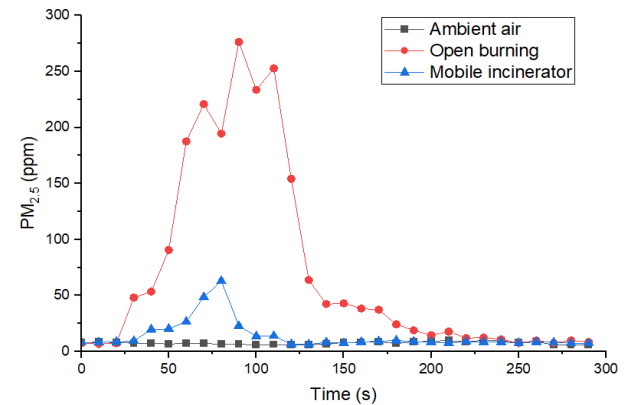


Figure 3. $PM_{2.5}$ concentration at location B

In addition to reducing airborne particulate concentrations, the mobile incinerator effectively retained a large portion of combustion residues within the system. The internal tray and ash collection compartment captured a significant fraction of the generated ash, preventing it from dispersing into the surrounding environment. Field observations indicated that the incinerator reduced visible ash emissions by approximately 90-95% compared with traditional open burning practices.

Table 4. $PM_{2.5}$ concentrations by waste treatment methods

Location	$PM_{2.5} (\mu\text{g}/\text{m}^3)$		Removal Efficiency
	Open burn	Incinerator	
Location A	934.5	189.3	80%
Location B	276.4	63.1	77%

The mobile incinerator also improved the combustion process by providing a controlled air supply through the integrated ventilation system. This mechanism enhanced combustion efficiency and reduced incomplete combustion products. As a result, the amount of visible smoke released during operation was substantially lower than that observed during open burning. The optimized combustion conditions also minimized the occurrence of strong burning odors typically associated with yard waste combustion. Consequently, the emitted gases were more readily dispersed and diluted in the surrounding atmosphere, reducing the potential impact on nearby campus activities.

Overall, the monitoring results demonstrate that the mobile incinerator provides a more controlled and environmentally favorable alternative to conventional open burning for managing yard waste on university campuses.

Table 5. $PM_{2.5}$ concentrations by waste treatment methods

Location	$PM_{2.5} (\mu\text{g}/\text{m}^3)$		T_0	Removal Efficiency
	Open burn	Incinerator		
Location A	221 ± 296^a	34 ± 44	3.414***	84.6 %
Location B	77 ± 87	15 ± 13	3.655***	80%

***: $p < 0.001$

4. Conclusion

The study estimated that approximately 2.69 tons of yard waste are generated weekly on the campus of UD-DUT. The waste stream is dominated by plant-based organic materials, primarily dry leaves and branches, with a high C/N ratio, bulk density ranging from 6.25-7.4 kg/m^3 , and pH values between 6.51 and 6.93, indicating slightly acidic to neutral characteristics. Spatial analysis showed that Zones D and K contributed the largest proportions of yard waste generation, accounting for 20.9% and 20.5% of the total weekly volume, respectively. These areas therefore represent priority locations for implementing improved yard waste management practices. Survey results revealed that open burning of yard waste negatively affects campus users, with respondents reporting impacts such as reduced aesthetic quality (89.7%), eye irritation (85.7%), respiratory discomfort (82.4%), and decreased concentration during academic activities (80.2%).

Experimental results demonstrate that the mobile yard waste incinerator significantly improves emission control compared with conventional open burning. The operation of the system reduced $PM_{2.5}$ concentrations and visible smoke emissions by approximately 80%, indicating its effectiveness as a localized air pollution mitigation measure. In addition, the design facilitates ash collection, allowing potential reuse as a soil amendment or composting material. The benefits of this approach have been demonstrated in several previous studies, as ash derived from yard waste contains high concentrations of calcium, potassium, and magnesium, which can provide essential nutrients for soil and plant growth. Plants grown in soils amended with ash derived from yard-waste biomass have also been reported to exhibit reduced aluminum and manganese toxicity [13]. Moreover, combining this ash with compost derived from organic waste can enhance nutrient recycling efficiency and improve soil fertility [14]. Within the framework of the circular economy, this application is highly suitable for reusing waste as a resource to improve soil environmental quality [15]. These findings suggest that the mobile incinerator represents a practical and environmentally improved alternative for managing yard waste within university campuses.

A limitation of the present study is that it did not evaluate the potential formation of secondary pollutants, particularly dioxins and furans, which may be generated when the combustion temperature is inadequately controlled, as reported by Tran Van Vang and Tran Thanh Son [12]. Future research will focus on optimizing combustion chamber temperature, assessing the formation

of secondary pollutants under different operating conditions, and refining the operational parameters to ensure stable performance and broader applicability of the proposed incineration model for garden waste with varying moisture contents.

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