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Assessing Traditional Composting Monitoring Limitations to Inform Real-Time IoT-Based Monitoring: A Feasibility Study at the Kenya Institute of Organic Farming

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Abstract: *The rapid urbanization in developing countries has increased the volumes of municipal solid waste, wherein 40%–70% is organic waste. Whereas composting is one of the sustainable methods used to treat organic waste and for climate mitigation, its effectiveness can slow down due to poor monitoring practices. Traditional composting practices at the Kenya Institute of Organic Farming rely mainly on traditional monitoring, resulting in inconsistent compost quality, inefficient decomposition, and limited capacity to track or reduce greenhouse gas emissions (GHG). The purpose of this study is to assess the limitations of current composting practices at the Kenya Institute of Organic Farming in terms of monitoring accuracy, parameter consistency, and GHG estimation capability as a foundational step toward designing a real-time IoT monitoring system. A case study design was employed. Structured questionnaires were administered to a sample of 20 composting practitioners at the Kenya Institute of Organic Farming using purposive sampling. Quantitative data were analyzed using descriptive statistics, chi-square tests, and Spearman rank-order correlations, and qualitative data from each question's responses were subjected to inductive thematic coding. The findings revealed that moisture imbalance and temperature instability were the main operational challenges. Respondents strongly agreed that traditional monitoring is insufficient, and a chi-square test confirmed that these perceptions are universal across composting technologies. The study concludes that traditional monitoring constitutes a systemic limitation at the Kenya Institute of Organic Farming, regardless of the composting technology used. The study recommends accelerating the adoption and implementation of IoT-based real-time monitoring systems.*

Keywords: *IoT monitoring; composting; traditional monitoring limitations; greenhouse gas emissions; Kenya; organic farming; climate change mitigation.*

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1. Introduction

Climate change is one of the most pressing global environmental challenges, driven mainly by greenhouse gas (GHG) emissions from human activities such as agriculture, waste mismanagement, and industrial processes (Sahu & Arya, 2024). Studies show that organic waste makes up approximately 40–70% of all municipal solid waste, especially in developing countries, consisting primarily of food waste, garden waste, and other biodegradable materials (Sharma et al., 2020; Wei et al., 2017). Composting is a controlled aerobic biological process that converts organic waste into nutrient-rich fertilizer (Ayilara et al., 2020). When managed effectively, it prevents methane emissions, sequesters soil carbon, and supports sustainable agricultural production. However, the effectiveness of composting in achieving these environmental outcomes depends critically on maintaining optimal process conditions particularly temperature, moisture content, pH, and aeration within defined ranges throughout the decomposition cycle (Symeon et al., 2025; Anayet et al., 2024).

Traditional composting methods used in agricultural institutions depend on periodic physical inspection to assess process conditions. As noted by Awasthi et al. (2015), this approach leads to inconsistent compost quality, inefficient decomposition cycles, and elevated Green House Gas emissions due to undetected anaerobic conditions. The inability to monitor composting parameters continuously means that process failures moisture imbalance, temperature collapse, or anaerobic transition often go undetected until visible symptoms appear, by which time significant quality and emissions damage has already occurred.

The Kenya Institute of Organic Farming (KIOF) operates functional composting facilities that process crop residues, food waste, and animal manure into compost for use in organic farming demonstrations and training programs. Despite KIOF's central role in promoting sustainable agriculture in Kenya, composting operations rely predominantly on traditional monitoring. This study assesses the current status of these composting practices and tests whether the type of composting technology employed is associated with practitioners' perceptions of traditional monitoring limitations, a foundational question for determining the readiness and urgency of transitioning to an IoT-based real-time monitoring system.

1.1 Statement of the Problem

Organic waste mismanagement is a significant environmental challenge in developing countries, where most waste is biodegradable (Sharma & Jain, 2020). Poorly managed organic waste produces methane, a potent greenhouse gas that contributes to climate change (Wei et al., 2017). Although composting is an effective and environmentally friendly method of managing organic waste, traditional composting practices rely on manual monitoring, which is labor-intensive, prone to human error, and unable to provide continuous real-time information (Fan et al., 2022). At the Kenya Institute of Organic Farming (KIOF), these limits effective monitoring of critical composting parameters such as temperature, moisture, and pH (Anayet et al., 2024), leading to inefficient decomposition, lower compost quality, and increased greenhouse gas emissions. Consequently, there is a need for an affordable IoT-based real-time monitoring prototype that can continuously monitor composting conditions, enable timely management decisions, improve compost quality, reduce emissions, and promote climate-smart organic waste management in.

1.2 Objective

To assess the limitations of traditional composting monitoring practices at the Kenya Institute of Organic Farming as a basis for designing a real-time IoT monitoring system.

1.3 Questions

1. What are the current composting monitoring practices at the Kenya Institute of Organic Farming (KIOF)?

2. What are the limitations of traditional composting monitoring practices at KIOF?

3. What is the perceived feasibility and potential effectiveness of an IoT-based real-time compost monitoring system in addressing these limitations?

2. Literature Review

2.1 Composting and Environmental Parameter Management

Composting is a managed aerobic biological process in which microorganisms decompose organic matter into a stable, humus-like material. Operational parameters that directly affect microbial activity during composting, including aeration, temperature, moisture, C/N ratio, and pH must be carefully managed to achieve efficient decomposition and quality end product (Rath et al., 2022). Optimal decomposition occurs within a temperature range of 40–65°C, with effective pathogen elimination requiring sustained temperatures of 55°C (Noor et al., 2024). Moisture content must be maintained between 50% and 60% to support microbial activity without creating anaerobic conditions (Guo et al. 2012). When these parameters are not maintained, aerobic decomposition transitions to anaerobic decomposition, producing methane a GHG approximately 28–34 times more potent than carbon dioxide over 100 years (Intergovernmental Panel on Climate Change-IPCC, 2021).

The consequences of inadequate parameter monitoring are well documented. Bernal et al. (2017) observed that institutions relying on visual and traditional inspection miss the early indicators of process deviation, leading to prolonged composting cycles, nutrient loss, and higher emissions. Yeo et al. (2020) found that decentralized composting in Sub-Saharan Africa has significant potential in reducing material flows and GHG emissions.

2.2 The Need to Assess Composting Monitoring Practices

According to Hemidat et al. (2018), evaluation of composting monitoring systems serves multiple purposes. These includes identifying process failures, establishing practitioner perceptions of current system adequacy, and determining the design requirements for improved monitoring interventions. Awasthi et al. (2015) state that real-time monitoring of composting parameters is essential for achieving consistent compost quality and reducing GHG emissions. Nikoloudakis et al. (2018) demonstrated that IoT-based compost monitoring systems can significantly improve process efficiency and environmental outcomes.

Before IoT solutions can be meaningfully designed and deployed, the specific limitations of current traditional practice must be empirically established, a gap this study addresses. This aligns with Rogers (2003) Diffusion of Innovations theory, which posits that an innovation's perceived relative advantage over existing practices is the strongest predictor of adoption. Universal dissatisfaction with a current practice, as hypothesized here, constitutes the foundational condition for such perceived advantage.

2.3 Limitations of Traditional Monitoring in Composting Practice

Traditional monitoring of composting processes is characterized by several systematic limitations. Firstly, infrequent inspection creates temporal blind spots in which parameter deviations develop undetected (Fan et al., 2022). Secondly, the lack of standardized measurement instruments means that traditional temperature and moisture assessments are subjective and difficult to reproduce consistently across operators or time periods. Finally, the inability to measure gas emissions particularly methane, carbon dioxide, and ammonia means that the environmental impact of traditional composting operations cannot be quantified or managed effectively (Wei et al., 2017). These limitations are particularly consequential in institutional settings like KIOF, where composting serves both a production function and a training and demonstration function.

2.4 Conceptual Framework

The conceptual framework illustrates the relationship linking composting practice variables and the perceived limitations of traditional monitoring. The independent variables include technology type, monitoring method, and operational intensity effect the dependent variable, which is the perceived limitations of traditional composting monitoring. Institutional context, staff experience, infrastructure availability, and policy framework serve as moderating variables.

Conceptual Framework

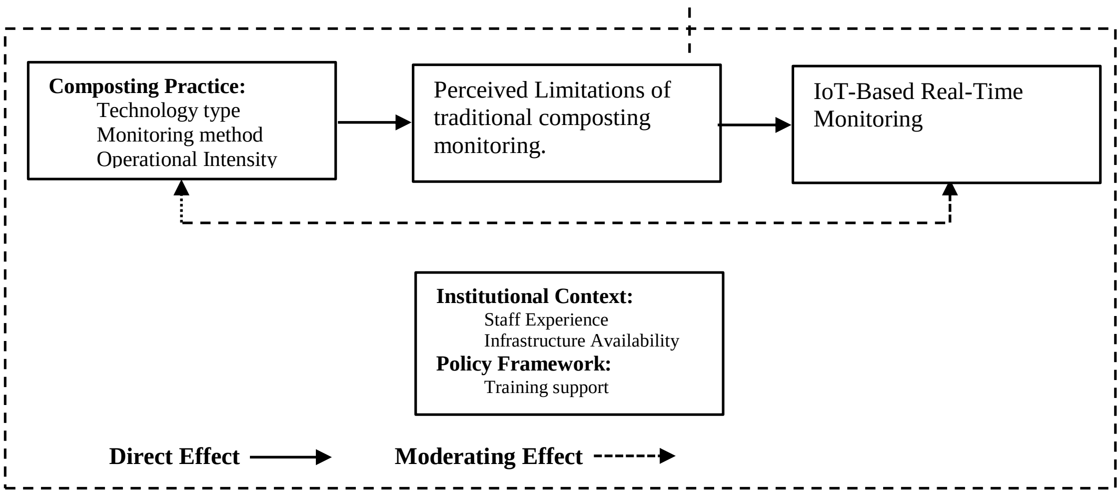

Figure 1: Conceptual framework linking composting practices to perceived traditional monitoring limitations

Source: Author, 2026

3. Methodology

2.5 Research Design

The study used a case study research design, which Yin (2003) identifies as one of the most effective research designs for information systems research due to its capacity to capture the interaction between technology and organizational context in depth. KIOF was selected because it is Kenya's leading institution for organic agriculture training and demonstration, and because its composting operations represent a practical test case for IoT monitoring feasibility in a resource-constrained developing country context.

2.6 Population and Sampling

The study population comprised farm technicians, composting attendants/operators, farm and soil management personnel, composting management staff, supervisors/instructors, trainers, and students who had direct experience with composting activities at the facility.

A total of 20 structured questionnaires were administered to all consenting participants. All 20 respondents completed the survey, yielding a 100% response rate. Purposive sampling was used to ensure that only participants with direct composting experience, management responsibility, supervisory roles, or training involvement were included.

2.7 Data Collection Instruments

Primary data were collected using a structured questionnaire developed based on the study objectives and relevant literature. The questionnaire consisted of both closed-ended and open-ended questions. Closed-ended questions were used to collect quantitative data on respondents' demographic characteristics, composting practices, operational challenges, and perceptions of traditional monitoring practices using a five-point Likert scale. Open-ended questions allowed respondents to provide additional information regarding the challenges and opportunities associated with compost monitoring. An observation checklist was also used to document existing composting practices and monitoring procedures at the study site, thereby complementing the questionnaire data.

2.8 Data Collection Procedure

The questionnaire was developed and administered electronically using KoboToolbox, an open-source digital data collection platform. The use of KoboToolbox enhanced data quality by minimizing data entry errors, facilitating real-time data capture, and ensuring secure storage of responses. In addition, direct observations of composting activities were conducted to validate questionnaire responses and provide contextual information on existing monitoring practices.

2.9 Data Analysis

Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize respondents' demographic characteristics and perceptions of traditional composting monitoring practices.

To examine relationships between variables, inferential statistical techniques were employed. The Chi-square test of independence was used to determine whether perceptions of traditional monitoring limitations differed according to the composting technologies used, while Spearman's rank-order correlation was applied to examine the relationship between perceived monitoring limitations and the expected effectiveness of IoT-based compost monitoring.

Qualitative data obtained from open-ended questions were analyzed using inductive thematic analysis. Responses were coded, categorized into emerging themes, and interpreted alongside the quantitative findings to provide a comprehensive understanding of the current limitations of traditional compost monitoring practices.

2.10 Ethical Considerations

Ethical approval for the study was obtained from the relevant institutional ethics committee, and a research permit was granted by the NACOSTI before data collection commenced. Permission to conduct the study was also obtained from the management of the KIOF.

Participation in the study was entirely voluntary. All participants were informed of the objectives of the research and provided informed consent before completing the questionnaire. Respondents' anonymity and confidentiality were maintained by ensuring that no personally identifiable information was collected. The data were stored securely and used exclusively for academic and research purposes in accordance with established ethical research principles.

4. Results and Discussion

4.1 Role of Respondents at the Composting Facility

The role distribution of the respondents shows that composting attendants/operators formed the largest group of respondents, accounting for 52.9% of valid responses. This indicates that most respondents were directly involved in the practical operations of the composting facility, including waste collection, sorting, compost production, and process monitoring. Farm and soil management personnel represented 17.6%, while composting managers/process managers and supervisors/instructors each accounted for 11.8%. Students or trainees represented 5.9% of the valid responses. Overall, the findings show that the study captured perspectives from operational, managerial, supervisory, technical, and learning roles within the composting facility.

4.2 Educational Level of Respondents

The educational levels of respondents. The majority (35.0%) held bachelor's degrees, while 30.0% each reported certificate and diploma qualifications. Only one respondent (5.0%) held a master's degree. The prevalence of tertiary-level education is encouraging for technology-based interventions, as higher educational attainment generally correlates with greater receptivity to innovation (Rogers, 2003).

4.3 Composting Experience of Respondents

The majority of respondents (65.0%) had 1 to 5 years of composting experience, while 35.0% had less than 1 year. No respondent had more than 5 years of experience. This early-career profile may partly explain the challenges encountered with traditional monitoring systems (Fan et al., 2022) and simultaneously supports the case for technology-driven solutions that can supplement expertise gaps.

4.4 Main Objectives of the Composting Facility

Analysis of open-ended responses from 15 of 20 respondents revealed four thematic clusters regarding the main objectives of the composting facility. The dominant theme was farm use and on-site agricultural application (n=8; 53.3%), with many respondents describing composting in purely utilitarian terms as an agricultural input, suggesting a limited awareness of its broader environmental co-benefits. The second theme, organic waste recycling and environmental protection (n=4; 26.7%), reflected a more systems-oriented understanding, with respondents linking composting to waste reduction, soil health, and reduced chemical fertilizer dependence perspectives closely aligned with Sustainable Development Goal 2 (SDG2) and Sustainable Development Goal 12 (SDG12) frameworks (Ayilara et al., 2020). A smaller group (n=2; 13.3%) focused on soil fertility and compost quality optimization (Bernal et al., 2017), emphasizing input material

selection and product quality orientations particularly receptive to IoT-based monitoring solutions. One respondent (6.7%) identified education and community knowledge sharing as the facility's primary objective, reflecting KIOF's broader institutional mandate as an organic farming training center.

The distribution indicates a predominantly utilitarian workforce orientation, alongside a meaningful subset with environmental and quality-focused consciousness. This heterogeneity in objective framing suggests that IoT adoption messaging should be tailored to different staff cohorts (Rogers, 2003), emphasizing operational efficiency for agriculturally-oriented staff while foregrounding environmental accountability and pedagogical value for those with broader sustainability perspectives.

4.5 Status of Composting Technology at KIOF composting methods employed at KIOF (multiple responses allowed)

Table 1 shows the composting methods employed at KIOF. Open heap composting was the most widely used (70.0%), followed by pit composting (35.0%) and windrow composting (5.0%). Thermophilic composting, vermicomposting, and in-vessel methods were not reported.

Table 1: Composting methods employed at KIOF (multiple responses allowed)

Composting Method	Frequency (n)	% Of Respondents
Open Heap	14	70.0
Pit Composting	7	35.0
Windrow Composting	1	5.0
Thermophilic Composting	0	0.0
Vermicomposting	0	0.0
In-vessel Composting	0	0.0
Open Heap	14	70.0

Note: n = 20; multiple responses permitted. Percentages exceed 100% due to multiple selections. Source: Field Data, 2026.

4.6 Average Compost Maturation Period

Figure 2 below presents the distribution of average compost maturation periods. The variability in maturation shows that more than half of respondents (55.0%; n = 11) reported a maturation cycle of 6 to 8 weeks, while 20.0% (n = 4) reported cycles of 9 to 12 weeks. Three respondents (15.0%) reported cycles of less than 6 weeks, and 2 respondents (10.0%) reported cycles exceeding 12 weeks. The variability in maturation periods signals the absence of standardized process control, consistent with the dominance of open-heap composting methods (Guo et al., 2012).

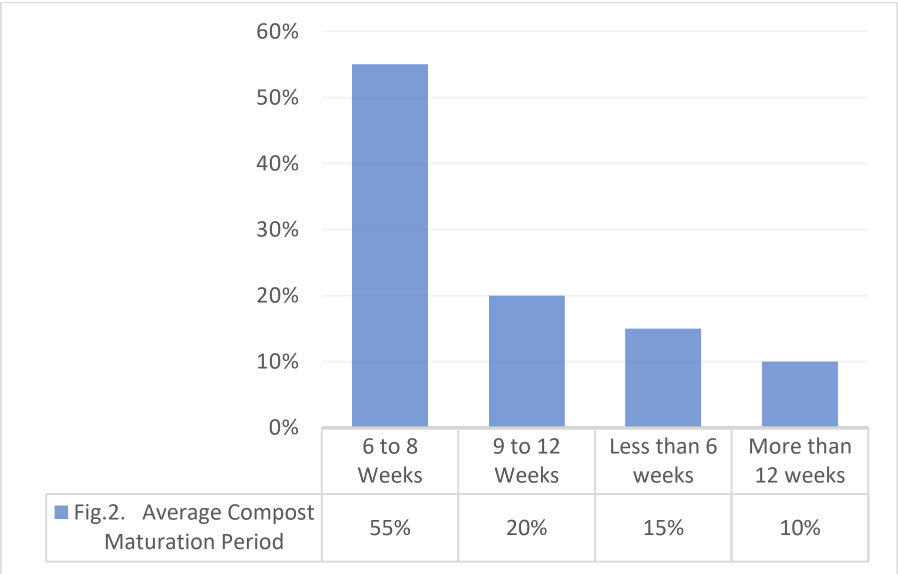

Figure. 2: Distribution of Average Compost Maturation periods

Source: Field Data, 2026

4.7 Operational Challenges Affecting Composting Efficiency

Figure 3 below presents the operational challenges most frequently cited by respondents. Moisture imbalance was the most prevalent challenge (80.0%; n = 16), followed by temperature instability (65.0%; n = 13), poor aeration (30.0%; n = 6), inconsistent compost quality (25.0%; n = 5), and odour emissions (15.0%; n = 3). These findings align with empirical investigation, which confirms that initial moisture content significantly influences composting temperature rise and microbial activity, with temperature identified as the largest environmental factor affecting bacterial community succession, while moisture content directly modulates the rate of heating and decomposition during the mesophilic phase (Li et al. 2023).

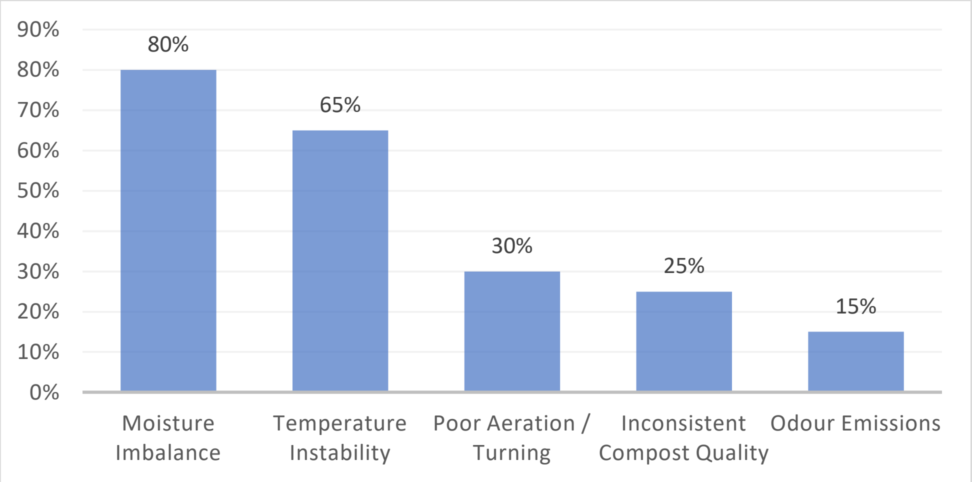

Figure 3: Operational Challenges Affecting Compost Efficiency

Source: Field Data, 2026

4.8 Perceived Limitations of Traditional Monitoring

Table 2 presents the Likert-scale responses on perceptions of traditional monitoring limitations. Across all three indicators, respondents expressed strong agreement that traditional monitoring is insufficient, with mean scores ranging from 4.05 to 4.25. The highest agreement was recorded for inconsistent monitoring of temperature, moisture, and pH (M = 4.25, SD = 1.02), interpreted as 'Strongly Agree' (4.21–5.00) (Anayet et al., 2024). The statement regarding difficulty in estimating GHG emissions recorded M = 4.05 (SD = 1.23) (Wei et al., 2017).

Table 2. Responses on Perceived limitations of Current Composting Monitoring Practices

Statement	SD n(%)	D n(%)	N n(%)	A n(%)	SA n(%)	Mean	SD	Interpretation
Traditional monitoring limits accuracy	1(5%)	0(0%)	2(10%)	9(45%)	8(40%)	4.15	0.99	Agree
Inconsistent monitoring of temperature, moisture & pH affects quality	1(5%)	0(0%)	2(10%)	7(35%)	10(50%)	4.25	1.02	Strongly Agree
Difficulty estimating and reducing GHG emissions traditionally	2(10%)	0(0%)	2(10%)	7(35%)	9(45%)	4.05	1.23	Agree
Statement	SD n(%)	D n(%)	N n(%)	A n(%)	SA n(%)	Mean	SD	Interpretation

ral; 3.41–4.20 = Agree; 4.21–5.00 = Strongly Agree. Source: Field Data, 2026.

Additional Qualitative Comments on Composting Practice Limitations

Open-ended responses from 14 of 20 respondents yielded five thematic categories reflecting the broader operational constraints facing the composting facility. The most prevalent theme was inadequate parameter monitoring of temperature, moisture, and pH (n=7; 50.0%), with respondents consistently describing current monitoring practices as technically insufficient. This qualitative convergence strongly reinforces the structured Likert findings (Q9, M=4.15; Q10, M=4.25), and notably, several respondents independently articulated the very operational gap that the IoT prototype is designed to address.

The second theme, lack of technical expertise and knowledge (n=3; 21.4%), indicated that staff were aware of their own capability limitations, a form of metacognitive awareness generally conducive to technology adoption. Output quality and human resource gaps (n=2; 14.3%) highlighted how labour scarcity contributes to monitoring inconsistency (Fan et al., 2022), which in turn produces variable compost quality, further reinforcing the case for automated monitoring as a labour augmentation tool. Financial and capital constraints (n=1; 7.1%) and infrastructure and environmental challenges (n=1; 7.1%), though minority views, carry practical design implications pointing toward the use of low-cost open-source sensor platforms and waterproof hardware enclosures respectively.

Collectively, these themes reveal a coherent and mutually reinforcing pattern of systemic limitation, wherein inadequate monitoring serves as the root constraint underpinning quality inconsistency, knowledge gaps, and capital justification challenges. The fact that practitioners independently identified real-time automated parameter monitoring as the most critical operational need lends strong grassroots credibility to the study's central research premise.

4.9 Internet of Things Awareness and Feasibility Assessment

The assessment shows that staff at the KIOF have a positive view of using IoT for compost monitoring. Respondents showed moderate to high awareness of IoT and understood its usefulness in agriculture and waste management. However, their practical experience with IoT tools is still limited. Most respondents agreed that IoT-based compost monitoring is feasible and beneficial because sensors can track temperature, moisture, and gas emissions in real time. This can improve decision-making, reduce manual work, and support better compost quality. However, challenges such as cost, technical skills, and maintenance must be addressed through training and support.

4.10 Prior Awareness of IoT Technologies

Figure 4 shows that 11 respondents (55.0%) had no prior awareness of IoT technologies, while 9 (45.0%) were aware. Among those aware, familiarity was mainly moderate (n=5; 55.6%), with fewer reporting low (n=2; 22.2%) or very low familiarity (n=1; 11.1%). Only 3 respondents (33.3%) had hands-on IoT experience, mainly in smart energy management. Overall, awareness existed, but practical experience was limited, highlighting the need for capacity-building and structured training to support successful implementation within the target population effectively (Rogers, 2003).

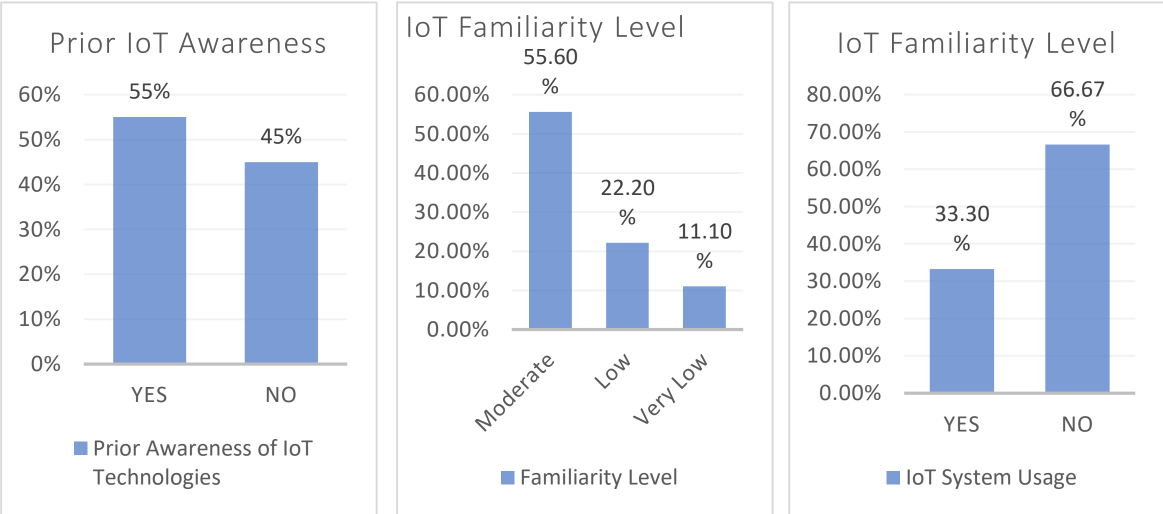

Figure 4: IoT Awareness and Prior Usage

Source: Field Data, 2026

4.11 Parameters Recommended for Continuous IoT Monitoring

Respondents were asked to identify which composting parameters they believed should be continuously monitored by the proposed IoT prototype. As shown in Table 10, temperature (80.0%; n=16) and moisture (75.0%; n=15) were most frequently selected, confirming their primacy as operational control variables. pH was selected by 9 respondents (45.0%), gas emissions by 5 (25.0%), and oxygen by 4 (20.0%). Composting, like other biological processes, is affected by nutrient availability and environmental conditions, with moisture content, C/N ratio, particle size, pH, and oxygen content consistently identified across the scientific literature (Anayet et al., 2024; Guo et al., 2012) as the key parameters that influence the process parameters that must be both initially adjusted and continuously monitored to ensure effective decomposition. and directly inform the sensor configuration for the IoT prototype design.

Table 3. Parameters Recommended for Continuous IoT Monitoring (multiple responses allowed)

Parameter	Frequency (n)	Percentage (%)
Temperature	16	80.0
Moisture	15	75.0
Ph	9	45.0
Gas Emissions	5	25.0
Oxygen	4	20.0

Note: n = 20; multiple responses permitted. Source: Field Data, 2026.

4.12 Preferred Monitoring Frequency

Respondents' preferred monitoring frequency was distributed across four options. The largest single group (45.0%; n=9) preferred weekly monitoring, followed by real-time continuous monitoring (25.0%; n=5), once-daily monitoring (20.0%; n=4), and several times daily (10.0%; n=2). The preference for weekly monitoring among a plurality may reflect concerns about data overload or unfamiliarity with real-time systems. However, the combined preference for sub-daily or real-time monitoring (55.0% aggregate) supports the viability of a continuous IoT monitoring approach, particularly given the dynamic nature of composting biochemistry (Fan et al., 2022).

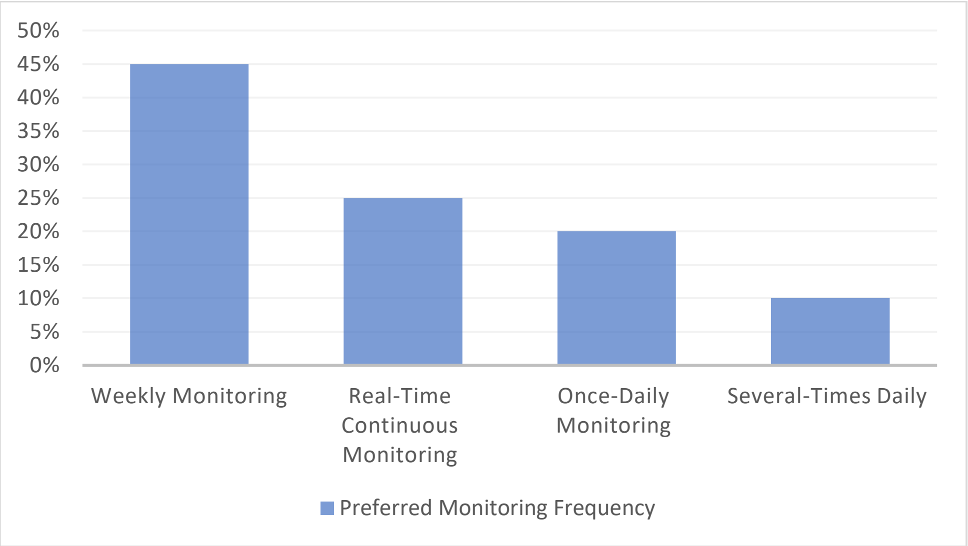

Figure 5: Preferred Monitoring Frequency among Respondents (source: field data, 2026)

4.13 Available Infrastructure for IoT Deployment

Table 4 presents available infrastructure for IoT deployment. Internet connectivity was the most widely available asset (80.0%), followed by smartphone access (50.0%). Reliable electricity and solar power were each available to only 30.0% of respondents, presenting a deployment challenge that must be addressed through solar-powered IoT node design.

Table 4. Available infrastructure for IoT Deployment (multiple responses)

Infrastructure Type	Frequency (n)	Percentage (%)
Internet Connectivity	16	80.0
Smartphone Access	10	50.0
Reliable Electricity	6	30.0
Solar Power	6	30.0

Source: Field Data, 2026 (n=20; multiple responses permitted).

4.14 Preferred Alert and Notification Methods Identified for IoT Monitoring System

The preferred alert and notification methods identified by respondents. Email notifications were overwhelmingly preferred, selected by 14 respondents (70.0%). SMS alerts were preferred by 5 respondents (25.0%), and a web dashboard by 1 respondent (5.0%). No respondent selected a mobile app dashboard. The strong preference for email-based notifications aligns with the high internet connectivity reported (80.0%) and suggests that the IoT prototype's alert module should prioritize email integration as its primary communication channel.

4.15 IoT Prototype Effectiveness Evaluation

The evaluation shows that respondents at KIOF viewed the IoT compost monitoring prototype as useful and effective. They believed the system could improve composting by monitoring temperature, moisture, and gas emissions in real time, thereby reducing dependence on manual checks and enabling better decision-making using accurate data (Fan et al., 2022). Respondents also felt that the prototype could improve compost quality, support better process control, and reduce the risk of composting failure (Bernal et al., 2017). It may also help reduce GHG emissions through improved aeration and moisture control (Guo et al., 2012). However, cost, maintenance, and staff training remain important challenges.

4.16 Perceived Impact on Compost Quality

Respondents strongly affirmed the potential of real-time IoT monitoring to improve compost quality (Table 5). The statement recorded a mean Likert score of M = 4.40 (SD = 1.05), indicating strong agreement among respondents. In terms of distribution, 13 respondents (65.0%) strongly agreed, 4 respondents (20.0%) agreed, 2 respondents (10.0%) were neutral, and 1 respondent (5.0%) strongly disagreed. This pattern of responses demonstrates a clear dominance of positive perceptions toward the effectiveness of IoT-based monitoring in composting processes.

The high level of agreement reflects respondents' recognition of the limitations associated with manual monitoring and their confidence that automated, real-time data collection would significantly enhance consistency in compost quality (Li et al., 2023). Overall, these findings suggest strong perceived effectiveness of the IoT prototype in improving operational efficiency and supporting more reliable composting outcomes at KIOF.

Table 5. Real-Time Monitoring would Improve Compost Quality

Response	Frequency (n)	Percentage (%)	Cumulative (%)
Strongly Disagree (SD)	1	5.0	5%
Disagree (D)	0	0.0	5%
Neutral (N)	2	10.0	15%
Agree (A)	4	20.0	35%
Strongly Agree (SA)	13	65.0	100%
Total | Mean = 4.40 | SD = 1.05	20	100.0	-

Source: Field Data, 2026.

4.17 Estimated Reduction in Composting Time

Table 6 shows the estimated percentage reduction in composting time respondents attributed to IoT monitoring. Half of all respondents (50.0%; n=10) projected a reduction of more than 40%, while 6 respondents (30.0%) estimated reductions in the 11–25% range. Two respondents (10.0%) each estimated reductions in the 1–10% and 26–40% ranges. The aggregate of respondents anticipating reductions of 11% or greater amounts to 90.0% of the sample, illustrating strong confidence in the time-optimization potential of the proposed technology

.

Table 6. Estimated Reduction in Composting Time Using IoT Monitoring

Estimated Reduction Range	Frequency (n)	Percentage (%)
0%	0	0.0
1 – 10%	2	10%
11 – 25%	6	30%
26 – 40%	2	10%
More than 40%	10	50%
Total	20	100%

Source: Field Data, 2026.

4.18 Effectiveness in Reducing Odour and GHG Emissions

Regarding the potential of IoT monitoring to reduce odour and GHG emissions, Figure 6 illustrates that 9 respondents (45.0%) rated the technology as "Extremely Effective," while 4 respondents (20.0%) considered it "Very Effective," and 5 respondents (25.0%) rated it as "Moderately Effective." In contrast, only 2 respondents (10.0%) indicated that the system is "Slightly Effective," and none rated it as "Not Effective." The cumulative proportion of responses from "Moderately Effective" and above accounts for 90.0%, indicating a strong overall positive perception of the system's effectiveness.

This distribution demonstrates a clear consensus among respondents regarding the environmental benefits of IoT-enabled composting systems, particularly in reducing odour and GHG emissions. The high concentration of positive ratings suggests that respondents recognize the importance of improved process monitoring, especially in regulating temperature, moisture, and aeration, as a key mechanism for minimizing emissions (Guo et al., 2012; Wei et al., 2017) and enhancing environmental sustainability in composting operations.

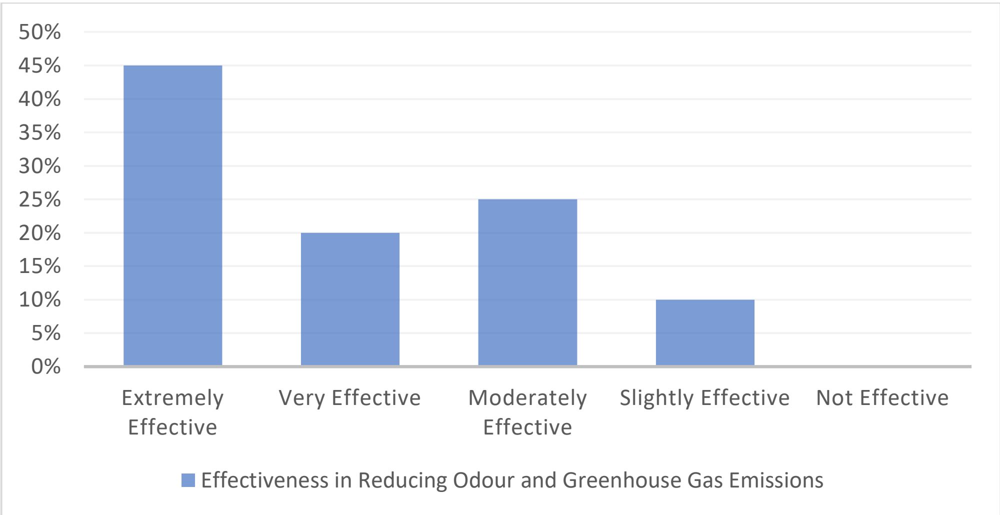

Figure. 6. Effectiveness in Reducing Odour and GHG Emissions

4.19 IoT and Scalability of Compost Production

The statement that IoT monitoring would enhance the scalability of compost production elicited strong positive responses (Table 7). The mean score was 4.30 (SD = 0.98), indicating collective agreement. Ten respondents (50.0%) strongly agreed and 8 (40.0%) agreed, yielding a cumulative agreement rate of 90.0%. This near-consensus view reinforces the transformational potential of IoT technology not merely as a quality-assurance tool but as a strategic instrument for scaling KIOF's composting enterprise (Nikoloudakis et al., 2018).

Table 7. IOT Monitoring would Enhance Scalability of Compost Production

Response	Frequency (n)	Percentage (%)	Cumulative (%)
Strongly Disagree (SD)	1	5.0	5%
Disagree (D)	0	0.0	5%
Neutral (N)	1	5.0	10%
Agree (A)	8	40.0	50%
Strongly Agree (SA)	10	50.0	100%
Total | Mean = 4.30 | SD = 0.98	20	100.0	—

Source: Field Data, 2026.

4.20 Contribution to Climate Change Mitigation in Kenya

Respondents were asked to rate the overall contribution that IoT-supported composting could make to climate change mitigation in Kenya. 10 respondents (50.0%) rated the contribution as ‘Very High’, 4 (20.0%) as ‘High’, and 5 (25.0%) as ‘Moderate.’ Notably, no respondent rated the contribution as ‘None’ or ‘Low’, indicating unanimous acknowledgement of the technology’s positive environmental implications.

4.21 Discussions

4.21.1 Interpretation of Key Findings

The findings show that traditional composting monitoring at KIOF is inadequate, and this inadequacy is recognized by practitioners across technology type, age, education, and experience.

Moisture imbalance (80.0%) and temperature instability (65.0%) emerged as the main operational challenges. This supports Haug (2018), who identified moisture and temperature control as critical to decomposition efficiency. Fan et al. (2022) also emphasized real-time monitoring as essential for improving compost stability and uniformity. The reliance on open heap (70.0%) and pit composting (35.0%) further increases vulnerability, as these systems are exposed to environmental fluctuations that traditional inspection cannot effectively monitor (Wei et al., 2017).

4.21.2 Chi-Square Test: Composting Technology and Manual Monitoring Limitation

A chi-square test was conducted to examine whether the type of composting technology (traditional vs. modern) is associated with perceived limitations of manual monitoring in terms of accuracy and consistency.

The results revealed χ^2 (3) = 2.031, p = 0.566. This indicates that there is no statistically significant association between the type of composting technology used and perceptions of manual monitoring limitations. This finding may be influenced by the relatively small number of respondents using modern composting technologies (n = 4). However, it suggests that the perception of manual monitoring as a limitation is a cross-cutting issue shared across both traditional and modern system users, highlighting a universal operational concern.

This finding resonates with Rogers' (2003) Diffusion of Innovations theory. The theory holds that the perception of a new technology's relative advantage over current practice is the most powerful driver of adoption. When dissatisfaction with current practice is universal, as demonstrated here, the perceived relative advantage of an IoT-based monitoring system is maximized, creating optimal conditions for adoption.

4.21.3 Spearman Correlation: Manual Monitoring Limitations and Expected IoT Quality Improvement

Spearman's rank-order correlation was used to examine the relationship between perceived limitations of manual monitoring and anticipated IoT-driven improvements in compost quality, given the ordinal nature of the Likert-scale data.

The results show a strong positive and statistically significant relationship between manual monitoring limitations and expected IoT quality improvement, with a correlation coefficient of $r_s = 0.726$ and $p = 0.0003$. This indicates that respondents who strongly perceived manual monitoring as limiting were also more likely to believe that IoT-based monitoring would significantly improve compost quality. This finding is consistent with theoretical expectations (Rogers, 2003) and provides empirical evidence supporting the study's core assumption that deficiencies in manual monitoring drive the perceived value of IoT-based solutions in composting systems.

4.21.4 Spearman Correlation: Monitoring Quality Concerns and IoT Scalability

A further Spearman correlation analysis was conducted to examine the relationship between perceived monitoring-related quality degradation and perceptions of IoT scalability benefits.

The results indicate a very strong and statistically significant positive correlation ($r_s = 0.844$, $p < 0.0001$). This implies that respondents who more strongly perceived monitoring deficiencies as a cause of reduced compost quality were also more likely to believe that IoT systems would enhance the scalability of composting operations.

Overall, the findings suggest that concerns about current monitoring inefficiencies are a key driver of acceptance of IoT solutions (Rogers, 2003). They further highlight that improving monitoring systems is perceived as the most important factor in enabling the expansion and scalability of composting operations at KIOF (Nikoloudakis et al., 2018).

5. Conclusion and Recommendations

5.1 Conclusion

The aim of this study was to evaluate the current status of composting practices and the limitations of traditional monitoring methods in organic waste composting as a foundational assessment for the design of an IoT-based monitoring mode. The findings from 20 respondents, all with direct composting experience, produce a consistent and convergent picture.

The respondent profile reveals a predominantly young, relatively educated, and early-career workforce, can be able to adopt digital monitoring technologies with appropriate support. Traditionally managed open heap and pit composting dominate KIOF's operations, creating maximum exposure to the environmental variability that traditional monitoring cannot adequately track. Maturation cycles vary widely from under 6 weeks to over 12 weeks reflecting the absence of standardized process control attributable directly to monitoring deficits.

Moisture imbalance and temperature instability are the primary operational challenges the same parameters that traditional inspection is least equipped to monitor continuously and accurately. The study further concludes that traditional monitoring limits accuracy, consistency, and GHG estimation capability. The limitation is in the monitoring practice, not in the technology that relies on it. The current status of composting at KIOF is therefore characterized by a universal monitoring deficit that constitutes clear empirical justification for the design and deployment of a real-time IoT monitoring prototype. The proposed IoT model provides an effective framework for real-time monitoring and optimization of organic waste composting processes, thereby enhancing efficiency, sustainability, and climate change mitigation efforts.

5.2 Recommendations

1. The study recommends that KIOF prioritize the deployment of a real-time IoT monitoring prototype incorporating both minimum temperature and moisture sensors, as these are the parameters most critically implicated in the operational challenges documented here.

2. Future studies should implement and evaluate the proposed IoT prototype under operational conditions to determine its impact on compost quality, greenhouse gas emission reduction, and compost maturation time.

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References

Anayet, A. H., Hamzah, M. M. H. B., & Najib, M. Z. M. (2024). Optimizing food waste decomposition through pH, moisture content, and temperature control: A comprehensive study. Civil and Sustainable Urban Engineering, 4(1), 42-54. https://doi.org/10.53623/csue.v4i1.411

Awasthi, M. K., Pandey, A. K., Bundela, P. S., & Khan, J. (2015). Co-composting of organic fraction of municipal solid waste mixed with different bulking waste: Characterization of physicochemical parameters and microbial enzymatic dynamic. Bioresource Technology, 182, 200-207. https://doi.org/10.1016/j.biortech.2015.01.104

Ayilara, M. S., Olanrewaju, O. S., Babalola, O. O., & Odeyemi, O. (2020). Waste management through composting: Challenges and potentials. *Sustainability, 12*(11), 4456. https://doi.org/10.3390/su12114456

Bernal, M. P., Sommer, S. G., Chadwick, D., Qing, C., Guoxue, L., & Michel, F. C. (2017). Current approaches and future trends in compost quality criteria for agronomic, environmental, and human health benefits. *Advances in Agronomy*, 144, 143-233. https://doi.org/10.1016/bs.agron.2017.03.002

Fan, Y., Wang, X., Funk, T., Rashid, I., Herman, B., Bompoti, N., Mahmud, M. S., Chrysochoou, M., Yang, M., Vadas, T. M., Lei, Y., & Li, B. (2022). A critical review for real-time continuous soil monitoring: Advantages, challenges, and perspectives. *Environmental Science & Technology, 56*(19), 13546-13564. https://doi.org/10.1021/acs.est.2c03562

Guo, R., Li, G., Jiang, T., Schuchardt, F., Chen, T., Zhao, Y., & Shen, Y. (2012). Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost. *Bioresource Technology*, 112, 171-178.

Haug, R. (2018). The practical handbook of compost engineering. Routledge.

Hemidat, S., Jaar, M., Nassour, A., & Nelles, M. (2018). Monitoring of composting process parameters: a case study in Jordan. *Waste and Biomass Valorization*, *9*(12), 2257-2274. https://doi.org/10.1007/s12649-018-0197-x

Intergovernmental Panel on Climate Change (IPCC). (2021). Climate change 2021: The physical science basis. Cambridge University Press.

Li, Y., Xue, Z., Li, S., Sun, X., & Hao, D. (2023). Prediction of composting maturity and identification of critical parameters for green waste compost using machine learning. *Bioresource Technology*, 385, 129444.

Nikoloudakis, Y., Panagiotakis, S., Manios, T., Markakis, E., & Pallis, E. (2018). Composting as a service: A real-world IoT implementation. *Future Internet, 10*(11), 107. https://doi.org/10.3390/fi10110107

Noor, R. S., Shah, A. N., Tahir, M. B., Umair, M., Nawaz, M., Ali, A., Ercisli, S., Abdelsalam, N. R., Ali, H. M., Yang, S. H., Ullah, S., & Assiri, M. A. (2024). Recent trends and advances in additive-mediated composting technology for agricultural waste resources: *A comprehensive review. ACS Omega, 9*(8), 8632-8653. https://doi.org/10.1021/acsomega.3c06516

Rath, P. P., Das, K., & Pattanaik, S. (2022). Microbial activity during composting and plant growth impact: A review. *Journal of Pure & Applied Microbiology, 16*(1), 63-73. https://doi.org/10.22207/JPAM.16.1.53

Rogers, E. M. (2003). Diffusion of innovations (5th ed.). Free Press.

Sahu, S., & Arya, S. K. (2024). Mitigation of greenhouse gas emissions in agriculture and food processing through sustainable management practices for climate change. In [Editor name(s)], (Ed.), Advances and technology development in greenhouse gases: Emission, capture and conversion (pp. 71-96). Elsevier. https://doi.org/10.1016/B978-0-443-19231-9.00010-7

Sharma, K. D., & Jain, S. (2020). Municipal solid waste generation, composition, and management: The global scenario. *Social Responsibility Journal*, *16*(6), 917-948. https://doi.org/10.1108/SRJ-06-2019-0210

Symeon, G. K., Akamati, K., Dotas, V., Karatosidi, D., Bizelis, I., & Laliotis, G. P. (2025). Manure management as a potential mitigation tool to eliminate greenhouse gas emissions in livestock systems. *Sustainability*, *17*(2), 586. https://doi.org/10.3390/su17020586

Wei, Y., Li, J., Shi, D., Liu, G., Zhao, Y., & Shimaoka, T. (2017). Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. Resources, Conservation and Recycling, 122, 51-65. https://doi.org/10.1016/j.resconrec.2017.01.024

Yeo, D., Dongo, K., Mertenat, A., Lüssenhop, P., Körner, I., & Zurbrügg, C. (2020). Material flows and greenhouse gas emissions reduction potential of decentralized composting in sub-Saharan Africa: A case study in Tiassalé, Côte D'Ivoire. *International Journal of Environmental Research and Public Health*, *17*(19), 7229. https://doi.org/10.3390/ijerph17197229

Yin, R. K. (2003). Case study research: Design and methods (3rd ed.). Sage Publications.