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CASE STUDY

Sustainability index analysis of organic fertilizer production from paunch manure and rice straw waste

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ABSTRACT

BACKGROUND AND OBJECTIVES: Substantial quantities of livestock waste and organic pollutants, such as nitrogen and phosphate, which pose environmental risks are generated from agriculture activities. A combination of paunch manure and rice straw is used as organic fertilizer. Therefore, this study confirmed sustainability of organic fertilizer from paunch manure and rice straw waste.
METHODS: Data were collected through focus group discussions and the closure of questionnaires which contained 29 attributes related to environmental, economic, social, and technological dimensions. The data collected was analyzed using the Multidimensional Scaling method, Rapfish software, and Monte Carlo analysis to ascertain the level of sustainability status and leverage attributes, and examine scoring errors and variations.
FINDINGS: Sustainability index for organic fertilizer production was 74.55 percent. The result showed that the method contributed to the growth of sustainability in various operational phases, including the processing and commercialization of organic fertilizer. According to analysis of the four dimensions, the environmental dimension held the highest leverage value at 90.1 percent, followed by social, economical, and technological dimensions at 70.50 percent, 63.69 percent, and 73.93 percent, respectively. This study identified seven leverage attributes that are very influential to sustainability of organic fertilizer production. These include water use and raw material efficiency, potential business scale increase, market absorption, the potential for public unrest, the manager or worker level of expertise in the manufacture of organic fertilizer as well as the process used to determine its quality and output.
CONCLUSION: The proposed inquiry conducted within the context of this study identified the pivotal factors that influenced organic fertilizer supply framework as the quality, quantity, and market absorption of organic production. As a result, the o use of agricultural waste as a valuable addition to a perfect social, economical, and technological development system needs to be encouraged. The study is significant because it offered information about the viability of producing organic fertilizer in Indonesia, which the government and other stakeholders may use to guide their policies and programs.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
104	5	5

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INTRODUCTION

The intensive use of inorganic fertilizer in agriculture causes numerous problems, such as irreversible health and environmental pollution. However, organic farming offers a potential solution because it has the capacity to reduce or even eliminate the harmful impacts of inorganic fertilizer on the environment and human health (Sharma and Chetani, 2017; Samimi *et al.,* 2023). By relying on organic sources, this farming type is one of the sustainable agricultural strategies to produce safe, healthy, and cost-effective food, including restoring soil fertility (Timsina, 2018) and mitigating climate change (Nugroho *et al*., 2023). While challenges related to composting of agricultural waste persist due to environmental concerns, experts are actively developing alternative solid waste management methods (Weekes *et al.,* 2021; Le Dinh *et al.* 2022; Sivakumar *et al.* 2022; Maphosa and Maphosa, 2022). These methods encompass a wide array of organic fertilizer raw materials sourced from agricultural and non-agricultural waste, which have gained endorsement from the solid waste industry over the past two decades for treating agricultural waste (Brotosusilo *et al.* 2022; Zaman *et al.* 2021). Organic substances, including protein and carbohydrates, such as starch, cellulose, hemicellulose, lignin, and organic acids, vary in the composition of agricultural waste (Suhartini *et al.,* 2022). This diversity underscores the need for affordable and environmentally friendly alternatives (Roy *et al.,* 2023), particularly as the costs associated with processing agricultural waste for environmental management are considerable and of global concern (Aziz *et al*., 2022; Ghazali *et al.,* 2021; Samimi and Mansouri, 2023). Compositing has emerged as a pivotal method due to its multifaceted benefits in managing agricultural waste. It effectively reduces waste volume and weight, produces nutrient-rich fertilizer that enhance soil quality, and provides a safe, stable, and advantageous practice (Roy *et al*., 2023). From sustainability standpoint, the innovative use of agricultural and food waste for biogenic nanoparticle synthesis depicts a novel method for repurposing resources aligned with waste-to-wealth principle (Pushparaj *et al*., 2022). Preliminary studies elucidating the efficacy of aquatic plants (Samimi and Shahriari Moghadam, 2018) and microorganisms (Samimi and Shahriari Moghadam, 2020), specifically Lemna minor and Chlamydomonas incerta, have proven their capacity to remediate organic pollutants (Samimi and Shahriari Moghadam, 2021). Such bio-remediation aligns with improved water quality standards and offers a sustainable avenue for production of organic fertilizer (Kamyab *et al*., 2017). Composting food waste is an economically and environmentally viable strategy. This becomes evident when considering the potential to reduce landfill-bound solid waste and significantly curb GHG emissions by 47 percent (%) and 90%, respectively. These tangible benefits underscore the importance of integrating viable waste management practices into contemporary sustainability indices Kamyab_2015_b. Both rice straw and cow dung are potential raw materials for organic fertilizer. In an agriculturally dependent nation like Indonesia, where rice is a staple food, farmers use their farm produce and livestock as a source of food and revenue. The extensive rice harvest area spanned approximately 10.45 million hectares, with production of 54.75 million tons of dry-milled grain (GKG) in 2022, accentuated the need for resource optimization (BPS, 2022). Supposing the residual from rice cultivation, estimated at 54.75 million tons of straw waste aligned with grain production, poses an environmental challenge. The removal of rice straw after harvest tends to reduce biogenic methane emissions. It can inadvertently lead to increased nitrous oxide and carbon dioxide emissions due to intensified fertilizer use for optimal rice yields (da Silva *et al*., 2021). Crop residues such as biomass offer both potential benefits and challenges for farmers. Unused or burnt agricultural biomass can contribute to environmental pollution (Samimi and Shahriari Moghadam, 2023; Samimi, 2024). For instance, burning residual rice straw waste is of particular concern (Singh *et al*., 2021). The transition from burning to using rice straw as animal feed led to a 13% increase in global warming potential (GWP) (Launio *et al*., 2016). Despite the complexities involved, alternative straw management plays a significant role in a broader program to mitigate the environmental impact of rice production. This would entail modifying individual habitats and the general ecology (Romasanta *et al*., 2017). In order to avoid the adverse consequences of burning as well as tap into the enormous energy potentials, it is imperative to advocate for the diverse use of straw for various benefits. Rice straw, for instance, serves multiple purposes, such as animal feed (Launio *et al*., 2016), fertilizer (Devianti *et al*., 2021), methanol production (da Silva *et al.,* 2021), energy generation (Pryshliak and Tokarchuk 2020), and the manufacture of biochar (Zhao *et al*., 2014). Apart from rice straw, another valuable source of organic matter is paunch manure produced from slaughtered ruminants, specifically in abattoirs. These facilities, where cattle are massively slaughtered for consumption, generate waste comprising a mixture of fat, protein, complex organic compounds, water, and rumen. Improper management of these wastes can result in environmental harm through the release of odors, pathogens, and disease-causing agents (Mohammed *et al*., 2019). The application of paunch manure offers various advantages, including its use as organic fertilizer, biogas energy production (Mohammed *et al*., 2019), and feed ingredients (Garcia *et al*., 2021). The use of this manure, particularly when obtained from abattoirs, is a critical step in supporting sustainable livestock production and mitigating environmental risks (Garcia *et al*., 2021). In Australia, its application on agricultural land has been proposed as a cost-effective and practical environmental option (Antille *et al*., 2018). According to Lestari *et al*. (2017), cattle paunch manure, as a digestive residue, contains organic matter and nutrients, including 2.56%, 0.15%, and 0.11% of N, P, and K. Paunch manure also contains 12.5%, 8 .1%, 38.02%, 0.37%, 0.26%, and 2,361 kcal/kg of dry matter, crude protein, crude fiber, calcium, phosphorus, and metabolic energy, respectively (Moningkey *et al*., 2020). Antille *et al*. (2018) stated that the resulting rumen contents have a fresh weight within the range of 25 and 40 kg stomachs/cow, translating to approximately 4 to 6 kg dry matter. This is consistent with a previous study, which posits the quantity of rumen content produced is estimated at 5 kg of dry matter (Kocu *et al.,* 2018). Huda *et al*. (2020) stated that the liquid rumen content of cattle contains five beneficial bacteria, namely *Pseudomonas, Cellulomonas sp., Acinetobacter sp., Lactobacillus sp.*, and *Bacillus sp*. These bacteria play a critical role in the composting process by increasing nitrogen levels, accelerating compost fermentation, promoting compound formation, and triggering the activities of microorganisms. Based on the bacterial makeup of rumen contents, it emerges as a promising source of raw material for organic fertilizer production. Lestari *et al*. (2017) stated that composting cow paunch manure as a source of organic matter improves water retention, enhances aeration and drainage as well as facilitates healthy plant root development by aiding nutrient absorption. The use of paunch manure on agricultural land proves economically prudent compared to traditional disposal methods and is widely acknowledged as an environmentally sound option. It can be managed in several ways, including 1) off-site disposal of guts and other solids, 2) on-site composting and application of materials, and (3) on-site composting, followed by off-site use (Antille *et al*., 2018). Devianti *et al*. (2021), stated that organic fertilizer possess the potential to boost land fertility sustainably while reducing environmental degradation and improving both the quality and quantity of agricultural produce. Long-term use of organic fertilizer can bolster farm productivity and counteract land degradation. In assessing the viability of agricultural waste composting, computing sustainability index using multidimensional scaling (MDS) offers an ideal method. A multivariate statistical method, also referred to as MDS, is used as a variable to assign positions to items based on their similarities or dissimilarities. MDS can convert preferences and opinions into multidimensional distances that can be interpreted scientifically. It formally refers to various statistical methods that visualize the underlying relationships between groups to condense preference data (Wan *et al*., 2021). MDS proves effective in interpreting and refining the preferences and opinions of respondents concerning organic fertilizer sustainability index theme. This method, widely used for sustainability assessment, was extensively employed in evaluating the feasibility of developing different agricultural commodities. Remarkable examples include garlic (Mar'atusholikha *et al*., 2019), cacao (Fairuzia *et al*., 2020), corn (Ariningsih *et al*., 2021), beef cattle (Kapa *et al*., 2019), dairy cattle (Mastuti *et al*., 2019), buffalo (Syarifuddin *et al*., 2022), shrimp (Pongoh *et al*., 2021), coffee (Yusuf *et al*., 2022), rice (Rachman *et al*., 2022), rice and duck (Rohaeni *et al*., 2021), oil palm (Nashr *et al*., 2021), red chili (Nuraini and Mutolib, 2023), microalgae (*Santoso et al*., 2023a), and black soldier fly (Santoso *et al*., 2023b). Given the nuanced nature of agriculture sustainability, its meaning encompasses multidimensional interpretations (Yusuf *et al*., 2022). Previous studies on sustainability used ecological, economic, social, technological, and institutional dimensions, while others delved into ethics, marketing, and political aspects during analysis. There exists divergence in the opinions held by these studies regarding the number and selection of dimensions to use. In this study, a four-dimensional framework encompassing environmental, economic, social, and technological facets aimed to provide practical insights and considerations for decision-makers vested in sustainable development. It is hypothesized in the present study that the use of rice straw and pig dung as organic fertilizer will lessen pollution and enhance soil conditions. The practical MDS method offers valuable information to assist decision-makers in organic fertilizer industry, particularly concerning waste management. The present study seeks to achieve the following objectives 1) identify sustainability index dimensions, 2) calculate sustainability index across environmental, social, economic, and technological dimensions, and 3) identify the critical factors influencing organic fertilizer production system. It also evaluates the viability of organic fertilizer production supply system. This study which was conducted in the Environmental and Sustainable Agribusiness Systems study group at the National Research and Innovation Agency, Indonesia, contributes to understanding viable practices in agriculture.

MATERIALS AND METHODS

Materials

The present study focused on the combination of rice straw waste and pound manure as the core material for investigation. Rice straw waste is considered a promising source of organic fertilizer raw materials, with its detailed contents shown in (Tables 1) and (Table 2). Meanwhile, the chemical composition of paunch manure is shown in (Table 3).

The combination of paunch manure and rice straw produces quality organic fertilizer. This is supported by Ratnawati *et al.* (2018), that the combination of paunch manure and rice straw produces organic fertilizer in accordance with the established quality standards. This is characterized by high phosphorus (P) and potassium (K) macronutrient values, a balanced carbon per nitrogen (C/N) ratio, and an optimal potential of hydrogen (pH) level. Furthermore, it was found that the best combination was 40% paunch manure and 60% rice straw produced by organic fertilizer with a pH specification and C/N ratio of 6.79 and 15, including macronutrients P and K of 8.35% and 9.72%, respectively. This formulation meets the established organic fertilizer quality standards, encompassing a pH and C/N ratio within the range of 4 to 9 and 15 to 25 and a minimum macronutrient content of 2% for both P and K.

Organic materials from rice straw waste and livestock manure (such as stomach manure) offer significant benefits in overcoming fertilizer requirements and boosting soil fertility. These organic matters contribute to effective fertilization in the following ways (Mclllfaterick, 2017):

a. Organic matter contained in rice straw and rumen contents (livestock manure) contributes significantly to enhancing soil structure. This is achieved by effectively binding soil particles into larger aggregates, thereby facilitating enhanced air

Table 1: Chemical composition of rice straw waste

No.	**Nutrient elements**	**Composition (%)**		
		(Ngi *et al.*, 2006)	(Sarnklong *et al.*, 2010)	(Poripolli *et al.*, 2016)
1	DM	92.8	96.3	90.6
2	CP	4.2	-	4.2
3	CF	35.1	-	-
4	NDF	69.1	73.0	73.2
5	ADF	42.4	41.6	44.9
6	ADL	4.8	4.8	3.2
7	EBSi	-	4.3	-
8	Ash	18.1	12.1	-
9	Ca	0.29	1.58	-
10	P	0.09	0.12	-
11	Na	0.27	0.13	-
12	K	1.8	0.27	-

Table 2: Nutrient contents of several sources of compost raw materials (Lemma and Abera, 2020)

No.	Sources raw materials	Moister (%)	Total nitrogen (%)	Carbon/ Nitrogen ratio	P available (mg/kg)	K available (mg/kg)
1	Paunch manure	77.28	3.03	10.31	1,523	597.7
2	Cattle manure	65.67	2.01	14.38	1,329	927.8
3	Paunch manure + wheat straw	79.18	1.58	16.26	1,226	682.3
4	Cattle manure + wheat straw	69.71	1.51	17.51	1,023	988.0
5	Paunch manure + cattle manure + wheat straw	76.10	2.08	14.34	1,408	933.0

Table 3: Chemical composition of paunch manure

No	Nutrient elements	Composition (%)		
		LAPTIAB-BRIN	Dowd *et al.* (2022)	Garcia *et al.* (2021)
1	MC	9.85	-	-
2	CP	7.59	11.30	-
3	Crude Fiber	30.35	-	-
4	Crude Fat	5.14	2.58	-
5	NDF	63.12	63.65	75.3
6	ADF	52.28	38.30	41.9
7	ADL	19.58	8.12	33
8	Ash	9.85	8.50	-
9	Carbohydrate	67.15	53.73	-
10	Ca	-	0.46	-
11	P	-	1.17	-
12	TS	-	15.84	-
13	N	-	1.59	-
14	Cellulose	-	33.65	-
15	Hemicellulose	-	28.80	-
16	VS (% of TS)	-	92.90	-

and water circulation within the soil.

b. Organic matter contains various nutrients such as Nitrogen, Phosphorus, and Potassium. When it is decomposed by microorganisms in the soil, these nutrients are progressively released into the soil, ensuring a gradual and efficient supply.

c. Organic matter can retain moisture in the soil, helping it stay moist for a longer period of time and reducing water evaporation.

d. Organic materials serve as nourishment for microorganisms in the soil. These microorganisms facilitate the decomposition of organic matter and production of plant-friendly compounds. Higher microbial activity also has the potential to enhance overall soil fertility.

e. By integrating organic matter into the soil, agriculture can reduce its dependence on synthetic chemical fertilizer. This tends to reduce the environmental footprint caused by its excessive use.

f. Organic matter increases the water storage capacity of the soil, this helps keep plants hydrated during dry weather conditions and reduces the risk of shortages.

The conversion of plant residues into organic matter involves a natural decomposition process that produces compounds beneficial to the soil and ecosystem. This intricate process relies on the collaborative efforts of microorganisms such as bacteria, fungi, and worms, working harmoniously to decompose these organic materials. However, this transformation is significant as it reduces waste, enhances soil quality, and provides essential nutrients for plant growth. Several methods are used to achieve the conversion of plant residues into organic matter. These methods include natural composting, making compost, vermicompost, liquid fertilizer, and fast composting using bacteria or microorganisms.

Study procedure

Focus Group Discussions (FGDs) were used to analyze the survey data, involving experts in solid waste, organic fertilizer, and business domains. These individuals were selected based on their qualifications, requiring a minimum of five years of experience in organic fertilizer production and management. The primary goal of the FGDs was to evaluate the current business environment and the available resources for organic fertilizer production at the study site, providing essential insights for formulating dimensions and sustainability attributes. The present study incorporated a total of 29 attributes organized into four dimensions, namely environmental, economic, social, and technological. A questionnaire was crafted to quantify these dimensions and attributes, using a Likert scale for response options. Expert participants were assigned scores of 0, 1, and 2 to indicate poor, average, and good responses.

Data analysis

Data analysis was performed using MDS alongside the rapid appraisal for organic fertilizer method (Rap-fertilizer). This method was adopted and developed from the rap-fish (rapid appraisal for fish) method and modified to assess sustainability of organic fertilizer production. Furthermore, the following stages determine this evaluation process (Lloyd *et al.*, 2022; Pitcher and Preikshot, 2001).

1) The present study assessed sustainability by examining four dimensions, each comprised of 29 attributes.

2) Perform a structured assessment of the attributes through scoring. The scores assigned to the attributes form an X matrix (n x p), where n is the number of regions and their reference points, and p signifies the number of attributes used. The scores were then standardized for each attribute using Eq. 1 (Borg *et al.*, 2018).

$$\mathrm{X_{ik}sd} = \frac{\mathrm{X_{ik}} - \mathrm{X_k}}{\mathrm{s_k}} \tag{1}$$

Where;

$X_{ik}sd$ = the i-th regional standard score (including reference points) = 1, 2, ..., n for each k-th attribute = 1, 2, ..., p

X_{ik} = the i-th standard score (including reference points) = 1, 2, ..., n for each k-th attribute = 1, 2, ..., p

X_k = the mean score on each k-th attribute = 1, 2, ..., p

S_k = the standard deviation of scores for each k-th attribute = 1, 2, ..., p

The shortest interval from the Euclidian distance was calculated using Eq. 2. Subsequently, this data was projected into a two-dimensional Euclidian space (d_{12}) using the regression formula in Eq. 3. The ALSCAL algorithm facilitated the regression process, with iterations aimed at setting the intercept value in the equation to zero (a = 0). This transformation led to the conversion of Eq. 4 (Borg *et al.*, 2018). The repetition process stopped when the stress (S) value was <0.25, which was obtained using Eq. 5 (Borg *et al.*, 2018).

$$\mathrm{d} = \sqrt{\left(\left|\mathrm{x_1} - \mathrm{x_2}\right|^2 + \left|\mathrm{y_1} - \mathrm{y_2}\right|^2 + \left|\mathrm{z_1} - \mathrm{x_2}\right|^2 + \ldots\right)} \tag{2}$$

$$\mathrm{d_{ij}} = \alpha + \beta\delta\beta_{\mathrm{ij}} + \varepsilon \tag{3}$$

$$\mathrm{d_{12}} = \mathrm{bD_{12}} + \mathrm{e}; \tag{4}$$

$$\mathrm{s} = \sqrt{\frac{1}{\mathrm{m}}\sum_{\mathrm{k=1}}^{\mathrm{m}}\left[\frac{\sum_{\mathrm{i}}\sum_{\mathrm{j}}\left(\mathrm{d_{ijk}^2} - \mathrm{o_{ijk}^2}\right)^2}{\sum_{\mathrm{i}}\sum_{\mathrm{j}}\mathrm{o_{ijk}^4}}\right]} \tag{5}$$

3) Conduct an assessment to determine sustainability index and its associated status. The categorization of sustainability status for organic fertilizer production is delineated by distinct index ranges, 0.00 to 25.00 (not sustainable), 25.01 to 50.00 (less sustainable), 50.01 to 75.00 (moderately sustainable), 75.01 to 100.00 (highly sustainable), as validated by Rachman *et al.* (2022).

4) Conduct a sensitivity (leverage) analysis to determine the main attributes that strongly influence sustainability of organic fertilizer production in farming. This analysis prioritized changes in the root mean square (RMS) ordination on the x-axis. However, assuming the RMS has a significant value, it depicts that the role of this attribute is becoming more prominent in shaping sustainability status (more sensitive).

5) Perform Monte Carlo analysis using the Rap-fertilizer method to estimate the random error rate in the model resulting from MDS evaluation of all dimensions with a 95% confidence level. The smaller the difference between the results of MDS and Monte Carlo analyses, the better the Monte Carlo model produced by the Rap-fertilizer method. The goodness of fit in MDS is reflected in the values of S and coefficient of determination (R^2). A low S value denotes a good fit, while the reverse is the case when its high. With the Rap-fertilizer method, a good model is indicated by an S value less than 0.25. The R^2 value close to 1 indicates that the attributes used to examine a specific dimension are reasonably accurate (Borg *et al*., 2018; Pitcher and Preikshot, 2001)

RESULTS AND DISCUSSION

Dimension and attribute

The level of sustainability in organic fertilizer production was assessed using MDS method. Furthermore, the dimensions and attributes impacting sustainability were identified by thoroughly analyzing their effects on organic fertilizer production (Lloyd *et al.,* 2022). The proposed hypothesis stated that using organic fertilizer from waste materials increases sustainability of the agricultural production system. This is achieved by identifying the most significant attribute within each environmental, social, economic, and technological dimension. Expert input from fertilizer production was used to determine the attributes of each dimension. MDS calculations were based on data obtained from a questionnaire, with a comprehensive breakdown of dimensions and attributes shown in (Table 4).

A structured method was employed in assessing the viability of composting processes for organic fertilizer production. This involved organizing the various features within each dimension into a questionnaire. Experts from relevant fields were then consulted to obtain their professional opinions on the scientific feasibility of these composting processes. The outcomes of these professional evaluations were also analyzed using MDS method and the Rapfish program. The resulting sustainability scores for each dimension are shown in (Table 5).

Various factors contribute to sustainability of organic fertilizer production, namely environmental carrying capacity, production input accessibility and procedures, product processing, marketing

Table 4: Dimensions and attributes of organic fertilizer production sustainability

Environmental	Social	Economical	Technological
1. Efficient use of materials (biodegradable) for organic fertilizer production 2. Efficiency in the use of chemical materials for organic fertilizer production 3. Efficiency in the use of electricity and fuel during organic fertilizer production process 4. Efficiency of water use during organic fertilizer production process 5. The potential for air pollution 6. The potential for water and land pollution 7. Exploitation level of natural resources and land use during organic fertilizer production 8. Potential spread of disease due to the existence of organic fertilizer industry	9. Education level of industry manager or entrepreneur 10. Involvement of family members in organic fertilizer industry 11. Level of business motivation 12. The potential for public unrest due to organic fertilizer industrial process 13. The potential for other job losses is due to organic fertilizer industry. 14. Managers or workers knowledge level of organic fertilizer production or environmental conservation and restoration 15. Potential for work accidents 16. Potential job creation for residents	17. The productivity level of organic fertilizer 18. Management level of organic fertilizer production 19. Potential increase in business scale or success rate 20. Contribution to improving the welfare of managers or workers 21. Efficient use of raw materials 22. The level of ease of obtaining raw materials for organic fertilizer production 23. Market absorption rate of organic fertilizer production 24. Contributing to the increase in substitution of organic fertilizer	25. The easy level of adoption of organic fertilizer production system for the surrounding community 26. The level of specialization, expertise, or skills required to manage the people's organic fertilizer industry 27. Availability of organic fertilizer production facilities and infrastructure 28. Potential for increasing technology or organic fertilizer production 29. The level of technical or method sensitivity to the quality and quantity of organic fertilizer production

Table 5: Sustainability index outcomes for all dimensions, accompanied by data quality indices

Dimension	Index (%)	Stress	R^2(SQR)	Status
Environmental	90.1	0.135	0.947	good sustainable
Social	70.5	0.141	0.949	fairly sustainable
Economical	63,69	0.138	0.947	moderately sustainable
Technological	73,93	0.144	0.947	fairly sustainable
Average	74.55			fairly sustainable

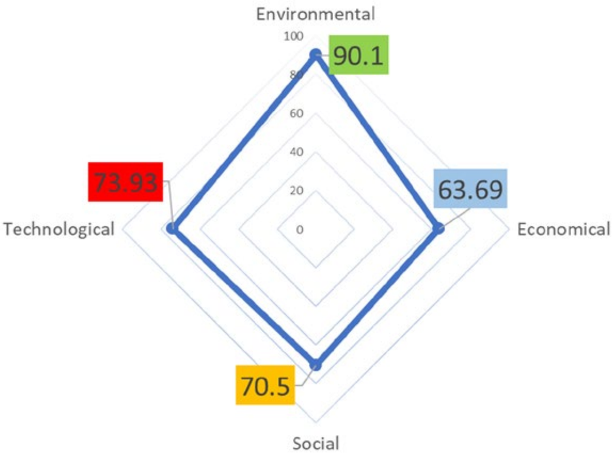

Fig. 1: The level of sustainability achieved in organic fertilizer production

strategies, and the roles of pertinent organizations. These factors along with their sustainable practices, use organic fertilizer production an economically and environmentally favorable alternative to the manufacture of conventional animal feed (Rehman *et al*., 2020). With a stress value of 0.14, equivalent to 50%, the results of MDS analysis on production of ecologically friendly organic fertilizer are shown in (Fig. 1). This shows the validity and accuracy of the four dimensions determined by the Monte Carlo test. Additionally, organic fertilizer production system yielded sustainability value of 74.55. While the economic dimension has the lowest sustainability index, it remains notably sustainable. The environmental, social, and technological dimensions fall within sustainability category, as shown in (Table 5).

Environmental dimension

Based on the MDS analysis results, 90.1% of the index value of the environmental dimension, serves as a barometer for sustainability. This commendable index status should be maintained as a positive reference point. The leverage analysis was used to identify water consumption efficiency in organic fertilization as a one-dimensional attribute that significantly influences environmental sustainability. The use of organic fertilizer inhibits soil degradation, which causes the loss of nutrients and organic matter. It also enhances the retention property of the soil, thereby protecting plants from dehydration. The positive impact extends to clay soils, where improved porosity ensures smooth drainage and prevents stagnation. These collective effects enhance soil fertility and quality, attributed to heightened organic matter content and improved water-holding capacity (Adugna, 2016). Several studies have validated the water-saving potential of using organic fertilizer. For instance, Dharminder *et al*. (2021) emphasized its water-saving properties, while El-Mageed *et al*. (2018) reported potential conservation of approximately 15%. This insight is specifically pertinent in the face of global water scarcity concerns, and agriculture is a major consumer of freshwater resources. In regions where water scarcity is prevalent, efficient usage becomes important to ensure its availability for other essential purposes. The availability of water is closely related to its quality, as deterioration of water quality

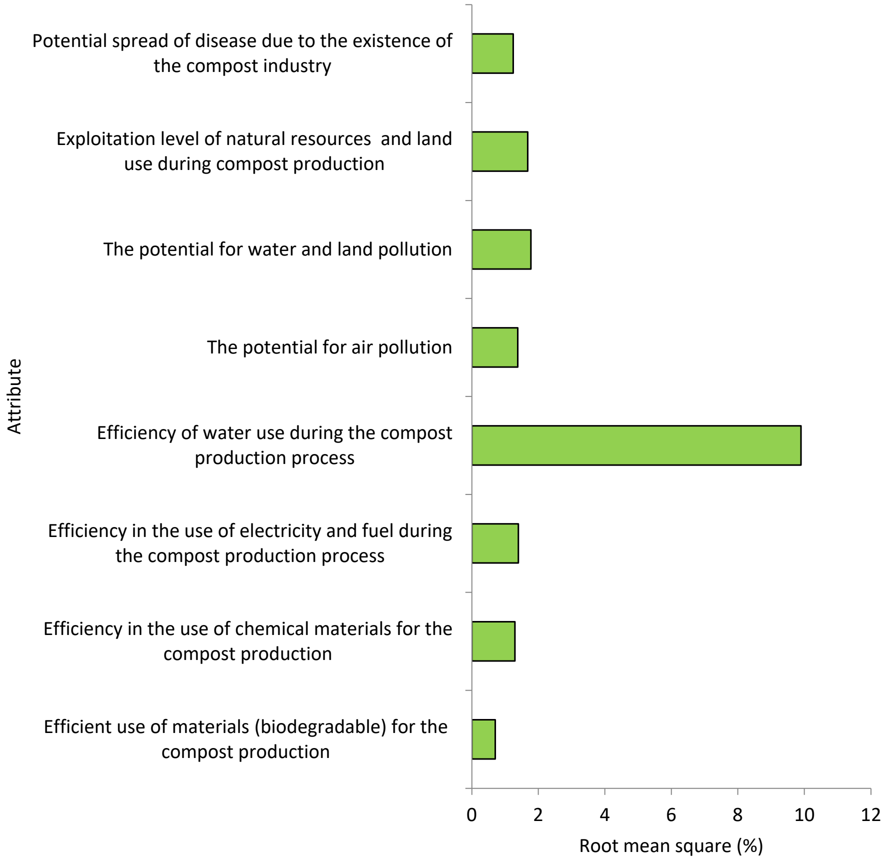

Fig. 2: Leverage of environmental attributes

limits its fitness for specific applications (e.g. drinking water). These pressures on the environment have led to a growing interest in exploring alternatives to reduce waste and the use of resources. The world need to move away from simplistic, and readily available methods to more comprehensive solutions. Embracing the principles of the circular economy and harnessing technological advancements aids to enhance sustainability and provide new market dynamics regarding the water cycle. This transition is essential to elevate sustainability efforts and effectively address evolving demands placed on water resources.

A new circular water management system that considers the various elements of the water cycle aimed at maximizing efficient usage need to be developed. Several measures need to be adopted based on the principles of the circular economy model. The initial focus rests on curbing water consumption through the redesign of products and services, coupled with the eradication of operational inefficiencies. This concerted effort led to the reduction of water usage by improving its system efficiency and resource allocation. The next step revolves around reuse, involving the establishment of a closed-loop framework for water circulation or redirecting it to alternative systems or communities. Recycling is also important for external operations. However, the ultimate goal remains centered on the restoration of natural reserves, achieved by safely reintroducing water to its original watersheds, such as rivers, lakes, and oceans. Water reuse is a concept gaining attention, viewed as an innovative way to combat its scarcity. This entails repurposing treated wastewater as a valuable resource for various non-potable applications, including irrigation, industrial processes, urban consumption, and even rejuvenating aquifers and surface waters (Plevri *et al*., 2020). The result from the experiment conducted showed that the efficiency of water use during the compost-producing process had the highest leverage value of 9.9. This observation aligns with the pressing global concern of water scarcity, exacerbated by the substantial demands of the agricultural sector. In areas with severe water scarcity, prioritizing efficient use is crucial to ensure its availability for other essential purposes. Organic fertilizer production typically includes composting and digestion, which often require water for mixing, moisture control, and maintaining optimal conditions. Improving water efficiency in these processes reduces waste and also eases the strain on its resources. Organic fertilizer production requires water because it plays an important part in the decomposition process of organic matter. It is important to consider efficient rather than excessive use of water. Adopting proper monitoring and strategic control of water use can help reduce pressure on its resources while ensuring sustainable supplies. During composting, rainwater collection and storage potentially reduces dependence on sources like boreholes and tap water. Further progress lies in adopting efficient drip irrigation, employing soil moisture sensors for precise plant hydration, and integrating automatic systems for accurate water delivery. These technological measures promote water conservation, aligning with the broader goal of environmental stewardship. The inextricable relationship between water and energy warrants attention. Processes tied to water, from extraction to treatment and distribution, require energy inputs. Inefficient water use in fertilizer production indirectly triggers increased energy consumption and associated environmental impacts. Energy demands in water-related processes tend to be minimized by optimizing efficiency, resulting in overall resource savings and reduced greenhouse gas emissions. This endeavor resonates with integrating eco-friendly technologies that harness renewable energy sources such as solar panels and wind turbines. Wastewater is usually generated by producing organic fertilizer, specifically during processing and washing. Composting generates three water forms, namely leachates, condensates, and runoff. Leachates permeate through organic matter, condensates, and runoff resulting from moisture evaporation and areas around compost heaps, including traffic zones and windrow sides (Krogmann and Woyczechowski, 2000). Inefficient water usage leads to the generation of significant amounts of wastewater, presenting considerable challenges for its proper treatment and disposal. The discharge of untreated wastewater tends to contaminate water bodies, thereby causing ecological damage and posing potential threats to human health. In order to counteract the pollution of water sources by liquid waste, it is necessary to effectively segregate and treat wastewater, thereby preventing the contamination of groundwater and rivers with harmful substances. Implementing advanced water and wastewater management practices is instrumental in addressing the pollution risks associated with producing organic fertilizer. Organic fertilizer contain essential nutrients such as nitrogen, phosphorus, and potassium. Poor water management during production process, involving either excessive usage or inadequate control, results in the infiltration of these nutrients into groundwater or causes them to run off into nearby water bodies. This situation tends to trigger eutrophication, a phenomenon where excess nutrients cause algal blooms, oxygen depletion, and disruption of aquatic ecosystems. By embracing water-efficient strategies, the leaching of nutrients and runoff could be minimized, thereby preserving water quality and the integrity of aquatic ecosystems. In view of concerns revolving around water scarcity, energy consumption, wastewater generation, pollution, and the potential for nutrient leaching and runoff, the efficiency of water usage in producing organic fertilizer emerges as a pivotal consideration for achieving environmental sustainability. Through the optimization of water practices and the adoption of efficient management, production of organic fertilizer effectively mitigates its environmental impact and actively contributes to broader sustainability goals. Rice straw is one of the most common agricultural by-products in the world, specifically in China and Southeast Asia. Farmers extensively employ it as a primary source of forage for ruminant animals, owing to its widespread availability and cost-effectiveness. The robust cellulose-hemicellulose-lignin structure of rice straw protects the biomass from being attacked by enzymes and microorganisms (Yu *et al.*, 2016). This characteristic results in limited breakdown during fermentation processes resulting in low degradation during fermentation. Improving the decomposition process of straw increases the use of this abundant agricultural by-product and alleviates the shortage of high-quality forage for ruminants. The rumen of ruminants, rich in complex microbial community and cellulase system, adeptly converts lignocellulosic biomass (Xing *et al*., 2020). The best option for regulating lignocellulosic biomass involves using ruminal fluid as a biological inoculum (Liang *et al*., 2020). According to Wang *et al*. (2021), rumen juice dramatically enhanced hydrolysis and acid generation in cut grass. The factor that impacts environmental sustainability is water usage efficiency during the composting process. Microbial activities drive this procedure, and like other living organisms, bacteria need the right environment to survive and thrive. For the composting process to be successful, the bacteria need suitable nutrition, optimal humidity, pH levels, temperature, and oxygen (Seyedbagheri, 2010). For aerobic incubation, which takes place in the presence of oxygen, maintaining an appropriate humidity level to support the entire process is important. Materials with high fiber content, such as straw and wood chips, can hold higher moisture (exceeding 60%) without inducing anaerobic conditions. In contrast, materials with lesser structural strength, such as paper, grass clippings, soil, and fertilizer, tend to retain lower total moisture to prevent the development of anaerobic conditions. While the precise ideal moisture content varies depending on the pile material, a consensus typically places the optimal moisture range for on-farm composting between 50% and 60% by weight (Chen *et al*., 2011). Inadequate humidity leads to a shortage of essential water for bacteria metabolic processes, hampering their activity and causing a slowdown in the composting process. Excessive humidity means that the pores of the compost pile are filled with water rather than air, leading to anaerobic conditions. Humidity plays a pivotal role in regulating pile temperature, with drier ones experiencing more rapid temperature fluctuations than moister piles. In order to achieve the ideal moisture content, materials with different moisture content are mixed. Additional water may be added during mixing when the base material is overly dry to achieve the ideal moisture. Composting duration should be selected based on the precipitation likely to occur during the period. Moreover, seasons with high rainfall must be avoided. The precipitation problem is partially solved by covering the pile or placing it under a roof. Addressing the issue of nitrogen loss presents another consideration, this concern is alleviated by adopting mulching methods, such as covering the compost pile with either straw or plastic. Empirical observations revealed that in the absence of mulch, nitrogen loss reached 22%. This loss diminished to 13% when 25 cm of straw was used as mulch and was further curtailed to a mere 7% when a plastic layer was introduced between straw and the compost during the maturation stage. At the outset of the composting process, it is important to opt for covers that strike a balance between breathability and impermeability. Air-repellent coatings prevent aeration of the compost pile and evaporation of water. Unfortunately, this unintended consequence leads to a more anaerobic environment, exacerbating the risk of increased washout (Peigne and Girardin, 2004). Peigne and Girardin (2004) also suggested a strategic method, using straw as mulch at the start of composting and transitioning to tarpaulin when the compost is more stable during maturation. Covering the compost pile is always the best way to reduce runoff contamination because water seeping along its walls does not come in contact with manure. Opting for composting under a canopy, which offers wider coverage than a simple tarpaulin, is a more effective strategy to mitigate the adverse effects of precipitation and minimize the loss of contaminated water.

Social dimension

In the social dimension context, several influential factors come into play in the pursuit of sustainable organic fertilizer production. These factors include potential job displacement, civil unrest, and the knowledge levels of both managerial personnel and workers engaged in organic fertilizer production, as shown in (Fig. 3). According to Bartzas and Komnitsas (2020), the education level of farmers directly impacts their ability to access and effectively use modern technology for sustainable agricultural practices. The availability of technology that bolsters agricultural operations becomes crucial for these individuals to ensure the viability and lasting sustainability of their livestock enterprises. Rivero and Daim (2017) stated that technology is essential for profitable and easy-to-implement livestock production, enabling businesses to develop sustainably. This infusion empowers

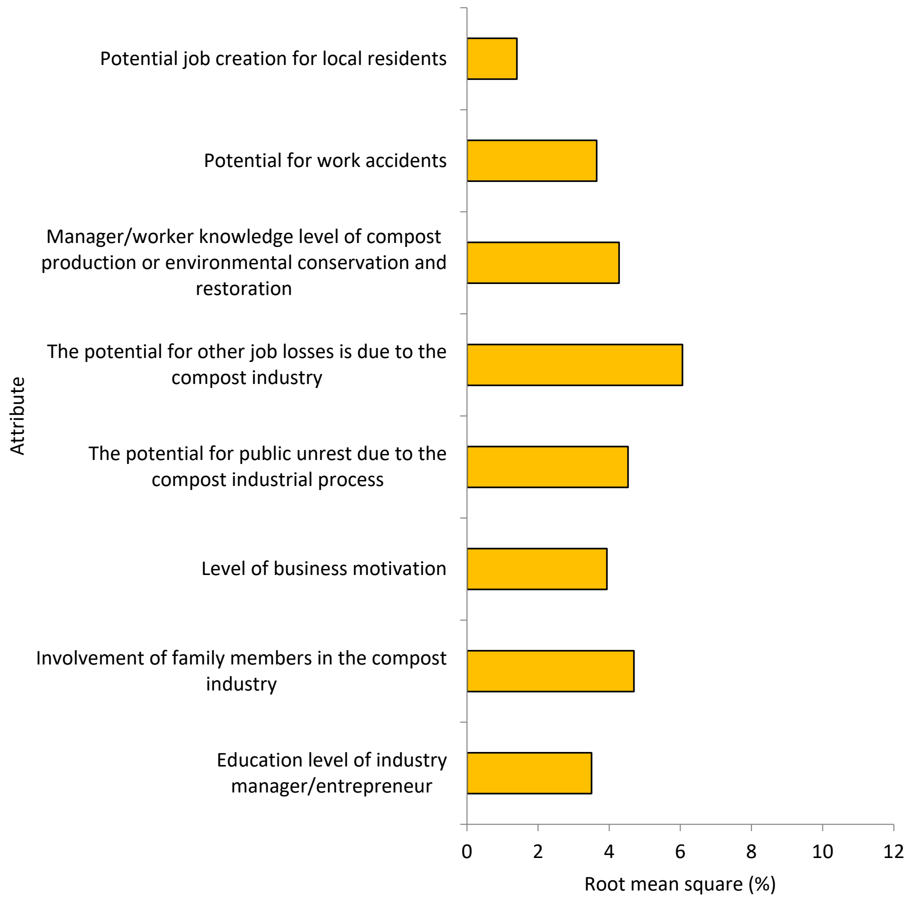

Fig. 3: Leverage of social attributes

businesses to thrive and lays the foundation for sustainable development.

In order to mitigate these adverse effects, it is important to implement regulations or adopt a family business management method. Among the various considerations, family engagement within the domestic sphere receives the highest rating, closely followed by business motives like biodiesel production, ranked second in importance. A prevailing practice within family-owned businesses involves enlisting family members to contribute to operational activities. This practice is driven by the expectation that family resources lighten the company load. The structure of family-owned enterprises often encourages managers to prioritize efficient business management. Previous studies have emphasized the importance of numerous social elements and socio-demographic traits in fostering sustainable growth and facilitating the adoption of cutting-edge farming practices and products among farmers (Pampuro *et al*., 2020). A remarkable method proposed by Sumane *et al*. 2018, revolves around establishing a multi-actor knowledge network that facilitates interactions between formal and informal sub-networks. Particularly pertinent regarding Manager/Worker knowledge levels of organic fertilizer production, this method emphasizes the value of blending insights from formal entities such as universities, study institutes, consulting services, and farmers' organizations, as well as informal sources ingrained in their daily activities. These informal networks comprise neighborhood associations, peer groups, family and personal relationships, including community connections, collectively forming a cohesive knowledge ecosystem within rural areas (Sumane *et al*., 2018). The potential job losses in other sectors due to the expansion of organic fertilizer industry have multifaceted implications for sustainability of production process. Davis (2022) stated that composting could lead to job losses in the fossil fuel industry as it reduces the demand for chemical fertilizer manufactured using non-renewable resources such as natural gas. This reduction in demand results in employment challenges for workers in the fossil fuel sector. In addition, Davis (2022) stated that implementing composting practices also causes job losses in waste management industry. As composting reduces the amount of organic waste sent to landfills, incinerators, or other disposal facilities, workers in waste management sector might face employment disruptions. Brand (2015) stated the broader consequences of job losses, which is significant in rural and remote areas, where such events can have far-reaching social and economic implications on affected workers and communities. With regard to the social attribute -the potential for public unrest surrounding organic fertilizer industrial process has various impacts on sustainability of its production. Sayara *et al.* (2020) stated that negative perceptions and attitudes from the public toward composting, fueled by concerns about issues such as odor, noise, pests, health risks, and aesthetics, trigger public unrest. This unrest, in turn, has the potential to undermine the social acceptance and active involvement of the public in composting initiatives. It could result in suboptimal waste separation, collection, and delivery practices, which significantly affect the overall effectiveness of composting initiatives. Purkiss *et al.* (2022) stated that public unrest also influences the policy and regulatory environment pertaining to composting. The pressure or resistance from the public shapes the development, implementation, and enforcement of composting initiatives, standards, incentives, and regulations. Finally, Purkiss *et al.* (2022) reported that public unrest hinders the market development and competitiveness of composting. The reduction in demand and supply of organic fertilizer products, driven by negative public sentiment, disrupts pricing strategies, distribution channels, and promotional activities in this industry. In relation to the impact of social attributes, specifically the Level of business motivation, this aspect has various effects on sustainability of organic fertilizer production. Mulasari *et al.* (2021) reported that entrepreneurship motivation drives investments and fosters innovation within waste management sector. This phenomenon triggers the development of enhanced technologies, greater efficiency, improved product quality, and heightened profitability. Soomro *et al.* (2023) stated that the level of motivation also influences the pursuit of guidance concerning issues related to market development and competitiveness of solid waste management. As a result, this affects factors such as the interplay between supply and demand, pricing strategies, distribution channels, and promotional efforts related to organic fertilizer products. Soomro *et al.* (2023) stated that business motivation shapes the policy and regulatory landscape surrounding organic fertilizer production. Businesses propelled by motivation often champion supportive measures because they adhere to industry standards and regulations and actively engage with relevant stakeholders to influence the overall policy environment. Furthermore, the insights provided by Zurbrugg and Ahmed (1999) reinforce this concept, suggesting that business motivation mirrors the social and environmental values intertwined with solid waste production. Zurbrugg and Ahmed (1999) also stated that business motivation reflects the social and environmental values associated with solid waste production. In essence, by aligning with principles like the circular economy, waste reduction, soil fertility, and climate change mitigation, motivated businesses contribute to the overarching sustainability goals of the composting industry. Considering the involvement of family members as a social attribute in green initiatives, it is evident that this factor has several impacts on sustainability of organic fertilizer production. Lunag *et al.* (2021) stated that family involvement contributes to increased awareness and participation of households in organic waste initiatives. This reduces the amount of waste sent to landfills and improves the quality of organic fertilizer feedstock (Idawati *et al*., 2023). Noufal *et al.* (2021) reported that family engagement in composting enhances the social and environmental values associated with this practice. By sharing their knowledge, experiences, and the benefits of composting, families foster a culture of waste reduction and soil fertility, spreading these ideals among their neighbors and communities. Brotosusilo *et al.* (2023) reported that family or community involvement goes beyond its societal implications to bolster the economic viability and resilience of solid waste management efforts. Families tend to use the resulting organic fertilizer on their farms or for gardening purposes, or they could decide to sell it to generate income. This diversified method reduces reliance on chemical fertilizer and external markets, enhancing economic independence. Moreover, Lunag *et al.* (2021) reported that family involvement in solid waste management promotes innovation and adaptation.These families often experiment with various composting methods, materials, and products that align with local needs, resources, and preferences, driving continuous improvement and customization, specifically within the composting process. The managers and entrepreneurs' education levels in organic fertilizer production industry significantly impact sustainability of the operations. It is important for university education to incorporate composting educational programs and training focused on maintaining soil fertility, preserving natural resources, and fostering more sustainable agricultural practices.

Economical dimension

The economic dimension gets the lowest sustainability index score (63,69%) but still meets sustainability criteria. Through leverage analysis, certain characteristics within this dimension are highly sensitive in influencing the financial viability of organic fertilizer production. These attributes encompass the betterment of Managers and workers welfare, optimal use of raw materials, potential for business scale expansion or success rate improvement, and the market absorption rate of the produced organic fertilizer, as shown in (Fig. 4). Improving the welfare of these employees involves various strategies, such as increasing salaries, providing better working conditions, fostering career advancement opportunities, and offering training programs. The effective use of raw materials in organic fertilizer offers multiple benefits, including cost reduction, increased productivity, reduced environmental impact, and overall sustainability. This efficient method reduces expenses related to procurement, transportation, processing, and organic fertilizer production waste costs. In terms of environmental considerations, the efficient use of raw materials emerges as a significant strategy to reduce adverse impacts. This includes reducing production waste, curbing energy consumption, and minimizing greenhouse gas emissions. Such a proactive method to raw material usage contributes significantly to the long-term sustainability of the company. Furthermore, enhancing the marketing of organic fertilizer products can substantially affect sustainability of its production in the studied areas. The presence of a viable market is integral to sustainability of any commodity-based business, as it facilitates the commercial exchange of products. Strengthened marketing endeavors yield considerable profits for farmers, empowering them to sustain and expand their agricultural operations. This perspective aligns with the previous study that underscores the pivotal role of marketing in driving the growth and sustainability of small, medium, and micro enterprises (SMMEs). For farmers to ensure sustainability, generating adequate income is crucial for reinvesting in their enterprises (Adesehinwa *et al*., 2019). This underscores the notion that organic fertilizer production is profitable and feasible for continued operations.

The contribution to the increase in the substitution of organic fertilizer refers to the degree to which the industry is able to replace the use of chemical types with organic products in agriculture or gardening practices (Tao *et al.,* 2015). According to Roy *et al*. (2021), achieving success in this regard requires greater emphasis on the development of organic fertilizer market, which contributes to the overall sustainability of the plants. It is evident that a significant contribution to the increase in the substitution of organic fertilizer plays a vital role in bolstering sustainability of the industry. Rashid and Shahzad (2021) stated that this method reduces the demand and consumption of fossil fuels and non-renewable resources used in production of chemical fertilizer. It also decreases greenhouse gas emissions and environmental pollution associated with chemical fertilizer while improving soil fertility. Limited contribution to the increase in substitution of organic fertilizer resulted in diminished sustainability. This scenario increases the demand for fossil fuels and non-renewable resources in chemical fertilizer production. It raises greenhouse gas emissions and environmental pollution while degrading soil fertility. Rashid and Shahzad (2021) stated that

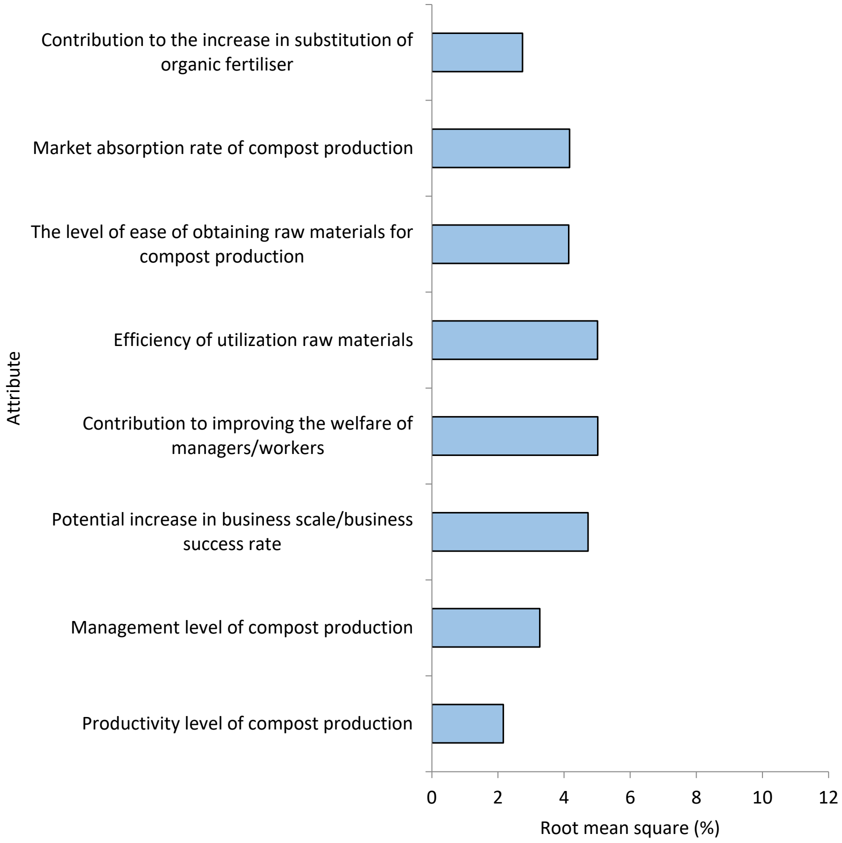

Fig. 4: Leverage of economical attributes

the contribution to the increase in the substitution of organic fertilizer also affects the economic and social sustainability of the industry. A substantial contribution tends to yield multiple benefits for the industry, including profitability and viability. This is achieved by fostering heightened demand and supply for organic fertilizer products. Such a situation influences crucial aspects like pricing, distribution strategies, and promotional efforts while generating income and creating employment opportunities. The market absorption rate of organic fertilizer production refers to the ratio of the quantity sold to the amount produced within a specific timeframe. This metric serves as an indicator of the ability to consume or absorb available organic fertilizer products. Pandyaswargo and Premakumara (2014) stated that a high market absorption rate indicates strong demand and a limited supply of these products. The earlier-mentioned scenario proves advantageous for organic fertilizer industry, enabling it to charge higher prices, increase profits, and expand production. Alexander (1990) reported that it also presents challenges such as maintaining quality standards, ensuring customer satisfaction, and competing with other sources of organic fertilizer. Conversely, a low market absorption rate suggests weak demand and an excess supply of these products. This scenario could be unfavorable for organic fertilizer industry, leading to lower prices, reduced profits, and surplus inventory. It also creates opportunities for enhancing product quality, promoting benefits, and diversifying the range of products and services the industry offers (Eggerth,1996). Focusing on municipal waste, McIllfaterick (2017) stated that the market absorption rate of organic fertilizer production also affects the environmental and social sustainability of the industry. The study further reported that a high market absorption rate reduces the volume of organic waste sent to landfills or incinerators while enhancing soil fertility. On the other hand, it leads to increased energy consumption and greenhouse gas emissions during organic fertilization and transportation processes. In order to achieve sustainability, organic fertilizer industry needs to strike a balance between economic, environmental, and social goals. Wilson (1989) stated that the feasibility of obtaining organic waste materials for organic fertilizer production relies on the availability, accessibility, and quality of its sources. These include agricultural and municipal solid wastes, as well as animal manure. Pergola *et al*. (2020) further reported that a high level of ease in obtaining raw materials for organic fertilizer production significantly facilitates the composting process. It ensures a consistent and sufficient supply of organic waste, reduces transportation costs and emissions while enhancing the quality and stability of the resulting product. A low level of ease in obtaining raw materials can impede the composting process, potentially leading to shortages or fluctuations in organic waste availability. This increases transportation costs and emissions and compromises the quality and stability of organic fertilizer product. Noor et al. (2023) propose that the ease of obtaining raw materials also has implications for the environmental and social sustainability of organic fertilizer industry. Noor *et al.* (2023) suggest that the level of ease in obtaining raw materials also affects the environmental and social sustainability of organic fertilizer industry. A high level of ease reduces the amount of organic waste sent to landfills or incinerators, benefiting soil fertility. The efficiency of raw material use in organic fertilizer production refers to the ratio of organic fertilizer products obtained to the quantity of waste used during the composting process. This metric highlights how effectively organic waste is transformed into fertilizer products. According to Pace *et al.* (1995), high efficiency of raw material use in organic fertilizer production enhances sustainability of the industry. It increases the yield and quality of the products, reduces waste generation and disposal, and improves overall resource efficiency and circularity. Ayilara *et al.* (2020) stated that enterprises and preliminary studies have considered using municipal garbage as raw materials. Low efficiency of raw material use in organic fertilizer production reduces sustainability. It reduces the yield and quality of organic fertilizer products, escalating waste generation and disposal and undermining overall resource efficiency and circularity. Singh (2021) reported that the efficiency of raw material use also affects the environmental and social sustainability of organic fertilizer industry. High efficiency reduces greenhouse gas emissions and energy consumption during composting and transportation processes while enhancing soil fertility. Ayilara *et al.* (2020) reported that this method might pose challenges, such as managing odor, pests, pathogens, and heavy metals in organic waste.

Technological dimension

The multidimensional analysis yielded a technological sustainability index 73.93% for organic fertilizer production using waste from rice straw and cow rumen contents. This value falls within the moderately favorable range, with a stress level of 0.148, categorizing it in the lowest stress group, as shown in (Table 4). From the results of this survey, it was inferred that the technology used in organic fertilizer production process is typically good. Despite its moderately favorable rating, there are still opportunities to enhance or adjust production technology, taking into account specific pros and cons within the manufacturing process. Leverage analysis highlights several factors influencing sustainability of organic fertilizer production technology. These include the level of managerial expertise required, the sensitivity of the method to the quality and quantity of organic fertilizer produced, the availability of facilities and infrastructure, as well as the potential for improving production technology or methods. The degree to which the local population embraces organic fertilizer production system is one of the most sensitive factors determining sustainability of the technological dimension, as shown in (Fig. 5).

The results of this study indicate that a certain level of expertise is optional for organic fertilizer industry managers. This suggests that production process is relatively straightforward to understand. The survey results show that organic fertilizer production, in terms of quality and quantity, is relatively sensitive to treatment variations during manufacturing. Indicators of the accessibility of facilities for producing organic fertilizer and the potential for technological advancements in production show reasonably acceptable values. However, there is still room for improvement. For small or medium-scale organic fertilizer production, fairly simple facilities and infrastructure are needed. This includes equipment such as choppers, grinders, and mixers, as well as storage spaces or buildings for housing organic fertilizer materials and facilitating the composting process. These essential facilities include investments with relatively low costs. The materials used for organic fertilizer production are primarily organic wastes such as rice straw, rumen contents, and cow manure. Supportive materials such as minerals, dolomite, molasses, and beneficial microbes are introduced to facilitate the process (Ginting, 2019). In the context of scaling up production, the incorporation of additional equipment becomes pivotal. This includes chopping and grinding equipment powered by electricity or fuel to make it more efficient. Simultaneously, establishing a permanent storage warehouse is imperative to ensure smooth operations. The indicators of the availability of manufacturing facilities and the potential for technological advancements are intertwined, playing a crucial role in their successful implementation. As technical progress is achieved, it necessitates parallel adaptations of manufacturing facilities and overall infrastructure to accommodate these innovations effectively. Improvements in organic fertilizer production technology and facilities are also related to sustainability in the economic dimension. The current study revealed modest organic fertilizer productivity based on production indicators. The infusion of technological improvements and upgrades in production facilities is anticipated to positively influence organic fertilizer output. Within the domain of environmental sustainability, a promising avenue emerges through the refinement of organic fertilizer production methods. One of production technologies or methods used to support sustainability in the environmental dimension is the development of superior microbial decomposition of organic matter, which speeds up the composting process. Moreover, reimagining the drying process for organic materials offers an opportunity to align with environmental objectives. Exploring innovations like dryers featuring solar cells and other environmentally friendly technologies holds promise. Apart from that, for drying organic materials, dryers with solar cells and other more environmentally friendly technologies could be developed, thereby supporting business sustainability from an environmental, economic, or social perspective. Another method that has the potential to be improved is optimizing the mixture of composted materials to ensure the resulting organic fertilizer is of good quality in terms of hygiene, stability, and maturity (Pezzolla *et al.*, 2021). Facilities and infrastructural development are levers to increase productivity and production. Aziz et al. (2018) highlight that economic analysis guides the management strategies within organic fertilizer production domain, aiming for efficiency while minimizing environmental burdens. Aziz *et al.* (2018) reported that management of organic fertilizer production area and the work methods

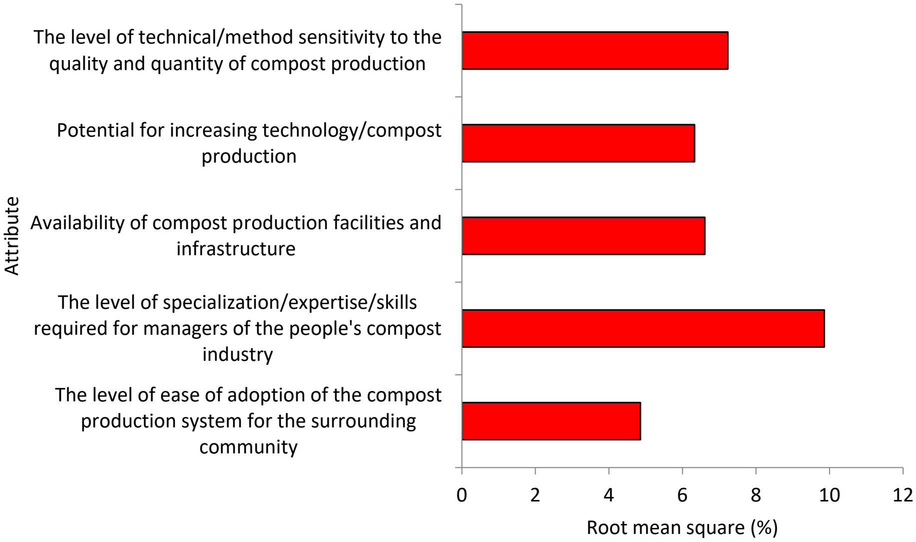

Fig. 5: Leverage of technology attributes

used are based on economic analysis to make it more efficient while minimizing environmental burden. This method encompasses critical aspects such as raw material storage and waste disposal. The simplicity of the composting method makes it accessible for implementation and adoption, even within the local community. However, the survey results indicate a heightened sensitivity to its adoption by the surrounding community, particularly concerning technological sustainability. This is presumably due to a knowledge gap within the local community pertaining to the significance of organic fertilizer in enhancing plant growth, augmenting soil fertility, and contributing to environmental preservation. The community appears to lack awareness of the promising economic value intertwined with organic fertilizer production. As a result, it becomes imperative to initiate focused efforts to enhance the acceptance indicators of organic fertilizer production system, thereby boosting the overall sustainability of the technical dimension. To address this challenge, targeted initiatives must be deployed to capture and sustain the interest of the community in organic fertilizer production derived from rice straw waste and cow rumen contents. This involves comprehensive socialization of production system, technology-centric exhibitions, practical emulation studies, and specialized training facilitated through collaborations with technology and business institutions. Therefore, the five technological dimension attributes studied still have the opportunity to be improved or developed by considering related aspects such as environment, economy, and society. Pergola *et al*. (2020) reported that the adoption of organic fertilizer production methods by farmers requires an evaluation of the environmental impact, energy consumption, and economic costs, specifically regarding the construction and management of facilities. Finally, production procedures rely on government support and careful consideration of key technological factors to achieve optimal and sustainable production. The Indonesian government is recommended to undertake the following roles. Regulations and Incentives: The government could enact policies encouraging proper waste management, potentially offering incentives to promote sustainable practices such as composting and waste conversion. Research and development Support: Investment in research is vital to optimize waste-to-fertilizer conversion. Government funding could substantially contribute to the development of efficient processing methods. Financial Boost: Provide financial support, subsidies, or grants to encourage organic fertilizer production among farmers, cooperatives, and businesses. Capacity Building: Government-led training sessions to educate stakeholders on organic fertilizer benefits, composting, and waste management best practices. Collaboration: Public-private partnerships involving the private sector, non-goverment organisations (NGOs), and international bodies can amplify expertise, resources, and scaling potentials. Market Creation: Government efforts to connect organic fertilizer producers to potential buyers in order to stimulate investment.

CONCLUSIONS

In conclusion, sustainability index for organic fertilizer production was determined using MDS method, considering factors affecting sustainability across four dimensions. The calculated sustainability index was 74.55%, indicating the growth potential when considering leverage factors in each dimension. The developed sustainability index was valid and limited in the area where it was developed due to diverse regional characteristics. Among these, the economic dimension had the lowest leverage value at 63.69%, while that of environmental, social, and technological were obtained at 90.1%, 70.5%, and 73.93%, respectively. Improving the economic aspects was prioritized, particularly those related to production and marketing. In terms of the environmental dimension, enhancing water efficiency during fertilizer production emerged as a pivotal factor. Efficient water use, specifically in high-water-usage environments such as paddy fields, reduces water waste, preserves resources, and supports environmental sustainability. The benefits of organic fertilizer were also recognized for countering soil degradation and enhancing its quality, as well as conserving groundwater. In the social dimension, addressing factors such as job security, community engagement, and knowledge levels of workers and managers was identified as crucial for achieving sustainable implementation. Strategies such as retraining, stakeholder engagement, communication, and capacity-building were deemed essential for promoting community well-being and fostering a sustainable agricultural system. Various factors, including worker welfare, raw material use, market expansion, and substitution of chemical fertilizer, influenced the economic dimension. The significance of strong marketing efforts in increasing profits and adoption rates was underscored. In the technological dimension, factors such as managerial expertise, production methods, availability of production facilities, and community adoption ease were recognized as influential in achieving sustainable organic fertilizer production. Finally, it was emphasized that government support and technological considerations were vital for promoting sustainable organic fertilizer production in Indonesia, specifically given the escalating demand for national fertilizer.

AUTHOR CONTRIBUTIONS

A.D. Santoso conducted the literature analysis, experimental activities, writing of the manuscript, getting result, data handling, data validation, MDS data analysis, analyzed the manuscript critically for significant intellectual content; F.D Arianti conducted the literature analysis, experimental activities, writing of the manuscript, data handling, MDS data analysis, analyzed the manuscript critically for significant intellectual content; E.S. Rohaeni conducted the literature analysis, writing of the manuscript, data and information collection, data handling, MDS data analysis, analyzed the manuscript critically for significant intellectual content; B. Haryanto conducted the literature analysis, experimental activities, writing of the manuscript, MDS data analysis, analyzed the manuscript critically for significant intellectual content, administration; Pertiwi, M.D conducted the literature analysis, experimental activities, writing of the manuscript, administration; L.P. Panggabean conducted the literature analysis, writing of the manuscript, data and information collection, data handling, analyzed the manuscript critically for significant intellectual content; A. Prabowo conducted the literature analysis, experimental activities, writing of the manuscript, data and information collection, MDS data analysis; S. Sundari conducted the literature analysis, writing of the manuscript, data and information collection, analyzed the manuscript critically for significant intellectual content; S.P. Wijayanti conducted the literature analysis, writing of the manuscript, experimental activities, data and information collection, MDS data analysis analyzed the manuscript critically for significant intellectual content; I.N. Djarot conducted the literature analysis, experimental activities, writing of the manuscript, MDS data analysis, analyzed the manuscript critically for significant intellectual content; F.D. Kurniawati conducted the literature analysis, writing of the manuscript, analyzed the manuscript critically for significant intellectual content; F.L. Sahwan conducted the literature analysis, experimental activities, writing of the manuscript, validation, MDS data analysis, analyzed the manuscript critically for significant intellectual content; T. Prasetyo conducted the literature analysis, experimental activities, writing of the manuscript, validation, MDS data analysist; A. Barkah conducted the literature analysis, writing of the manuscript, experimental activities, data and information collection, administration; T.A. Adibroto conducted the literature analysis, experimental activities, writing of the manuscript, validation, MDS data analysis, analyzed the manuscript critically for significant intellectual content; R. Ridlo conducted the literature analysis, experimental activities, writing of the manuscript, analyzed the manuscript critically for significant intellectual content; I. Febijanto conducted the literature analysis, experimental activities, writing of the manuscript, data and information collection, analyzed the manuscript critically for significant intellectual content; A.A. Wasil conducted the literature analysis, writing of the manuscript, data and information collection, data handling, administration; S. Lusiana conducted the literature analysis, writing of the manuscript, validation, MDS data analysis, administration; R. Rosmeika conducted the literature analysis, writing of the manuscript, validation, MDS data analysis, administration; Heryanto, R.B. conducted the literature analysis, experimental activities, writing of the manuscript, analyzed the manuscript critically for significant intellectual content.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication, double publication and submission, as well as redundancy, have been completely witnessed by the authors.

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ABBREVIATIONS

%	Percent
°C	Degree Celsius
ADF	Acid detergent fiber
ADL	Acid detergent lignin
ASCAL	Alternating least-squares algorithm
APHA	American public health association
C	Carbon
Ca	Calcium
CH_4	Methane
C/N ratio	Carbon-nitrogen ratio
CF	Crude fiber
CP	Crude protein
CSR	Corporate social responsibility
d	Euclidian distance
d_{ij}	Euclidian distance from point i to point j
d_{ijk}	Squared distance
FAO	Food and agriculture organization
DM	Dry matter
GDP	Gross domestic product
GKG	Dry milled grain
GWP	Global warming potential
H	Hydrogen
K	Kalium
kg	Kilogram
LCA	Life cycle assessment
Ltd	Limited
MC	Moisture content
MDS	Multidimensional scaling
mg	Milligram
$mgCH_4/kg$	Miligram methane per kilogram substrate
N	Nitrogen
Na	Natrium
NA	Not applicable
NGOs	Nongovernment organizations
O	Oxygen
P	Phosphorus
pH	Potential of hydrogen
ppm	Part per million
Raffish	Rapid appraisal for fisheries, an analytical method to assess sustainability of fisheries based on a multidisciplinary method
RH	Relative humidity
RMS	Root mean square, a frequently used measure of the differences between values
S	Sulphur
SR^2	Squared correlation
SQR	Structured query reporter, a programming language designed for generating reports from database management systems
TKN	Total Kjeldahl Nitrogen
TS	Total solid

USD	United States dollar
VS	Volatile solid
x-axis	Horizontal number line
y-axis	Vertical number line

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