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Utilization of Poultry Manure as an Organic Amendment for Sustainable Soil Management in Brunei Darussalam

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Abstract

Brunei, which is located in Southeast Asia, has predominantly Ultisols and Oxisols, which are highly weathered, nutrient-deficient, and acidic soil posing challenges for agriculture. As a result, the country struggles to meet self-sufficiency targets with rice production covering only 8.14% of local demand, while most of the crops are imported to meet consumption needs. To improve crop production, initiatives such as liming to reduce soil acidity, introducing high-yield seed varieties, and opening new land for cultivation have been implemented, though they pose economic and environmental challenges. In addition to crop production, poultry farming plays a key role in food security, achieving near self-sufficiency in broiler and egg production. Nevertheless, increased poultry farming generates significant waste, such as manure, which requires proper management to prevent pollution. The rise in waste output has led to higher landfill demand and environmental degradation. However, repurposing poultry waste into organic amendments, fertilizers, and biogas promotes sustainable waste utilization. The use of organic amendment derived from poultry manure can enhance soil fertility by improving nutrient availability, microbial activity, and soil structure, supporting sustainable soil management, and reducing reliance on synthetic fertilizers. By integrating these practices, Brunei can adopt circular agriculture, reintegrating agriculture by-products into the production cycle to enhance sustainability and food security. Hence, the objective of the presented review enables an approach that not only enhances soil fertility but also contributes to long-term agricultural sustainability which includes sustainable soil management and food security in Brunei.

Keywords: acid soil, soil management, waste management, circular agriculture

JEL code: Q01, Q10, Q16

SDG classification: SDG 2, SDG 12

Introduction

A common environmental problem that can significantly decrease crop production is the occurrence of acid soil. Brunei is situated in South-East Asia, a region characterized by the widespread occurrence of acidic soil (von Uexküll & Mutert, 1995). Soil evaluation conducted in Brunei have shown that its soil properties closely resemble those of typical acid soil, and many of which are found in the inland low-lying area, which are key zones for agricultural activities (Grealish & Fitzpatrick, 2013). Acid soils can affect the growth of plant root development and yield through nutrient imbalance, toxicity, and inadequacy of essential nutrient elements in the soil (Osman, 2018; Sade et al., 2016). As a result, Brunei is unable to achieve a self-sufficiency rate for crop production, which includes rice (8.15%), tropical vegetables (72.7%), tropical fruits (43%), and miscellaneous crops (10.9%) (Department of Agriculture and Agri-food, 2023). These low self-sufficiency levels have necessitated the importation of these crops to meet domestic consumption demands.

In response to this challenge, various initiatives have been undertaken to improve the situation. A common agricultural practice adopted by local farmers is the application of lime to reduce soil acidity and improve crop production, however, the effectiveness of the current approach may lead to under- or over-liming, which will result in yield loss and increase costs (Ringrose-Voasde et al., 2008). Brunei also introduced high-yield variety crops to improve crop production. An example is rice variety *Sembada 188*, with a paddy production of more than 4000 metric tonnes (Mt) in 2021, has contributed to the growth of paddy production (Department of Agriculture and Agri-food, 2022). Another initiative made by the government is the opening of new agricultural land for paddy production. The new 500 hectares of agricultural land is located in Kandol, Belait, and is expected to generate 6000 - 8000 Mt of rice yearly by 2025 (Wong, 2020). These efforts demonstrate Brunei's commitment to improving agricultural productivity; however, these practices must be carefully managed to avoid negative impacts such as soil degradation and nutrient imbalance. Thus, sustainable soil management remains a critical foundation for improving crop yield and achieving national food security goals.

In Brunei, the poultry sector currently leads in achieving self-sufficiency among all livestock industries, playing a crucial role in the nation's food security (Department of Agriculture and Agri-food, 2023). It is expected from this sector to produce a high amount of waste. It was estimated that 82,055 Mt of chicken manure from both broiler and layer was produced in 2023 (personal communication, 2024). However, despite this significant output, Brunei lacks a proper waste classification system, aside from arrangements for the disposal of hazardous waste; most waste is either combined with household refuse and common landfill sites (Department of Environment Parks and Recreation, n.d.)

Waste generation is defined as discarded material including municipal solid waste, hazardous and non-hazardous waste, and agricultural and animal waste. With Brunei Darussalam's limited land capacity and an addition to the landfills receiving waste daily, it has been estimated the landfill is to be at its full capacity by 2030 (*No Time to Waste*, 2021). Nonetheless, poultry litter consists of valuable nutrients and can be transformed into organic soil amendment through composting, co-composting, and pyrolysis. Several studies have provided results in improving the soil's chemical, physical and biological properties, at the same time increasing the yield of crops with soil organic amendment produced from poultry litter, moreover, organic-mineral fertilizer derived from poultry

waste proved to be as effective as costly commercial mineral fertilizer (Gržinić et al., 2023; Mironiuk et al., 2023). This promotes organic farming practices and at the same time reduces dependency on synthetic fertilizer and mitigating their environmental impacts. Therefore, this paper aims to explore approaches that improve soil fertility while supporting long-term agriculture sustainability, with a focus on sustainable soil management and strengthening food security in Brunei.

Methodology

To evaluate the current status of utilization of poultry manure for sustainable soil management, this review study followed the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA), which provides guidelines in selecting, identifying, and synthesizing studies (Page et al., 2021). This study utilized three databases: Scopus, EBSCOHost, and Google Scholar (non-Scopus database). The databases encompassed a broad selection of peer-reviewed academic journal articles, providing comprehensive coverage for literature data. The search study employed a combination of keywords and Boolean operators to ensure inclusion of all relevant studies. The keywords included, but were not limited to, acid soil, tropical soil, sustainable soil management, poultry manure, organic amendment, and Southeast Asia Agriculture.

To prevent the generalization of this literature study, a list of criteria was designed to ensure that the retrieved documents fell within the search scope and relevance of this study (Figure 1). The inclusion and exclusion criteria were as follows:

- i. Papers from 2015 to 2025,
- ii. English medium and English translated documents,
- iii. Documents are limited to countries of Southeast Asia,
- iv. Studies conducted use organic amendment (compost and biochar) from poultry manure with and/or without adding other sources,
- v. Studies conducted on acid soil conditions,
- vi. Outcome on improvement in crop yield and soil chemical, biological, and physical properties,
- vii. Studies unrelated to the use of organic amendment, and acid soil,
- viii. Studies that only focus on plant growth and yield without linking results to soil improvements.

Following the retrieval of relevant literature, Mendeley software was used to manage the references and remove the duplicates. For each included study, the following information was extracted: title, author, year, abstract, keywords, and relevance to Brunei.

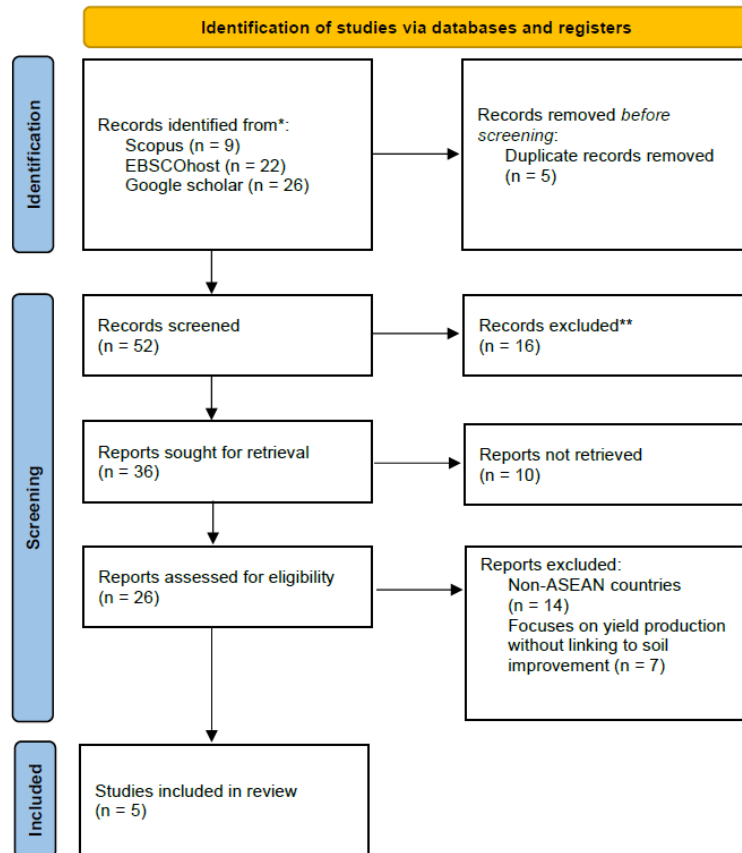


Figure 1. Literature search and documents analysis process.

Based on the search conducted, Figure 1 reveals that only 5 documents were included in the final review for this document analysis process. Of the three databases used and the records searched using the selected keywords, a total of 52 documents were identified after removing duplicate documents. During the screening process, only 26 documents were assessed for eligibility, as several documents were not retrieved and excluded because their titles, abstracts, and keywords were not relevant to the topic. The final screening process assessed the eligibility of the documents according to the inclusion and exclusion criteria stated above, and only five studies were included for review, as shown in Table 1.

Results and Discussion

Inadequate information on the production of organic amendment from poultry manure in Brunei Darussalam

A total of 5 documents were eligible and included in this study review. The documents were further assessed for their relevance to Brunei and environmental benefits, which align with the topic of this study. Although these studies were not conducted in Brunei, each study is highly relevant to Brunei’s agricultural issues. The listed documents (Table 1) are highly relevant to Brunei’s agricultural issues because each of the studies was

conducted in areas affected by acid soil (von Uexküll & Mutert, 1995). According to studies conducted, the use of poultry waste is crucial in improving soil health and enhancing nutrient availability for plants. This is because poultry waste has high nutrient content, rich in essential elements, and the potential to improve soil fertility, making it a widely used raw material to produce organic amendments (Alarefee et al., 2021).

Globally, poultry waste production has increased over the past few years due to the intensification of poultry farming, which plays a significant role in modern poultry farming, while also providing food and nutritional security for the growing world population. However, this has left an environmental footprint due to several factors, and one of them is inefficient manure and litter management and use (Gržinić et al., 2023). It is essential to mention that direct use of fresh poultry litter can lead to several environmental problems, including ammonia volatilization, soil acidification and crop damage, transfer of pathogens, and heavy metal contamination (Alarefee et al., 2021; Drózdź et al., 2020). Without proper awareness of these issues, it can lead to improper soil management, leading to reduced crop yield and quality, vulnerability to pests and diseases, and environmental issues like water pollution. As suggested by Ali et al. (2023) and Alarefee et al. (2021), transforming poultry waste into an organic amendment is a sustainable and cost-effective method, a solution for soil health restoration, and productive management for crop production. Integrating such practices into a structured waste management framework would not only support circular agriculture by closing nutrient loops but also contribute to sustainable soil management in Brunei, particularly in addressing the challenges posed by its acidic and nutrient-poor soil.

Sustainable Agricultural Practices & Technologies

Table 1. List of documents included in literature studies relevant to Brunei

No.	Title	Publication year	Author(s)	Relevance to Brunei	Environmental benefits	Soil health effects	Type of document
1	Co-Composted Chicken Litter Biochar Increases Soil Nutrient Availability and Yield of <i>Oryza sativa</i> L.	2023	Ali et al.	Highly relevant	<ul style="list-style-type: none"> Mitigate environmental pollution Reduction in the use of inorganic fertilizer Waste management 	Improve nutrients availability soil and	Journal article
2	Efficiency of rice husk biochar with poultry litter co-composts in oxisols for improving soil physico-chemical properties and enhancing maize performance	2021	Alarefee et al.	Highly relevant	<ul style="list-style-type: none"> Waste management Reduce ammonia emissions Reduction in the use of inorganic fertilizer Reduce heavy metal uptake by the crop 	Increased soil macronutrients Restoration and stabilization of soil organic carbon	Journal article
3	Utilization of urea and chicken litter biochar to improve rice production	2021	Maikol et al.	Highly relevant	<ul style="list-style-type: none"> Reduce the need for synthetic N 	Improved soil nutrient retention	Journal article

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No.	Title	Publication year	Author(s)	Relevance to Brunei	Environmental benefits	Soil health effects	Type of document
					<ul style="list-style-type: none"> Reduces toxicity in soil Enhanced sequestration 	AI C Improve biological properties Enhanced water infiltration	
4	Growth and yield response of peanut, (<i>Arachis hypogaea</i> L.) and soil characteristics with application of inorganic and organic fertilizer and dolomite addition	2019	Arangote et al.	Highly relevant	<ul style="list-style-type: none"> Reduce soil N₂O emission Enhance crop yield 	Improve soil macro and micronutrients Improve soil texture and selected chemical properties	Journal article
5	Effects of biochar and chicken litter ash on selected soil chemical properties and nutrients uptake by <i>Oryza sativa</i> L. var. MR 219	2015	Yusof et al.	Highly relevant	<ul style="list-style-type: none"> Reducing reliance on chemical fertilizer 	Improved soil structure, water tension, and overall soil fertility	Journal article

Potential of using poultry manure to improve soil productivity and crop production

Poultry litter is a waste product from poultry farms, primarily consisting of manure with a mixture of shed feathers, spilled feed, and bedding materials. It is a significant byproduct of broiler and layer operations, and a valuable resource due to its high nutrient content. A study conducted by Rogeri et al., (2016) determined the composition of poultry manure, and the chemical properties of poultry litter presented pH of the poultry manure was alkaline, and the concentrations of N, P₂O₅, and K₂O were lower than 5.0%. Nitrogen (N) in poultry litter was in an organic form; however, ammonium was at 9.6% of total N, and very low traces of nitrate were detected. And the average organic carbon (C) and C/N ratio was at 28.3% and 11.2%, respectively. However, variation in the composition of poultry litter may occur due to different management of feed ration, dietary supplement, and litter storage and handling, which include the amount of bedding used, litter removal frequency, and use of windows to treat litter (Ashworth et al., 2020; Bolan et al., 2010) (Table 2).

Table 1. Nutrient composition of manures and composts (g/kg dry weight basis)

Nutrients	Poultry manure compost		Pig manure	Mushroom	Biosolid
	Layer	Broiler	compost	compost	compost
Nitrogen	32.8	25.7	15.2	17.5	21.8
Phosphorus	10.8	6.7	6.5	7.5	10.1
Potassium	15.2	10.1	8.2	9.2	5.9
Calcium	18.5	16.2	4.2	21.5	19.7
Magnesium	6.2	3.5	3.7	5.2	4.2
Sulphur	8.5	5.2	3.4	3.5	7.0

Source: Ashworth et al., (2020)

It is essential to analyze the nutrient composition of poultry manure to ensure that its application aligns with the specific nutrient requirements of the target crop. Compared to other manure sources, poultry litter contains exceptionally high levels of total N and phosphorus (P); however, the disproportionate relationship between these nutrients and the actual crop requirements can lead to nutrient imbalances in agricultural fields (Muduli et al., 2019). Therefore, transforming poultry litter into stabilized organic amendment is a critical process for mitigating hazards associated with its direct application and conserving the nutrients.

Improper management of poultry litter may pose significant environmental and human health risks. Poultry litter contains valuable nutrients, making it useful for agriculture, but also includes pollutants like ammonia and other odour compounds, and these substances can contribute to water, air, and land pollution, and they may even be toxic to human health due to improper disposal (Singh et al., 2018). Poultry production also generates ethane, ammonia, and nitrous oxide, which are greenhouse gases emitted through waste and litter management, as well as the application of untreated poultry manure as an organic amendment (Zisis et al., 2023). Without effective management and proper treatment of the poultry manure, this can waste the manure's potential, leading to nutrient loss through evaporation, runoff, and leaching.

Effective manure management can reduce environmental and health impacts while aiming for profitability and preventing nutrient loss. Several methods are available for the

management and disposal of poultry litter; however, this study specifically focuses on its utilization as a soil amendment through land application in agricultural systems. Composting is a cost-effective method that results in a more sustainable and stable product for application. This process kills pathogens and controls disease outbreaks, odour control, moisture management, and minimizes loss of important nutrients, such as nitrogen and phosphorus, from leaching and runoff, by adding additives like zeolite and biochar (Zisis et al., 2023; Drózdź et al., 2020; Singh et al., 2018). Similarly, pyrolysis involves the thermal decomposition of organic materials in the absence of oxygen, resulting in the production of biochar. This process transforms the poultry litter into a stable and carbon-rich solid, containing readily available phosphorus and potassium, and improves the physical properties of the organic amendment with high surface area and porosity, making it suitable for adsorption and filtration applications (Pandey et al., 2019; Yıldız et al., 2019). Biochar is also environmentally safe because of its ability to reduce emissions of ammonia and carbon dioxide (Drózdź et al., 2023; Simbolon et al., 2024). Given Brunei's emphasis on improving agricultural productivity and reducing reliance on imported inputs, these methods offer potential for enhancing soil fertility using locally available organic waste, while minimizing negative environmental and health impacts.

Implication of soil organic amendment in Brunei

The studies demonstrate the high relevance of poultry litter and co-application of compost and biochar for enhancing sustainable agriculture in Brunei (Table 1). Research by Alarefee et al., (2021), Ali et al., (2023), and Maikol et al. (2021) underscores the environmental benefits of these practices, including the reduction in the use of synthetic fertilizer, mitigation of ammonia and greenhouse gas emissions, improved waste management, and enhanced carbon sequestration. Utilizing and transforming poultry litter into a stable product for land application in agricultural systems has presented its benefits, particularly in addressing nutrient loss and pollution concerns. These practices align closely with the principles of circular agriculture, where agricultural waste is recycled back into the system to improve soil fertility, reduce external inputs, and close nutrient loops. Additionally, studies by Arangote et al. (2019) and Yusof et al. (2015) show significant improvements in soil health, including increased availability of macro- and micronutrients, stabilization of organic carbon, better water infiltration, and improved soil structure and fertility. The use of co-composted poultry litter and biochar also helps reduce heavy metal uptake in crops and alleviates soil toxicity, especially in acid-probe soils, which are prevalent in Brunei. Collectively, these findings highlight the potential of biochar and poultry litter amendments to improve crop yield, promote soil sustainability, support circular agriculture, and reduce environmental impact in Brunei's agriculture sector.

Conclusion

The review highlights the potential of utilizing poultry manure as a sustainable organic amendment to address the challenges posed by acid soil in Brunei. The findings demonstrate that poultry litter, when appropriately processed through composting or pyrolysis, significantly improves soil chemical, physical, and biological properties. These enhancements lead to increased crop productivity, reduced dependency on synthetic

fertilizers, and minimized environmental pollution. Although the reviewed studies were conducted in other Southeast Asia countries, their relevance to Brunei is evident due to similar soil conditions and agricultural challenges. The transformation of poultry waste into stable soil amendment not only supports sustainable agriculture but also aligns with Brunei's food security and waste management goals, thereby promoting circular agriculture practices.

However, it is important to note that most of the reviewed studies were conducted under controlled or small-scale conditions and may not fully capture the complexities of large-scale application in Brunei's agroecological context. Despite these limitations, it is recommended that Brunei adopt an integrated waste management system that facilitates the classification, collection, and processing of poultry manure to aid its conversion into compost and biochar. It is also important to initiate localized pilot project to test poultry litter amendments on Brunei's soil to validate and adapt findings from regional studies to the national context.

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References

- Alarefee, H., Ishak, C. F., Karam, D. S., & Othman, R. (2021). Efficiency of Rice Husk Biochar with Poultry Litter Co-Composts in Oxisols for Improving Soil Physico-Chemical Properties and Enhancing Maize Performance. *Agronomy*, *11*(12), 2409. <https://doi.org/10.3390/agronomy11122409>
- Ali, M., Ahmed, O. H., Jalloh, M. B., Primus, W. C., Musah, A. A., & Ng, J. F. (2023). Co-Composted Chicken Litter Biochar Increases Soil Nutrient Availability and Yield of *Oryza sativa* L. *Land*, *12*(1), 233. <https://doi.org/10.3390/land12010233>
- Arangote, V. R., De, R. B., Saura, L., James, R., & Rollon, C. (2019). Growth and yield response of peanut, (*Arachis hypogaea* L.) and soil characteristics with application of inorganic and organic fertilizer and dolomite addition International Journal of Biosciences | IJB |. *Int. J. Biosci*, *15*(6), 164–173. <https://doi.org/10.12692/ijb/15.6.164-173>
- Ashworth, A. J. J., Chastain, J. P. P., & Moore, P. A. A. (2020). Nutrient Characteristics of Poultry Manure and Litter. *Animal Manure: Production, Characteristics, Environmental Concerns, and Management*, April, 63–87. <https://doi.org/10.2134/asaspecpub67.c5>
- Bolan, N. S., Szogi, A. A., Chuasavathi, T., Seshadri, B., Rothrock, M. J., & Panneerselvam, P. (2010). Uses and management of poultry litter. *World's Poultry Science Journal*, *66*(4), 673–698. <https://doi.org/10.1017/S0043933910000656>

- Department of Agriculture and Agri-food. (2022). *Agriculture & Agrifood Statistics in Brief 2021*. <http://www.agriculture.gov.bn/SiteCollectionDocuments/Statistik/Brunei Darussalam Agriculture Statistics in Brief 2021.pdf>
- Department of Agriculture and Agri-food. (2023). *Agriculture & Agrifood Statistics in Brief 2023*.
- Department of Environment Parks and Recreation. (n.d.). *Status Of Hazardous Waste Management In Brunei Darussalam*. <http://www.env.gov.bn/SitePages/Status Of Hazardous Waste Management In Brunei Darussalam.aspx>
- Drózdź, D., Malińska, K., Wystalska, K., Meers, E., & Robles-Aguilar, A. (2023). The Influence of Poultry Manure-Derived Biochar and Compost on Soil Properties and Plant Biomass Growth. *Materials*, 16(18), 6314. <https://doi.org/10.3390/ma16186314>
- Drózdź, D., Wystalska, K., Malińska, K., Grosser, A., Grobelak, A., & Kacprzak, M. (2020). Management of poultry manure in Poland – Current state and future perspectives. *Journal of Environmental Management*, 264. <https://doi.org/10.1016/j.jenvman.2020.110327>
- Grealish, G. J., & Fitzpatrick, R. W. (2013). Acid sulphate soil characterization in Negara Brunei Darussalam: a case study to inform management decisions. *Soil Use and Management*, 29(3), 432–444. <https://doi.org/10.1111/sum.12051>
- Gržinić, G., Piotrowicz-Cieślak, A., Klimkowicz-Pawlas, A., Górny, R. L., Ławniczek-Wałczyk, A., Piechowicz, L., Olkowska, E., Potrykus, M., Tankiewicz, M., Krupka, M., Siebielec, G., & Wolska, L. (2023). Intensive poultry farming: A review of the impact on the environment and human health. *Science of The Total Environment*, 858, 160014. <https://doi.org/10.1016/j.scitotenv.2022.160014>
- Maikol, N., Haruna, A. O., Maru, A., Asap, A., & Medin, S. (2021). Utilization of urea and chicken litter biochar to improve rice production. *Scientific Reports*, 11(1), 9955. <https://doi.org/10.1038/s41598-021-89332-y>
- Mironiuk, M., Samoraj, M., Witek-Krowiak, A., Górecki, H., Moustakas, K., & Chojnacka, K. (2023). Processing of nuisance animal waste into agricultural products. *Environmental Pollution*, 319(July 2022). <https://doi.org/10.1016/j.envpol.2022.120924>
- Muduli, S., Champati, A., Popalghat, H. K., Patel, P., & Sneha, K. (2019). Poultry waste management: An approach for sustainable development. *International Journal of Advanced Scientific Research*, 4(January), 8–14. www.allscientificjournal.com
- No Time to Waste. (2021, February 8). Borneo Bulletin. <https://borneobulletin.com.bn/no-time-to-waste/>
- Osman, K. T. (2018). Acid Soils and Acid Sulfate Soils. In *Management of Soil Problems* (pp. 299–332). Springer, Cham. <https://doi.org/10.1007/978-3-319-75527-4>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., ... Moher, D. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ*, 372, n71. <https://doi.org/10.1136/bmj.n71>

- Pandey, D. S., Katsaros, G., Lindfors, C., Leahy, J. J., & Tassou, S. A. (2019). Fast Pyrolysis of Poultry Litter in a Bubbling Fluidised Bed Reactor: Energy and Nutrient Recovery. *Sustainability*, 11(9), 2533. <https://doi.org/10.3390/su11092533>
- Ringrose-Voasde, A., Wong, M., Winston, E., Fitzpatrick, R., Grealish, G., & Hicks, W. (2008). *Soil Fertility Evaluation/Advisory Service in Negara Brunei Darussalam Volume 2 – Soil Management in the Agricultural Development Areas*.
- Rogeri, D. A., Ernani, P. R., Mantovani, A., & Lourenço, K. S. (2016). Composition of Poultry Litter in Southern Brazil. *Revista Brasileira de Ciência Do Solo*, 40, 1–7. <https://doi.org/10.1590/18069657rbcs20140697>
- Sade, H., Meriga, B., Surapu, V., Gadi, J., Sunita, M. S. L., Suravajhala, P., & Kavi Kishor, P. B. (2016). Toxicity and tolerance of aluminum in plants: Tailoring plants to suit to acid soils. *BioMetals*, 29(2), 187–210. <https://doi.org/10.1007/s10534-016-9910-z>
- Simbolon, L. M., Pandey, D. S., Horvat, A., Leahy, J. J., Tassou, S. A., & Kwapinska, M. (2024). Influence of the pyrolysis temperature on fresh and pelletised chicken litter with focus on sustainable production and utilisation of biochar. *Biomass Conversion and Biorefinery*, 14(20), 26443–26457. <https://doi.org/10.1007/s13399-023-04787-5>
- Singh, P., Mondal, T., Sharma, R., Mahalakshmi, N., & Gupta, M. (2018). Poultry Waste Management. *International Journal of Current Microbiology and Applied Sciences*, 7(08), 701–712. <https://doi.org/10.20546/ijcmas.2018.708.077>
- von Uexküll, H. R., & Mutert, E. (1995). Global extent, development and economic impact of acid soils. *Plant and Soil*, 171(1), 1–15. <https://doi.org/10.1007/BF00009558>
- Wong, A. (2020, December 29). *Increased production costs raise price of poultry in Brunei*. BizBrunei. <https://www.bizbrunei.com/2020/12/increased-production-costs-raise-price-of-poultry-chicken-brunei/>
- Yıldız, Z., Kaya, N., Topcu, Y., & Uzun, H. (2019). Pyrolysis and optimization of chicken manure wastes in fluidized bed reactor: CO₂ capture in activated bio-chars. *Process Safety and Environmental Protection*, 130, 297–305. <https://doi.org/10.1016/j.psep.2019.08.011>
- Yusof, M. R. M., Ahmed, O. H., King, W. S., & Zakry, F. A. A. (2015). Effects of biochar and chicken litter ash on selected soil chemical properties and nutrients uptake by *Oryza sativa* L. var. MR 219. *International Journal of Biosciences (IJB)*, February 2015, 360–369. <https://doi.org/10.12692/ijb/6.3.360-369>
- Zisis, F., Giamouri, E., Mitsiopoulou, C., Christodoulou, C., Kamilaris, C., Mavrommatis, A., Pappas, A. C., & Tsiplakou, E. (2023). An Overview of Poultry Greenhouse Gas Emissions in the Mediterranean Area. *Sustainability*, 15(3), 1941. <https://doi.org/10.3390/su15031941>