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Comparative study of soil amendment and organic fertilizer use to optimize agricultural dryland

Suherman [a, 1, *], Edi Kurniawan [b, 2], Asysyuura [c, 3], Husni Asmi [a, 4], Indah Fitriani [a, 5], Zulkifli [a, 6], Abdul Halil Fatwa [a, 7]

[a] Department of Agrotechnology, Universitas Muhammadiyah Parepare, Parepare, Indonesia
[b] Department of Agribusiness, Universitas Muhammadiyah Parepare, Parepare, Indonesia
[c] Department of Agrotechnology, Sekolah Tinggi Ilmu Pertanian Yapi Bone, Bone, Indonesia
[1] suherman.umpar@ymail.com; [2] kurniawan87mj@gmail.com;
[3] new.asysyuura2022@gmail.com; [4] husniasmi1234@gmail.com;
[5] indahfitriani161104@gmail.com; [6] zulk3133@gmail.com; [7] abdulhalil127@gmail.com
* Corresponding author

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ABSTRACT

This study investigates the effects of different organic soil amendments on the chemical characteristics of dryland soils to enhance agricultural practices in arid areas. Employing a randomized complete block design, six treatments were administered oversix-months on acidic soils with low organic matter concentration, exemplifying typical dryland conditions in tropical areas. The treatments comprised high and moderate doses of mixed organic compounds, alongside control groups without amendments. Soil samples were analyzed pre- and post-treatment for pH, carbon, nitrogen, phosphorus, and potassium concentrations. Results demonstrate that high-dose organic mixtures markedly enhanced soil pH, carbon content, and nutrient availability, particularly phosphorus and potassium, in comparison to control and lower-dose treatments. The research underscores the essential importance of suitable amendment kinds and quantities in improving soil quality and sustainability. The findings indicate that the strategic application of organic amendments can markedly enhance the chemical properties of dryland soils, hence promoting more sustainable farming operations.

Conflict of interest: The authors declare that they have no conflicts of interest.

Introduction

Drylands are an essential resource in the worldwide agricultural sector, particularly in areas characterized by little precipitation and restricted water supply. The agricultural sector is vital as it sustains the livelihoods of over 1.3 billion individuals globally and plays a crucial role in food production[1,2], particularly in arid and semi-arid areas with constrained agricultural land that are extremely susceptible to climate change[3–5]. In Indonesia, this sector is very pertinent, given that the number of farmers totals 29.34 million, the majority of whom manage independent agricultural enterprises. Approximately 41% of the global geographical area is designated as drylands[6,7], encompassing Indonesia[8]. While Indonesia is predominantly recognized for its tropical climate, it also features significant seasonal dryland areas, particularly in the eastern sections, including East Nusa Tenggara and portions of Sulawesi[9,10]. These areas have prolonged arid seasons and restricted water resources, thereby confronting analogous issues to those encountered by arid zones globally. Drylands are frequently employed for agricultural production, notwithstanding considerable problems associated with the soil's physical and chemical characteristics. Soils in arid regions typically exhibit low water retention capacity, limited organic matter content, and a deficiency of essential nutrients, including nitrogen, phosphate, and potassium, necessary for optimal plant growth[11,12]. Dryland soils frequently exhibit inadequate water retention, diminished organic matter, and shortages in essential nutrients, significantly constraining agricultural productivity. To directly tackle these limitations, different measures have been employed to improve the fertility of dryland soils, including the application of organic material additions called bio ameliorants[13]. Organic soil additives, including compost, biochar, green manure, and other organic wastes, are known for their capacity to improve the physical, chemical, and biological characteristics of soil. The application of bio ameliorants can augment the cation exchange capacity (CEC) and water retention of the soil, while also enhancing its organic matter content and microbiological activity, hence improving nutrient availability[12,14]. A substantial gap persists in identifying the ideal dosage of organic amendments appropriate for diverse soil conditions in arid regions. The integration of organic and inorganic additions markedly enhances soil nutrient concentrations[15]. Prior research has demonstrated that improper amendment dosages can result in nutritional imbalances in the soil, adversely impacting plant output, as excessive amounts may induce toxicity and undesirable nutrient deficits[16]. This research also emphasizes that the calibration of soil amendment dosages must account for the distinct attributes of dryland soils, including texture, pH, cation exchange capacity, and initial organic matter content, alongside environmental conditions and the type and quantity of amendments employed to attain the desired results[11,16–18].

Moreover, extensive studies on the impact of bioameliorants on the stability of soil fertility remains scarce. Bioameliorants can enhance soil conditions that have deteriorated due to excessive chemical use[19]. Many studies emphasize short-term effects, neglecting the long-term alterations in soil chemical composition and the durability of soil fertility following the application of organic amendments.

Prolonged application of bioameliorant to soil enhances its structure and chemistry by augmenting organic matter, cation exchange capacity, and water retention, thus mitigating the effects of drought intensified by climate change[20,21]. Moreover, bioameliorant enhances soil microbial diversity, diminishes reliance on synthetic chemical inputs, and improves fertilizer efficacy[22,23]. In the context of climate change, the involvement of bioameliorant is crucial as an adaptation and mitigation approach, and facilitates carbon sequestration, hence promoting sustainable and resilient agricultural practices in arid regions. Comprehensive research on the long-term effects of organic bioameliorants is essential to comprehend the chemical alterations in dryland soils and to promote sustainable agricultural methods[12].

This study seeks to assess the chemical alterations in soil subsequent to the application of diverse organic material amendments as bioameliorants in arid regions. It quantifies the levels of essential nutrients and pertinent chemical parameters to evaluate the efficacy of soil amendments in enhancing soil fertility in arid regions. The study’s conclusions aim to yield precise suggestions regarding the dosages and varieties of bioameliorants useful in enhancing the sustainable utilization of drylands.

Method

Research Location

This study was performed on arid terrain in Lapadde Village, Ujung District, Parepare City, South Sulawesi, Indonesia, at coordinates 3°59'04.9" S and 119°38'55.7" E. This site was selected due to its representation of tropical dry terrain with Regosol soil, which is classed as immature, possessing a sandy texture, crumbly structure, and limited water retention ability.

Climate Characteristics

Throughout the study period (April to September), the research site experienced an extended dry season, with monthly precipitation continuously under 100 mm, indicative of extreme aridity. Average daily temperatures fluctuated between 28.5°C and 29.2°C, resulting in heightened evapotranspiration rates and exacerbating soil moisture shortages. Despite elevated atmospheric humidity levels (70%–90%), soil water availability was constrained due to the disparity between insufficient precipitation and significant water loss via evapotranspiration.

Experimental Design

The research employed a completely randomized design (CRD) featuring six treatments and three replications, yielding a total of 18 experimental plots. Each plot was 2 meters by 2 meters. The treatments administered comprised: (A) a blend of organic materials at a rate of 30 tons per hectare, (B) a blend of organic materials at a rate of 20 tons per hectare, (C) a control with no treatment, (C1) chicken manure at a rate of 30 tons per hectare, (C2) cow manure at a rate of 30 tons per hectare, and (C3) burnt rice husk at a rate of 30 tons per hectare.

Soil was prepared through tilling and weed removal. Modifications were implemented based on the dosage and treatment type, followed by thorough mixing of the soil. Following application, the experimental plots were sustained at an optimal moisture level with adequate sprinkler irrigation to facilitate the decomposition of the organic components.

Soil Sampling and Analysis

Soil samples were obtained at two intervals: prior to treatment (at the study's commencement) and after 6 months of treatment (at the study's conclusion). The composite sampling method was utilized, wherein soil samples were gathered from five locations within each experimental plot and subsequently amalgamated for laboratory examination. The soil samples were examined to ascertain pH, carbon (C) content, nitrogen (N), C/N ratio, available phosphorus (P), and available potassium (K). The gathered soil samples underwent analysis at the South Sulawesi Agricultural Instrument Standardization Center (BSIP).

Results and Discussion

The study results demonstrated that the application of a combination of organic materials (Treatments A and B) exerted the most substantial effect on enhancing soil pH, carbon content, and the nutrient availability (P and K). The application of charred rice husk (C3) positively influenced potassium content, although was less successful in augmenting phosphorus levels. Simultaneously, chicken (C1) and cow (C2) dung were successful in enhancing the availability of nitrogen and phosphate, while providing a moderate contribution to potassium. These treatments exhibit significant potential for improving soil quality in arid regions, necessitating the adjustment of dosage and type of amendments based on the unique requirements of the soil and crops. Table 1 presents the chemical characteristics of soil subjected to different types and quantities of amendments in arid regions.

The application of substantial quantities of organic material combinations, specifically in Treatment A (30 tons/ha) and Treatment B (20 tons/ha), successfully elevated soil pH to a neutral range, attaining values 6.43 and 6.36, respectively. The increase in pH is significant as a neutral pH improves the availability of nutrients like phosphorus and potassium, which are frequently deficient in acidic soils. In contrast, Treatment C (control) demonstrated the lowest pH of 5.64, signifying that in the absence of amendments, the soil remains acidic, hence limiting the availability of essential nutrients for plants. The application of burnt rice husk in Treatment C3 (30 tons/ha) marginally reduced soil pH to 5.56, indicating diminished efficacy in enhancing soil chemical characteristics relative to other amendments. In contrast, chicken dung (Treatment C1) and cow dung (Treatment C2) elevated soil pH to 5.96 and 5.99, respectively, demonstrating their capacity to mitigate soil acidity, albeit less successfully than the organic material mixes. The elevation in soil pH noted in Treatment A (30 tons/ha) and Treatment B (20 tons/ha) can be ascribed to the capacity of organic materials to mitigate soil acidity by neutralizing hydrogen ions (H^+). During the decomposition of organic materials, chemicals like calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) are liberated into the soil, functioning as bases to neutralize H^+ ions in the soil solution. This technique elevated the soil pH to a neutral range, specifically between 6.43 and 6.36.

Table 1 | Effect of different types and dosages of soil amendments on soil chemical properties in drylands.

Treatments	pH	C	N	C/N	P dissolved	K dissolved
		--- % ---			--- ppm ---	
A (mix 30 ton/ha)	6.43	2.61	0.11	24	178	349
B (mix 20 ton/ha)	6.36	1.91	0.11	17	135	204
C (control)	5.64	1.30	0.11	12	31	158
C1 (chicken dung 30 ton/ha)	5.96	1.48	0.13	11	64	174
C2 (cow dung 30 ton/ha)	5.99	1.80	0.14	13	117	163
C3 (burnt rice husk 30 ton/ha)	5.56	1.56	0.13	12	32	229

The alteration of soil pH is significantly influenced by the kind and characteristics of the amendment applied. Mixtures of organic materials yield the most substantial increase in pH by releasing basic ions and augmenting cation exchange capacity. Conversely, organic substances such as burnt rice husk have diminished efficacy owing to their protracted breakdown and chemically stable characteristics[24,25]. Chicken and cow dung demonstrate moderate efficacy in elevating pH by releasing soluble bases[26,27]. These findings underscore the significance of choosing the correct type and amount of soil amendments to enhance soil acidity in arid regions.

The carbon content of soil rose markedly with elevated quantities of organic material. Treatment A (2.61%) and Treatment B (1.91%) exhibited the highest carbon content, signifying that the organic material mixture substantially enhances soil organic matter. In contrast, Treatment C (control) had the lowest carbon concentration at 1.30%, highlighting the necessity of utilizing amendments to improve soil quality. Chicken dung and cow dung exhibited carbon contents of 1.48% and 1.80%, respectively, underscoring the essential function of organic resources in facilitating the soil carbon cycle. The burnt rice husk in Treatment C3 (1.56%) exhibited greater carbon but was less amenable to decomposition than other organic components. The notable rise in soil carbon in Treatment A (2.61%) and Treatment B (1.91%) is ascribed to the direct input of the applied organic materials. Organic materials possess elevated concentrations of organic carbon, serving as the principal source for augmenting soil carbon levels. The increase in soil carbon content is significantly influenced by the type and quantity of organic amendments utilized[28,29]. Mixtures of organic materials enhance soil carbon, both by introducing easily decomposable organic matter and by facilitating the accumulation of stable carbon as humus[30,31]. Chicken and cow dung yield moderate carbon amounts, exhibiting variations in decomposition rates and the stability of the resultant carbon. Burnt rice husk provides more stable carbon but is less effective in enhancing short-term carbon levels. These findings highlight the importance of integrating organic amendments to improve the soil carbon cycle and elevate soil quality in arid regions.

The nitrogen percentage in the soil exhibited relative stablity throughout all treatments, varying from 0.11% to 0.14%. Chicken dung and cow dung exhibited marginally elevated nitrogen concentrations relative to other treatments (0.13% and 0.14%, respectively), signifying that these substances are effective nitrogen providers for the soil. This consistency in nitrogen levels indicates that the efficacy of amendments is predominantly determined by the type and decomposition rate of the organic materials employed.

In Treatment C1 (chicken dung) and C2 (cow dung), the nitrogen concentration was 0.13% and 0.14%, respectively, surpassing that of other treatments. This elevated nitrogen levels in animal dung can be ascribed to organic compounds, chiefly proteins and amino acids. In alternative treatments, specifically Treatment A and B (organic material mixes), nitrogen content was approximately 0.11%. Desoite the high carbon content of these organic amendments, the nitrogen levels in the utilized organic materials may be inferior to those found in animal dung. Nitrogen emitted during the decomposition of organic materials continues to adequately fulfill plant needs [32]. The stability of nitrogen in alternative treatments indicates that the decomposition of organic materials and the type of amendment significantly affect nitrogen availability in the soil. Consequently, choosing the appropriate amendment type and overseeing decomposition techniques are crucial to gauranteeing optimal nitrogen supply for plants[33,34].

The elevated C/N ratio in Treatment A (24) signifies a slower decomposition of organic materials, yielding long-term advantages via the progressive nutrient release. The decreased C/N ratios in chicken dung (Treatment C1, 11) and cow dung (Treatment C2, 13) indicate expedited decomposition, enhancing nutrient availability but providing diminished long-term effects on soil organic matter. The burnt rice husk in Treatment C3 (C/N 12) has a comparable effect to the control treatment, indicating a diminished capacity to enhance the carbon and nitrogen equilibrium in the soil.A high C/N ratio, as observed in Treatment A (24), signifies that the organic material treated has a markedly greater carbon content relative to nitrogen. This elevated C/N ratio impedes the decomposition of organic materials[35], as soil microorganisms necessitate additional time to convert carbon into simpler chemicals[36]. In contrast, the reduced C/N ratios in Treatment C1 (chicken dung, 11) and C2 (cow dung, 13) indicate that organic materials with elevated nitrogen content decomposition at a accelerated rate. Soil microorganisms can efficiently assimilate these organic materials, resulting in expedited nutrient release within a brief timeframe[37].

The concentration of phosphorus markedly rose in Treatment A (178 ppm) and Treatment B (135 ppm), indicating the efficacy of high-dose organic material combinations in supplying phosphorus to plants. Conversely, Treatment C (31 ppm) and Treatment C3 (32 ppm) exhibited minimal phosphorus concentration, indicating that burnt rice husk is an inferior phosphorus source. Cow dung in Treatment C2 (117 ppm) exhibited a suoerior rise in phosphorus levels compared to chicken dung in Treatment C1 (64 ppm). The notable rise in soil phosphorus levels, recorded in Treatment A (178 ppm) and Treatment B (135 ppm), demonstrates the capacity of high-dose organic material combinations to improve phosphorus accessibility. The decomposition of organic materials liberates organic phosphorus into more bioavailable inorganic forms, chiefly as orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-})[38]. In Treatment C2 (cow dung), phosphorus concentration attained 117 ppm, above that of chicken dung in Treatment C1 (64 ppm). Cow dung contains a greater concentration of phosphorus owing to its elevated phosphate mineral content compared of chicken dung[39,40]. Phosphorus in cow dung is progressively liberated via microbial decomposition, offering a more stable phosphorus source for plants. Chicken dung, while more abundant in nitrogen, generally possesses lower phosphorus concentrations, hence constraining its efficacy in enhancing soil phosphorus levels.

The availability of soluble potassium also v treatments. Treatment A (349 ppm) yielded the highest potassium concentration, essential for facilitating photosynthesis and improving plant stress resilience. Burnt rice husk in Treatment C3 (229 ppm) significantly enhanced potassium availability, but to a lesser extent than the organic material mixes. Chicken dung and cow dung had potassium concentrations of 174 ppm and 163 ppm, respectively, indicating their viability as intermediate potassium sources.

The substantial rise in soil potassium levels in Treatment A (349 ppm) underscores the efficacy of high-dose organic material combinations as a source of accessible potassium. In Treatment C3 (burnt rice husk), the potassium consentration attained 229 ppm, signifying that burnt rice husk substantially enhances soil potassium availability. Potassium in burnt rice husk predominantly exists as stable minerals that can be progressively liberated during decomposition[41]. The elevated potassium concentration in burnt rice husk results from is mineral accumulation during the pyrolysis process, wherein organic materials decompose into biochar with an enhanced mineral content[42]. Treatment C1 (chicken dung) and C2 (cow dung) yielded potassium concentrations of 174 ppm and 163 ppm, respectively, signifying that both serve as moderate sources. Chicken dung often contains higher potassium levels than cow dung due to the respective animals.

Dryland agriculture substantial obstacles stemming from inadequate soil fertility, diminished organic matter levels, and restricted water resources. This study evaluates the efficacy of high-dose organic mixes, cattle manure, poultry manure, and rice husk biochar in enhancing soil chemical characteristics. The high-dose organic mixture yielded the most substantial enhancements in critical parameters including pH, carbon (C), nitrogen (N), phosphorus (P), and potassium (K), succeeded by cattle and poultry manure. These findings highlight the necessity of choosing the correct type and amount of soil amendments to improve fertility in arid soils, where resources are scarce and soil conditions are delicate.

The utilization of high-dose organic material mixes was the most efficacious in enhancing soil chemical characteristics, succeeded by cow dung and chicken dung. Burnt rice husk demonstrated diminished efficacy in improving soil chemical characteristics. These findings emphasize the significance of choosing the correct type and dosage of soil amendments to optimize the use of arid agricultural land.

Furthermore, the utilization of organic modifications strongly supports broader global sustainability objectives. This work contributes to improved food security by enhancing the agricultural productivity of marginal drylands. It also promotes more sustainable patterns of consumption and production through the use of locally sourced organic waste as soil amendments, fostering resource circularity and reducing dependency on synthetic inputs that may degrade soil health. By improving soil quality in vulnerable dryland areas, this research aids in preserving land ecosystems and strengthening their long-term health and resilience.

Conclusion

This study illustrates that organic-based soil amendments, namely the organic material mixture at a dosage of 30 tons/ha (Treatment A), exerted the most pronounced effect on enhancing soil pH (6.43), carbon content (2.61%), phosphorus (178 ppm), and potassium (349 ppm). These results highlight the efficacy of high-dose treatments in improving soil chemical characteristics. In contrast, untreated control soil exhibited the lowest pH and nutrient levels. Chicken and cow dung moderately enhanced the availability of phosphorus and potassium, whereas burnt rice husk was more effective in augmenting potassium but less advantageous for other nutrients. These findings suggest that high-dose organic material combinations should be employed as a main method for enhancing soil quality in arid regions. Further research is essential to examine the long-term impacts of diverse soil amendments in arid regions, specifically concerning the stability of organic matter and crop yield across varying climatic conditions and soil types to promote sustainable agriculture.

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References

1. V, K., D, V., D, B., M, K. & V, S. *Transforming Agricultural Extension Systems Towards Achieving Food And Nutritional Security Volume-I* (Royal Book Publishing, 2022). https://doi.org/10.26524/royal.124
2. Govind, S. *et al. Recent Trends in Agriculture towards Food Security and Rural Livelihood Volume 3* (Royal Book Publishing, 2022). https://doi.org/10.26524/royal.101
3. Rufo, B. M., Njuguna, C. W. & Muiruri, S. M. Enhancing household livelihood outcomes through resilient agri-food systems among small-scale farmers in Kitui County, Kenya. *East Afr. J. Arts Soc. Sci.* **5**, 210–221 (2022). https://doi.org/10.37284/eajass.5.1.705
4. Nunow, A. A. The nexus between climate change and livelihoods in arid and semi-arid (ASAL) areas of Kenya: Evidence from the literature. *Int. J. Soc. Sci. Hum. Res.* **7**, (2024). https://doi.org/10.47191/ijsshr/v7-i06-113
5. Kurnianto, B. T. The future of agriculture in Indonesia: Facing climate change and globalization. *West Sci. Agro* **2**, 171–177 (2024). https://doi.org/10.58812/wsa.v2i04.1309
6. Li, Y., Chen, Y. & Li, Z. Dry/wet pattern changes in global dryland areas over the past six decades. *Glob. Planet. Change* **178**, 184–192 (2019). https://doi.org/10.1016/j.gloplacha.2019.04.017
7. Wang, H., Liu, Y., Wang, Y., Yao, Y. & Wang, C. Land cover change in global drylands: A review. *Sci. Total Environ.* **863**, 160943 (2023). https://doi.org/10.1016/j.scitotenv.2022.160943
8. Mulyani, A. *et al.* Geospatial analysis of abandoned lands based on agroecosystems: The distribution and land suitability for agricultural land development in Indonesia. *Land* **11**, 2071 (2022). https://doi.org/10.3390/land11112071
9. Matheus, R., Basri, M., Rompon, M. S. & Neonufa, N. Strategi pengelolaan pertanian lahan kering dalam meningkatkan ketahanan pangan di Nusa Tenggara Timur. *PARTNER* **22**, 529 (2017). https://doi.org/10.35726/jp.v22i2.246
10. Killa, Y. M. *et al.* Kajian sifat fisik tanah pada lahan kering beriklim kering di Kecamatan Wulla Waijelu Kabupaten Sumba Timur. *J. Galung Tropika* **13**, 19–26 (2024). https://doi.org/10.31850/jgt.v13i1.1161
11. Rane, J. *et al.* Effective use of water in crop plants in dryland agriculture: Implications of reactive oxygen species and antioxidative system. *Front. Plant Sci.* **12**, (2022). https://doi.org/10.3389/fpls.2021.778270
12. Nangia, V. & Oweis, T. Supplemental irrigation: A promising climate-resilience practice for sustainable dryland agriculture. In *Innovations in Dryland Agriculture* 549–564 (Springer, Cham, 2016). https://doi.org/10.1007/978-3-319-47928-6_20
13. Srivastava, P. K. *et al.* Amelioration of sodic soil for wheat cultivation using bioaugmented organic soil amendment. *Land Degrad. Dev.* **27**, 1245–1254 (2016). https://doi.org/10.1002/ldr.2292

14. Pino-Vargas, E. *et al.* Deep machine learning for forecasting daily potential evapotranspiration in arid regions, case: Atacama Desert header. *Agriculture* **12**, 1971 (2022). https://doi.org/10.3390/agriculture12121971
15. Astiko, W., Ernawati, N. M. L. & Silawibawa, I. P. The application of several bioameliorant formulations to increase soil nutrient concentration and yields maize-soybeans intercropping flexible to climate change in suboptimal land North Lombok, Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* **1253**, 012036 (2023). https://doi.org/10.1088/1755-1315/1253/1/012036
16. Leogrande, R. & Vitti, C. Use of organic amendments to reclaim saline and sodic soils: A review. *Arid Land Res. Manag.* **33**, 1–21 (2019). https://doi.org/10.1080/15324982.2018.1498038
17. Song, H. *et al.* Combined application of chemical and organic fertilizers promoted soil carbon sequestration and bacterial community diversity in dryland wheat fields. *Land* **13**, 1296 (2024). https://doi.org/10.3390/land13081296
18. Shaheen, S. M., Hooda, P. S. & Tsadilas, C. D. Opportunities and challenges in the use of coal fly ash for soil improvements – A review. *J. Environ. Manage.* **145**, 249–267 (2014). https://doi.org/10.1016/j.jenvman.2014.07.005
19. Wang, L. *et al.* Long-term application of bioorganic fertilizers improved soil biochemical properties and microbial communities of an apple orchard soil. *Front. Microbiol.* **7**, (2016). https://doi.org/10.3389/fmicb.2016.01893
20. Kumar, A. *et al.* Sustainable soil management under drought stress through biochar application: Immobilizing arsenic, ameliorating soil quality, and augmenting plant growth. *Environ. Res.* **259**, 119531 (2024). https://doi.org/10.1016/j.envres.2024.119531
21. Chang, F. *et al.* Long-term optimization of agronomic practices increases water storage capacity and available water in soil. *Agronomy* **14**, 2286 (2024). https://doi.org/10.3390/agronomy14102286
22. Oktaviani, P. & Patiung, M. Exploring the potential of soil microbes as biofertilizer agents to enhance soil fertility and crop productivity. *Agric. Power J.* **1**, 1–11 (2024). https://doi.org/10.70076/apj.v1i1.19
23. Sabir, M. S. *et al.* Comparative effect of fertilization practices on soil microbial diversity and activity: An overview. *Curr. Microbiol.* **78**, 3644–3655 (2021). https://doi.org/10.1007/s00284-021-02634-2
24. Mon, W. W., Toma, Y. & Ueno, H. Combined effects of rice husk biochar and organic manures on soil chemical properties and greenhouse gas emissions from two different paddy soils. *Soil Syst.* **8**, 32 (2024). https://doi.org/10.3390/soilsystems8010032
25. Soltani, N., Bahrami, A., Pech-Canul, M. I. & González, L. A. Review on the physicochemical treatments of rice husk for production of advanced materials. *Chem. Eng. J.* **264**, 899–935 (2015). https://doi.org/10.1016/j.cej.2014.11.056
26. Sutardi *et al.* Increasing yield and economic value of upland rice using inorganic fertilizer and poultry manure in dryland. *Agronomy* **12**, 2829 (2022). https://doi.org/10.3390/agronomy12112829
27. Rayne, N. & Aula, L. Livestock manure and the impacts on soil health: A review. *Soil Syst.* **4**, 64 (2020). https://doi.org/10.3390/soilsystems4040064
28. Tao, J. *et al.* The comprehensive effects of biochar amendments on soil organic carbon accumulation, soil acidification amelioration and heavy metal availability in the soil-rice system. *Agronomy* **14**, 2498 (2024). https://doi.org/10.3390/agronomy14112498
29. Peltokangas, K. *et al.* Ligneous amendments increase soil organic carbon content in fine-textured boreal soils and modulate N_2O emissions. *PLoS One* **18**, e0284092 (2023). https://doi.org/10.1371/journal.pone.0284092

30. Li, X. *et al.* Soil organic carbon and humus characteristics: Response and evolution to long-term direct/carbonized straw return to field. *Agronomy* **14**, 2400 (2024). https://doi.org/10.3390/agronomy14102400
31. Gerke, J. The central role of soil organic matter in soil fertility and carbon storage. *Soil Syst.* **6**, 33 (2022). https://doi.org/10.3390/soilsystems6020033
32. Kant, S., Bi, Y.-M. & Rothstein, S. J. Understanding plant response to nitrogen limitation for the improvement of crop nitrogen use efficiency. *J. Exp. Bot.* **62**, 1499–1509 (2011). https://doi.org/10.1093/jxb/erq297
33. Mohanty, M. *et al.* How important is the quality of organic amendments in relation to mineral N availability in soils? *Agric. Res.* **2**, 99–110 (2013). https://doi.org/10.1007/s40003-013-0052-z
34. Brust, G. E. Management strategies for organic vegetable fertility. In *Safety and Practice for Organic Food* 193–212 (Elsevier, 2019). https://doi.org/10.1016/B978-0-12-812060-6.00009-X
35. Witasari, W. S., Sa'diyah, K. & Hidayatulloh, M. Pengaruh jenis komposter dan waktu pengomposan terhadap pembuatan pupuk kompos dari activated sludge limbah industri bioetanol. *J. Tek. Kim. Lingkung.* **5**, 31–40 (2021). https://doi.org/10.33795/jtkl.v5i1.209
36. Kästner, M., Miltner, A., Thiele-Bruhn, S. & Liang, C. Microbial necromass in soils – Linking microbes to soil processes and carbon turnover. *Front. Environ. Sci.* **9**, (2021). https://doi.org/10.3389/fenvs.2021.756378
37. Tamele, R. A., Ueno, H., Toma, Y. & Morita, N. Nitrogen recoveries and nitrogen use efficiencies of organic fertilizers with different C/N ratios in maize cultivation with low-fertile soil by 15N method. *Agriculture* **10**, 272 (2020). https://doi.org/10.3390/agriculture10070272
38. Tian, J. *et al.* Roles of phosphate solubilizing microorganisms from managing soil phosphorus deficiency to mediating biogeochemical P cycle. *Biology* **10**, 158 (2021). https://doi.org/10.3390/biology10020158
39. Chen, G. *et al.* Animal manures promoted soil phosphorus transformation via affecting soil microbial community in paddy soil. *Sci. Total Environ.* **831**, 154917 (2022). https://doi.org/10.1016/j.scitotenv.2022.154917
40. Ran, X. *et al.* Comparison of phosphorus species in livestock manure and digestate by different detection techniques. *Sci. Total Environ.* **874**, 162547 (2023). https://doi.org/10.1016/j.scitotenv.2023.162547
41. Xiu, L. *et al.* The fate and supply capacity of potassium in biochar used in agriculture. *Sci. Total Environ.* **902**, 165969 (2023). https://doi.org/10.1016/j.scitotenv.2023.165969
42. Li, Z. *et al.* Review on rice husk biochar as an adsorbent for soil and water remediation. *Plants* **12**, 1524 (2023). https://doi.org/10.3390/plants12071524

Author contributions

Suherman, **Asysyura**, and **Edi Kurniawan** were responsible for the conceptual design and preparation of materials. Data collection and analysis were carried out by **Suherman**, **Husni Asmi**, **Indah Fitriani**, **Zulkifli**, and **Abdul Halil Fatwa**. The first draft of the manuscript was written by **Suherman**. All authors have read and approved the final manuscript.