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Research Article

Soil Conditions and Feedstock in the Rice Field for Nomadic Duck Herding, South Sulawesi, Indonesia

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Abstract

Background and Objective: Integrating rice and ducks contributes to lowland rice fields' animal protein and soil fertility. The objective of this study was to analyze soil conditions, the availability of duck feed and the capacity of ducks grazing in the rice field. **Materials and Methods:** The research was conducted in three main duck-herding areas in South Sulawesi Province: Sidrap, Wajo and Pinrang Regencies. The analysis carried out is physical and chemical properties of soil, calculating the amount of duck feed and protein content and analysis of the number of ducks that can be accommodated in grazing. **Results:** The quality of rice field soil in Wajo Regency had decreased in organic matter content and increased soil density up to 1.4 g cm^{-3} . In contrast, the soil carbon in Sidrap and Pinrang Regencies was still relatively good. Sidrap Regency had the highest potential for duck feed availability and can provide an enormous amount of feed for a duck at 1,222.12 duck/ha/month, higher than Pinrang Regency and almost three times higher than Wajo Regency. **Conclusion:** The most prominent protein contributor in Sidrap Regency from the type of rice feed was 109.66 kg/hectare. Priority locations in the feed supply for duck livestock sequentially are Sidrap>Pinrang>Wajo.

Key words: Rice field, soil carbon, duck herder, feed stock, rice-duck combination

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In various tropical agricultural areas of Asia, the combination of rice-duck has been considered an alternative to integrated farming systems, which function as a livelihood system and improve the environment¹. In this system, ducks are put into the rice fields after harvest. The ducks eat the remaining grain, rice shoots, grass, insects and snails as well as soak and drink water, where activity and duck droppings can reduce the farmer's need for manual weeding, chemical pesticides and chemical fertilizers². In Japan offers a rice-duck combination in a settled system, the ducks grow together with rice in a fenced-in rice field in such a way that "rice-duck simultaneous cultivation" takes place³. However, in various regions of Asia, the combination of rice-duck in the form of shifting grazing is more dominant. This system is considered a new form of nomadism in India behind technological advances^{4,5}.

In South Sulawesi, the combination of rice-duck is also more widely practiced by nomadic duck herders. In 2019, this province's harvested area of rice fields was 1,010,188.75 ha, with a population of 4,987,533.00 ducks⁶. This rice-duck combination contributes to the production of millions of eggs as a source of animal protein, contributes to soil fertility and natural pesticides in rice field production and is a source of livelihood for duck herders, egg traders and duck traders and egg incubators⁷. Agricultural factors significantly affect people's income and impact the community's economic sector⁸. It means the sustainability of duck egg and meat production in South Sulawesi depends on nomadic duck herding for economic value.

Research on the combination of rice-duck is partly related to agronomic aspects such as its role in increasing productivity and improving rice aroma¹. Its role in enhancing nutrient absorption, soil nutritional improvement and proper aeration of the soil⁹ and the strengths and weaknesses of this system when applied on a large scale¹⁰. From the economic aspect, it has been found that shifting duck herders can adapt to various contexts of vulnerability so that this livelihood system can continue from generation to generation². Meanwhile, the duck herder is not wholly free to choose the location of the rice fields to be occupied because he is dictated by the planting season schedule and the location determination, which becomes his social network in an area. Therefore, it is urgent to know the difference in soil conditions, the potential for duck feed and the capacity of ducks that can be grazed in a particular area of rice fields.

Feed potential for ducks on the surface of harvested fields is influenced by the soil's physical, chemical and biological aspects¹¹. Soil physical characteristics through bulk density indicators provide an overview of soil density, where soil density affects soil drainage and aeration, which determines the activity of microorganisms in the soil¹². In the chemical and biological aspects, the availability of soil carbon is a determinant of the action of microorganisms because it is a food source for these microorganisms¹³. Thus, these three characteristics influence each other. Soil physical properties, especially low soil density values, can only be achieved if the organic matter content of the soil increases. The increase in soil organic matter is in line with the increase in microorganisms in the soil¹⁴. The activity of soil microorganisms strongly influences the decomposition of soil organic matter in breaking down organic matter into mineralization, improving aggregates, regulating soil temperature and being a source of nutrients for plants¹⁵⁻¹⁷. The activity of these microorganisms is positively correlated to the increase of worms and snails. They support soil fertility for the growth of rice shoots and grass, all of which are a source of feed for ducks. Thus, it can be assumed that the capacity of rice fields for grazing ducks is associated with the availability of feed on the surface of the rice fields, which is strongly influenced by physical, chemical and biological conditions in the soil. This study aims to analyze soil conditions and the availability of duck feed in association with the rice field capacity of the number of ducks grazing on it.

MATERIALS AND METHODS

Study area: This research was conducted in three main duck-herding areas in South Sulawesi Province: Sidenreng Rappang (Sidrap), Wajo and Pinrang Regencies. The research starts from October, 2021 to March, 2023.

Study design: In this study, two types of data were collected: Data on soil conditions and feed content on the surface of the rice field. Soil sampling was carried out on secondary, tertiary and pump-irrigated rice fields used as grazing land. The soil layer was taken in the tillage layer at a 0-20 cm depth with a soil drill. The types of soil samples taken were intact and disturbed soil samples. Analysis of the physical and chemical properties of the soil was carried out using the Soil Research Institute procedure¹⁸. Analysis for soil physical properties, namely, soil texture and bulk density (BD) and soil chemical properties; pH, soil carbon, cation exchange capacity (CEC),

nitrogen, P₂O₅ and base saturation (BS). Data on the content of feed on the surface of the rice fields were collected through tile samples of rice fields (1×1 m) and samples of duck cache. The tiling is made with a tile area of one square meter. Each tiling identified the type of feed and calculated the amount of feed available in the rice field.

Feed consumption/ducks are calculated by taking ducks displayed in the fields. At each displacement location, samples of 5 ducks were taken. The ducks taken as samples were ducks that had been fasted for 12 hrs then displayed in the fields for 10 hrs, after which the ducks were taken randomly. The ducks were taken as samples and immediately cut and harvested the craw. The duck's craw is split and the type of feed eaten is measured, then the amount of feed consumed by the ducks is calculated. Analysis in the laboratory was carried out in 2 stages, (1) Calculations to determine dry matter and (2) Analysis to estimate protein content in research samples.

The ability of ducks to consume feed in a day in rice fields was calculated based on an average of twice the full capacity of the duck's crop. Full crop capacity within ±5 hrs of ducks grazing in rice fields. In a day, ducks were grazed for ±10 hrs. Therefore, the duck feed consumption was calculated to be twice the full capacity of the duck's crop to accommodate feed. For dry matter analysis, fresh samples of known weight were put into envelopes and then heated in an oven at 70°C for 3 days; then, the samples were weighed using an analytical balance with Mettler Toledo type in the Feed Chemistry Laboratory of the Animal Husbandry Faculty, Hasanuddin University, Indonesia. The fresh material analyzed came from tiles consisting of grain, rice tillers, seeds, leaves, snails, etc. Based on the feed potential data at various grazing locations, the potential number of ducks that can be accommodated in the different rice fields was calculated.

Calculation of feed consumption of duck is carried out following the Susetyo procedure¹⁹. Determining the consumption of duck feed in one day (g/head/day) is the capacity of the duck's crop multiplied by two, with an estimate of 2 fullfills of the duck's cache in a day when grazing for 8 to 10 hrs in paddy fields. Then calculated with the equation:

$$\text{Total available feed dry matter} \frac{\text{kg}}{\text{m}^2} = \frac{\text{Amount of feed fresh matter}}{\text{kg}} \times \frac{\text{kg}}{\text{m}^2} \times \text{Dry mater (\%)}$$

Determining the carrying capacity of the number of ducks that can be grazed in 1 ha of rice field during a certain period of time can be determined by calculating the amount of feed production (kg) available in 1 ha divided by the number of ducks consumed (kg/head), with the equation:

$$\text{Carrying capacity} = \frac{\text{Amount of feed available (kg)}}{\text{Number of ducks consumed per head per day (kg)}}$$

All calculations were repeated three times to get a good average value.

Ethical consideration: Procedures for using animals in this research follow SNI 99002:2016²⁰. This standard specifies requirements and procedures in the management of purchasing, pre-slaughtering, post slaughtering, packaging, labeling, storage, transportation, facilities, hygiene and sanitation in the production process.

RESULTS AND DISCUSSION

Soil conditions in grazing rice fields: For grazing ducks, soil pH significantly affects the availability of macro and micronutrients in the soil²¹. The closer to neutral pH, the more nutrients that plants can absorb. Soil pH values in Sidrap and Pinrang Regencies have the criteria slightly acidic to neutral, while in Wajo Regency, it is slightly acidic (Fig. 1). Soil pH in the neutral range helps the activity of microorganisms in providing nutrients for plants and the development of faunal cultures²². The number of fauna in the soil is significant in supporting soil fertility for the growth of rice shoots and grass, all of which are a source of food for ducks. This makes Sidrap and Pinrang Regencies the center of destination for nomadic duck herders.

Soil carbon content in Sidrap and Pinrang Regencies is in the medium criteria, while Wajo Regency is in the low standards (Fig. 1). Soil carbon content (C-organic) is one of the factors in assessing soil fertility for agricultural development²³. The higher the carbon content of the soil, the better the soil quality^{24,25}. Soil carbon is a source of nutrients for plants and food for soil fauna²⁶. The activity of soil microorganisms strongly influences the decomposition of soil organic matter in breaking down organic matter into mineralization, improving aggregates, regulating soil temperature and being a source of nutrients for plants¹⁶. The high carbon content of the soil is directly proportional to the development of fauna in the soil²⁷. The increasing number of soil fauna will become a feed source for ducks. Johnston *et al.*²⁸ showed an increase in the content of the worm community in the soil was in line with the increase in the C-organic content in the soil. *Lumbricidae* sp. and *Tubifex* sp. worms and snails are the primary feed sources for ducks.

Soil nitrogen content is in a low category, only 0.1 to 0.2% (Fig. 1). A decrease in soil nitrogen content can also be caused by reducing conditions in the rice fields²⁹. Soil C:N values in

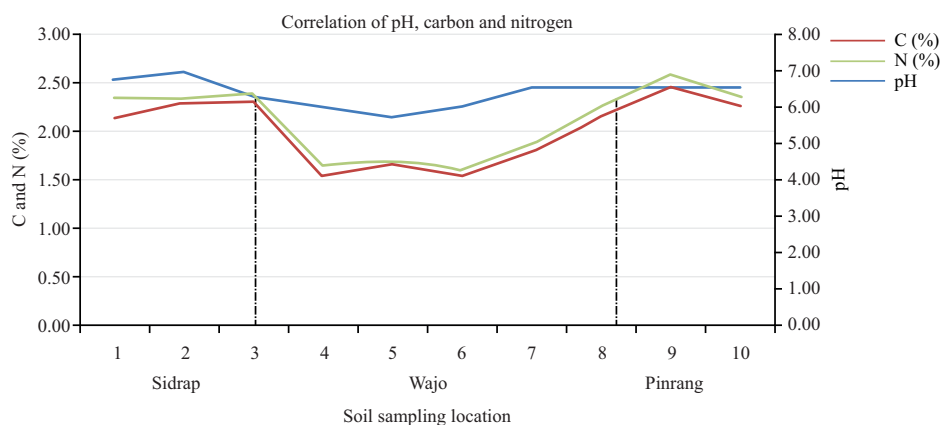


Fig. 1: Correlation of pH, C-organic and soil nitrogen content in Sidrap, Wajo and Pinrang Regencies

Table 1: Soil physical and chemical characteristic in Sidrap, Wajo and Pinrang Regency

Regency	Sampling number	Sand (%)	Silt (%)	Clay (%)	Texture class	BD (g cm ⁻³)	C/N	P ₂ O ₅ (ppm)	Ca (cmol+kg ⁻¹)	Mg (cmol+kg ⁻¹)	K (cmol+kg ⁻¹)	Na (cmol+kg ⁻¹)	CEC (cmol+kg ⁻¹)	BS (%)
Sidrap	1	14	26	60	Clay	1.2	10	13.93	8.44	1.02	0.24	0.34	27.89	36
	2	9	58	33	Silty clay loam	1.3	38	17.65	10.01	0.77	0.22	0.42	20.36	56
	3	8	63	29	Silty clay loam	1.3	28	17.25	7.87	1.10	0.55	0.39	18.85	53
Wajo	4	11	20	70	Clay	1.4	25	16.76	7.26	0.72	0.21	0.23	25.22	33
	5	22	30	49	Clay	1.3	14	15.13	4.54	0.74	0.14	0.24	28.08	20
	6	11	32	56	Clay	1.2	38	16.08	4.21	2.67	0.49	0.20	21.60	35
Pinrang	7	22	42	36	Clay loam	1.4	22	20.29	4.62	2.48	0.49	0.16	20.77	37
	8	3	59	37	Silty clay loam	1.2	21	13.23	7.67	0.72	0.49	0.29	17.72	52
	9	13	55	32	Silty clay loam	1.3	20	14.24	6.88	1.57	0.21	0.31	19.22	47
	10	7	66	27	Silty clay loam	1.3	28	12.71	4.54	2.07	0.30	0.26	18.47	39

Sidrap and Wajo Regencies have not met the appropriate standard to increase microbial work activity in the range of 20-30 (Table 1).

Mineralization will occur on C/N substrates with a ratio of 25. If the ratio is less than 20, N minerals are released early in decomposition³⁰. Changes in soil C/N can cause a significant decrease in carbon storage, so it is still necessary to return crop residues to the soil to improve soil C/N values. The soil phosphorus (P₂O₅) is still categorized as moderate to high (Table 1) in the three study locations; this is still related to the activity of farmers in adding high fertilizer to the treatment of lowland rice cultivation and its bond by the colloid of soil. It can also be seen from the base saturation value at the Pinrang and Sidrap locations, showing the best value in the range of >35% (Table 1). The rice field system is considered suitable and able to fulfill nutrients for plants and is beneficial for the activities of organisms in the soil. Things are different at the Wajo location, where farmers' activities in adding fertilizer and soil quality cannot support the cultivated rice field system and require more improved management for sustainable use of rice fields. The decline in the soil carbon of rice fields will impact the reduction of fauna on the soil and disrupt the sustainability of feed for nomadic duck herders³¹.

Farmers feel the negative impact of land degradation positively affects socio-economic conditions. Awareness of the importance of good land management and conservation practices is necessary to reduce land degradation for sustainability³².

The soil texture is dominated by clay and silty clay loam, with the CEC range of 17.72 to 28.08 cmol(+) kg⁻¹ in the medium to moderate category. A clay content of >25% can maintain soil moisture and is very suitable for rice soil management³³. The increase in the soil's clay fraction content and the decrease in the carbon content of the soil increased the value of the soil's bulk density (BD). It can reduce the faunal content in the soil because the dense soil affects drainage, aeration and inhibits the activity of organisms in the soil³⁴. The bulk density of rice soil in Wajo Regency has reached 1.4 g cm⁻³ in line with the soil's decrease in organic matter content. It makes Wajo Regency a place of movement for ducks to move not a major priority in the migration for duck feed.

Availability of duck feed in rice fields: The availability of feed in rice fields is one of the factors that can determine the number of ducks that can be grazed. The sustainability of local

Table 2: Potential availability of local duck feed in Sidrap, Wajo and Pinrang Regency

Regency	Sampling location	Amount of local duck feed available in rice fields			
		Wet weight (kg m ⁻²)	Dry weight (kg m ⁻²)	Wet weight (kg ha ⁻¹)	Dry weight (kg ha ⁻¹)
Sidrap	Duapitue (Salo Mallori)	0.22	0.10	2215.78	972.01
	Baranti (Tonrongnge)	0.13	0.07	1,317.26	688.21
	Average	0.18	0.08	1,766.52	830.11
Wajo	Sabbangparu	0.09	0.04	852.10	445.57
	Penrang	0.06	0.01	642.20	125.95
	Average	0.07	0.03	747.15	285.76
Pinrang	Cempa	0.11	0.04	1,079.47	442.09
	Lanrisang	0.17	0.07	1,734.06	735.36
	Average	0.14	0.06	1,406.76	588.72

Table 3: Availability of local duck feed in rice fields after harvest

Regency	Feed type	Wet weight (kg ha ⁻¹)	Dry weight (kg ha ⁻¹)	Wet weight (%)	Dry weight (%)
Sidrap	Rice	1,240.84	600.77	70.24	72.37
	Earthworms	10.09	1.80	0.57	0.22
	Golden snail	515.59	227.54	29.19	27.41
	Amount	1,766.52	830.11	100.00	100.00
Wajo	Rice	439.35	132.20	58.80	46.26
	Earthworms	14.55	8.57	1.95	3.00
	Golden snail	293.25	144.98	39.25	50.74
	Amount	747.15	285.76	100.00	100.00
Pinrang	Rice	653.27	286.74	46.44	48.71
	Earthworms	45.05	13.25	3.20	2.25
	Golden snail	708.44	288.73	50.36	49.04
	Amount	1,406.76	588.72	100.00	100.00

duck farmers who move is also determined by the potential for feed available in the rice fields. The palatable feed types (preferred by ducks) can increase the amount of feed consumption. The research that has been conducted to determine the potential of available feed in 3 districts spread over 6 locations in 3 districts was presented in Table 2.

Sidrap Regency has the highest potential for duck feed availability, followed by Pinrang Regency and the lowest is Wajo Regency. The standard feed potential in Wajo Regency is directly proportional to the low base saturation value of the soil, with an average value of only 31.25%. Base saturation and soil carbon greatly affect the soil's ability to provide nutrients for plants and soil macro-fauna as a feed supply for ducks³⁵. The availability of duck feed can be influenced by several factors, including the amount of rice wasted at harvest, soil carbon and water availability, which can accelerate the release of rice grains on the remaining rice harvest stems³⁶. Returning crop residue in the form of straw can also increase soil carbon. This follows the results of Thammasom *et al.*³⁷, where returning rice straw can improve soil carbon content and fertility. Stagnant water in the rice fields can also accelerate the growth of weeds and rice residues, which can be a food source for golden snails³⁸. Ducks grazing in rice fields prefer leftover rice and favor earthworms compared to golden snails, although consuming golden snails can improve the

performance and physical quality of eggs³⁹. Ducks can produce eggs if a large food supply and various types are available throughout the harvest season. The feed availability in the three regions can be seen in Table 3.

Most of the rice fields in Sidrap and Pinrang Regencies are irrigated, which causes faster plant and animal growth so that the impact on the feed needs of ducks can be met. In contrast, the rice fields in Wajo Regency are mostly rainfed paddy fields, indirectly impacting the availability of duck feed, which quickly runs out. Water availability in the rice cropping system is one of the inhibiting factors for land productivity⁴⁰.

The types of duck feed available in the three districts showed that the kind of rice provided the highest amount or contributed the most types of feed; furthermore, the kind of feed in the form of gold snails and earthworms. The availability of rice in paddy fields is strongly supported by the carbon content of the soil (Fig. 1), which contributes to soil fertility and the development of rice plants⁴¹. Feed availability from rice has a wet weight ranging from 653.27 to 1240.84 kg ha⁻¹ or 46.44 to 70.24%. The type of feed derived from golden snails has a damp weight ranging from 293.25-708.44 kg ha⁻¹ or 39.25 to 50.36%. Meanwhile, the minor type of feed came from earthworms ranging from 1.80 to 3.20 kg ha⁻¹ or 0.57 to 3.20%. The types of feed, such as rice straw and grass, are not counted because ducks in minimal quantities eat these types of feed. The abundance of golden snails in paddy fields

Table 4: Capacity of the number of ducks that the sample locations in each district can accommodate

		Number of ducks that can be grazed based on the availability of feed			
Regency	Sampling location	Wet weight (duck ha ⁻¹)	Dry weight (duck ha ⁻¹)	Wet weight (duck ha ⁻¹)	Dry weight (duck ha ⁻¹)
		1 month	1 month	2 month	2 month
Sidrap	Salo Mallori	1,532.93	1,210.44	766.46	605.22
	Baranti	911.31	857.03	455.65	428.51
	Average	1,222.12	1,033.74	611.06	516.87
Wajo	Sabbangparu	544.36	582.26	272.18	291.13
	Penrang	410.27	164.60	205.13	186.71
	Average	477.31	373.43	238.66	238.92
Pinrang	Cempa	720.93	524.69	360.47	262.34
	Lanrisang	1,158.10	872.75	579.05	436.38
	Average	939.52	698.72	469.76	349.36

Table 5: Protein availability in Pinrang, Wajo and Sidrap Regencies rice fields

		Protein availability		Contribution of protein for each type of feed	
Regency	Feed type	Wet weight (kg ha ⁻¹)	Dry weight (kg ha ⁻¹)	Wet weight (%)	Dry weight (%)
Sidrap	Rice	109.66	53.03	61.49	65.21
	Earthworms	7.14	1.24	4.00	1.52
	Golden snail	61.55	27.06	34.51	33.27
	Amount	178.35	81.32	100.00	100.00
Wajo	Rice	20.74	6.73	27.46	20.56
	Earthworms	7.14	4.39	9.46	13.41
	Golden snail	47.63	21.63	63.08	66.03
	Amount	75.51	32.75	100.00	100.00
Pinrang	Rice	38.30	16.77	33.55	37.12
	Earthworms	22.08	6.62	19.35	14.66
	Golden snail	53.77	21.78	47.10	48.22
	Amount	114.15	45.17	100.00	100.00

can reduce the quality of rice production because golden snails are classified as pests for rice plants⁴². Its abundance in the Wajo District is directly proportional to the decreased availability of rice feed in that location.

Rice field capacity to the number of ducks herding:

The ability of the area to supply the food needs of the grazed ducks is strongly influenced by the ability of rice fields to prepare food for the ducks. Rice field capacity will be reduced by half for the second month. The findings of the amount of duck feed consumption per month were presented in Table 4. Sidrap District, especially in the village of Salo Mallori can provide the largest amount of feed for a duck at 1,532.93 duck/ha/month, two times higher than Wajo District.

A capacity that exceeds the available feed will impact decreasing egg production. Likewise, on the other hand, a capacity that is less than the amount of available feed will have an impact on increasing duck egg production within a certain period. The increase in egg production is also determined by the high consumption of duck feed and the nutritional quality of the feed. The duck laying phase requires feed with a 15-17% crude protein content and metabolic

energy of 2,900 kcal kg⁻¹⁴³. The availability of protein in rice fields in the three districts was presented in Table 5.

High egg production in grazing ducks in Sidrap and Pinrang Regencies is supported by the availability of feed and nutritional content, especially protein content and energy metabolism of feed. The most prominent protein contributor in Sidrap Regency from the type of rice feed was 109.66 kg ha⁻¹. This is due to the high availability of rice feed at grazing locations. In contrast to Pinrang Regency and Wajo Regency, the protein contributors from the type of golden snail feed were 53.77 and 47.63 kg ha⁻¹, respectively. Generally, the golden snail has a higher protein content than rice feed⁴⁴. However, the golden snail is not liked by ducks, especially the sizeable golden snail, because it has a hard and sharp shell, causing ducks only to eat tiny goldsnails in limited quantities. Earthworms also have a fairly high protein content, but ducks have difficulty getting earthworms in the soil in line with the decrease of soil carbon content in the region.

CONCLUSION

The carbon content of the soil in Sidrap and Pinrang Regencies is in the moderate criteria, with a base saturation

value of >35%, while the Wajo Regency is in the low criteria. It is directly proportional to the low availability of feed in rice fields. The largest protein contributor in Sidrap Regency from the type of rice feed was 109.66 kg ha⁻¹. This is due to the high availability of rice feed at grazing locations. Sidrap Regency had the highest potential for duck feed availability and could provide an enormous amount of feed for a duck at 1,222.12 duck/ha/month. Priority locations in the feed supply for duck livestock sequentially are Sidrap>Pinrang>Wajo. The selection of Wajo Regency as a location for duck feed was because the breeders did not have other destinations to provide feed for ducks and reduce the risk of loss. It is necessary to regulate the distribution pattern or schedule the availability of feed for ducks and socialization for the owners of rice fields to improve land quality by returning the remaining straw to the fields for carbon stock.

SIGNIFICANCE STATEMENT

The work links the soil conditions, primarily soil carbon, with food availability for duck herders. A relationship between soil conditions and the abundance of food for ducks was found and it is significant for the migration route for moving ducks to get the best quality feed to produce protein. Collaboration with duck manure in improving soil carbon quality for sustainable land use needs to be investigated.

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REFERENCES

- Li, M., R. Li, J. Zhang, S. Liu, Z. Hei and S. Qiu, 2019. A combination of rice cultivar mixed-cropping and duck co-culture suppressed weeds and pests in paddy fields. *Basic Appl. Ecol.*, 40: 67-77.
- Kasim, K., D. Salman, A.R. Siregar, R.A. Nadjia and A. Ahmad, 2019. Vulnerability and adaptive strategies on duck breeder in Pinrang District, Indonesia. *IOP Conf. Ser.: Earth Environ. Sci.*, Vol. 235. 10.1088/1755-1315/235/1/012046.
- Pernollet, C.A., D. Simpson, M. Gauthier-Clerc and M. Guillemain, 2015. Rice and duck, a good combination? Identifying the incentives and triggers for joint rice farming and wild duck conservation. *Agric. Ecosyst. Environ.*, 214: 118-132.
- Nambi, V.A., 2001. Modern technology and new forms of nomadism: Duck herders in Southern India. *Nomadic Peoples*, 5: 155-167.
- Kaufmann, J.C., 2009. The sediment of nomadism. *Hist. Afr.*, 36: 235-264.
- Maharani, D., D.N.H. Hariyono, D.D.I. Putra, J.H. Lee and J.H.P. Sidadolog, 2019. Phenotypic characterization of local female duck populations in Indonesia. *J. Asia-Pac. Biodivers.*, 12: 508-514.
- Salman, D., K. Kasim, A. Ahmad and N. Sirimorok, 2021. Combination of bonding, bridging and linking social capital in a livelihood system: Nomadic duck herders amid the COVID-19 pandemic in South Sulawesi, Indonesia. *For. Soc.*, 5: 136-158.
- Ilyas, F., D.Q. Gillani, M. Yasin, M.A. Iqbal, I. Javed, S. Ahmad and I. Nabi, 2022. Impact of livestock and fisheries on economic growth: An empirical analysis from Pakistan. *Sarhad J. Agric.*, 38: 160-169.
- Mofidian, S. and S.M. Sadeghi, 2015. Evaluation of integrated farming of rice and duck on rice grain yield in Gilan, Iran. *Acta Universitatis Agric. Silviculturae Mendelianae Brunensis*, 63: 1161-1168.
- Suh, J., 2014. Theory and reality of integrated rice-duck farming in Asian developing countries: A systematic review and SWOT analysis. *Agric. Syst.*, 125: 74-81.
- Silver, W.L., T. Perez, A. Mayer and A.R. Jones, 2021. The role of soil in the contribution of food and feed. *Phil. Trans. R. Soc. B*, Vol. 376. 10.1098/rstb.2020.0181.
- Xu, Y., T. Jeanne, R. Hogue, Y. Shi, N. Ziadi and L.E. Parent, 2021. Soil bacterial diversity related to soil compaction and aggregates sizes in potato cropping systems. *Appl. Soil Ecol.*, Vol. 168. 10.1016/j.apsoil.2021.104147.
- Saito, M., E.H. Novotny and Y. Chen, 2023. Soil carbon and microbial processes in agriculture ecosystem. *Agriculture*, Vol. 13. 10.3390/agriculture13091785.
- Lu, J., S. Li, G. Liang, X. Wu and Q. Zhang *et al.*, 2021. The contribution of microorganisms to soil organic carbon accumulation under fertilization varies among aggregate size classes. *Agronomy*, Vol. 11. 10.3390/agronomy11112126.
- Sugiyarto, M. Efendi, E. Mahajoeno, Y. Sugito, E. Handayanto and L. Agustina, 2007. Preference of soil macrofauna to crops residue at different light intensity. *Biodiversitas J. Biol. Diversity*, 8: 96-100.
- Susilawati, Mustoyo, E. Budhisurya, R.C.W. Anggono and B.H. Simanjuntak, 2013. Soil fertility analysis with soil microorganism indicator on various systems of land use at Dieng Plateau [In Indonesian]. *Agric.*, 25: 64-72.
- Nicolás, C., T. Martin-Bertelsen, D. Floudas, J. Bentzer and M. Smits *et al.*, 2019. The soil organic matter decomposition mechanisms in ectomycorrhizal fungi are tuned for liberating soil organic nitrogen. *ISME J.*, 13: 977-988.
- López-Sánchez, J.F., A. Sahuquillo, G. Rauret, M. Lachica and E. Barahona *et al.*, 2002. Extraction Procedures For Soil Analysis. In: *Methodologies for Soil and Sediment Fractionation Studies*, Quevauviller, P. (Ed.), Royal Society of Chemistry, Piccadilly, London, ISBN: 978-0-85404-453-5, pp: 28-65.

19. Hae, V.H., M.M. Kleden and S.T. Temu, 2020. Production, botanical composition and carrying capacity of forage in native grassland at early dry season. J. Nukleus Peternakan, 7: 14-22.
20. Paly, M.B., 2021. Duck farming in coastal area: Assessing nutritional status and its contribution to egg production. Eur. J. Agric. Food Sci., 3: 50-55.
21. Neina, D., 2019. The role of soil pH in plant nutrition and soil remediation. Appl. Environ. Soil Sci., Vol. 2019. 10.1155/2019/5794869.
22. Duddigan, S., T. Fraser, I. Green, A. Diaz, T. Sizmur and M. Tibbett, 2021. Plant, soil and faunal responses to a contrived pH gradient. Plant Soil, 462: 505-524.
23. Adeboye, M.K.A., A. Bala, A.O. Osunde, A.O. Uzoma, A.J. Odofin and B.A. Lawal, 2011. Assessment of soil quality using soil organic carbon and total nitrogen and microbial properties in tropical agroecosystems. Agric. Sci., 2: 34-40.
24. Weil, R.R. and N.C. Brady, 2016. The Nature and Properties of Soils. 15th Edn., Pearson Education, Indianapolis, Indiana, ISBN: 9780133254556, Pages: 912.
25. Kirilov, I., V. Lozanova, I. Dimitrov and V. Pankov, 2020. Changes in some soil parameters of regosols under the influence of land use. Bulg. J. Agric. Sci., 26: 633-637.
26. Baretta, D., M.L.C. Bartz, I. Fachini, R. Anselmi, T. Zortea and C.R.D.M. Baretta, 2014. Soil fauna and its relation with environmental variables in soil management systems. Rev. Ciênc. Agron., 45: 871-879.
27. Ghiglieno, I., A. Simonetto, F. Orlando, P. Donna, M. Tonni, L. Valenti and G. Gilioli, 2020. Response of the arthropod community to soil characteristics and management in the Franciacorta Viticultural Area (Lombardy, Italy). Agronomy, Vol. 10. 10.3390/agronomy10050740.
28. Johnston, A.S.A., M. Holmstrup, M.E. Hodson, P. Thorbek, T. Alvarez and R.M. Sibly, 2014. Earthworm distribution and abundance predicted by a process-based model. Appl. Soil Ecol., 84: 112-123.
29. Ahmad, N., M. Abid, K. Hussain, M. Akram and M. Yousaf, 2003. Evaluation of nutrient status in the rice growing areas of the Punjab. Asian J. Plant Sci., 2: 449-453.
30. Ghimire, P., U. Lamichhane, S. Bolakhe and C.H.J. Lee, 2023. Impact of land use types on soil organic carbon and nitrogen stocks: A study from the Lal Bakaiya watershed in Central Nepal. Int. J. For. Res., Vol. 2023. 10.1155/2023/9356474.
31. Long, P., H. Huang, X. Liao, Z. Fu, H. Zheng, A. Chen and C. Chen, 2013. Mechanism and capacities of reducing ecological cost through rice-duck cultivation. J. Sci. Food Agric., 93: 2881-2891.
32. Saeed Ullah, M. Israr, S. Ahmad, N. Ahmad and A. Yaseen, 2019. Farming household socio-economic influences on land degradation in District Mardan of Pakistan. Sarhad J. Agric., 35: 449-458.
33. Dou, F., J. Soriano, R.E. Tabien and K. Chen, 2016. Soil texture and cultivar effects on rice (*Oryza sativa*, L.) grain yield, yield components and water productivity in three water regimes. PLoS ONE, Vol. 11. 10.1371/journal.pone.0150549.
34. Eftene, A., P. Ignat, I.A. Chiurciu, A. Manea, D. Raducu and S. Dumitru, 2020. Soil bulk density as important management factor and ecosystem services well function. Sci. Pap. Ser. Manage. Econ. Eng. Agric. Rural Dev., 20: 175-184.
35. Olorunfemi, I.E., J.T. Fasinmirin and F.F. Akinola, 2018. Soil physico-chemical properties and fertility status of long-term land use and cover changes: A case study in forest vegetative zone of Nigeria. Eurasian J. Soil Sci., 7: 133-150.
36. Kasim, K., D. Salman, A.R. Siregar, R.A. Nadjia and W. Pakiding, 2021. Potential and availability of feed in paddy fields for sustainable livelihoods of moving duck farmers in Pinrang Regency South Sulawesi Province. IOP Conf. Ser.: Earth Environ. Sci., Vol. 788. 10.1088/1755-1315/788/1/012219.
37. Thammasom, N., P. Vityakon, P. Lawongsa and P. Saenjan, 2016. Biochar and rice straw have different effects on soil productivity, greenhouse gas emission and carbon sequestration in Northeast Thailand paddy soil. Agric. Nat. Resour., 50: 192-198.
38. Türke, M., A. Schmidt, M. Schädler, S. Hotes and W.W. Weisser, 2018. Are invasive apple snails important neglected decomposers of rice straw in paddy fields? Biol. Agric. Hortic., 34: 245-257.
39. Sumiati, A. Darmawan and W. Hermana, 2020. Performance and egg quality of laying ducks fed diets containing cassava (*Manihot esculenta* Crantz) leaf meal and golden snail (*Pomacea canaliculata*). Trop. Anim. Sci. J., 43: 227-232.
40. Al Viandari, N., A. Wihardjaka, H.B. Pulunggono and Suwardi, 2022. Sustainable development strategies of rainfed paddy fields in Central Java, Indonesia: A review. Caraka Tani J. Sustainable Agric., 37: 275-288.
41. Ashfaquul Haque, A.N., M. Kamal Uddin, M.F. Sulaiman, A.M. Amin, M. Hossain, Z.M. Solaiman and M. Mosharraf, 2022. Rice growth performance, nutrient use efficiency and changes in soil properties influenced by biochar under alternate wetting and drying irrigation. Sustainability, Vol. 14. 10.3390/su14137977.
42. Saputra, K., Sutriyono and B. Brata, 2018. Population and distribution of golden snail (*Pomacea canaliculata* L.) as feed resources in paddy field ecosystem in Bengkulu City [In Indonesian]. J. Sain Peternakan Indonesia, 13: 189-201.
43. Fouad, A.M., D. Ruan, S. Wang, W. Chen, W. Xia and C. Zheng, 2018. Nutritional requirements of meat-type and egg-type ducks: What do we know? J. Anim. Sci. Biotechnol., Vol. 9. 10.1186/s40104-017-0217-x.
44. Rohaeni, E.S., A. Subhan, V.W. Hanifah, B. Bakrie and I. Sumantri, 2021. Effects of feeding alabio ducks with fresh golden snail on egg production and quality. J. Hunan Univ. Nat. Sci., 48: 305-313.