Research article

Assessing the Efficiency of Different Biogas Generators in Energy Production and Greenhouse Gas Emissions for Commercial Pig Farms in Cambodia

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Abstract Covered lagoon digesters are commonly used by commercial pig farms in Cambodia to manage their wastewater and produce biogas for electricity generation. In these biogas systems, dual or modified pure biogas generators are utilized, but the efficiency of different generators in the context of Cambodia has yet not been rigorously evaluated. Therefore, the current study aimed to (1) determine biogas production and quality in two pig farms, (2) compare the working performance of a pure biogas generator and a dual generator, and (3) estimate CO_2 emission reduction in the two cases. The study was carried out between May 2022 and May 2023 on two large-scale pig farms that hosted fully operational biogas systems. The first farm operated an all-in-all-out system with 8,000 fattening pigs in Kampong Speu Province, while the second farm operated a full system with 5,000 fattening pigs and 600 sows. The portable biogas analyzer, electrical power logger, and vortex flowmeter were used to measure biogas quality and record the power consumption and daily biogas production. The results show that the first farm produced 792 Nm^3/day, whereas the second farm produced 495 Nm^3/day of biogas daily. Additionally, the methane content in both cases was not significantly different (60% of CH_4). However, the dual generator can generate power up to 1,118 kWh/day, while the pure biogas generator can produce only 743 kWh/day. The first farm that used the dual generator could save up to 80% of total power consumption, whereas the second farm could save only 24% due to a larger demand for electricity. Thus, the first farm (3,408.2 t CO_2equ) could reduce more greenhouse gas emissions than the latter (697.8 t CO_2equ). The results of the study suggest that using biogas from wastewater treatment to produce electricity reduces both electricity costs and greenhouse gas emissions.

Keywords covered lagoon, pig farm, biogas, electricity, dual generator and greenhouse gas

INTRODUCTION

Pig production plays a major role in sustaining the Cambodian economy, producing meat, and providing jobs for millions of people. So far, there have been more than 8 million pigs raised nationwide, and about 21% of them are raised in commercial farms (NIS, 2021). Between 2017 and 2021, large-scale pig production increased more than two-fold, meaning that more wastewater is being generated. Without proper treatment, environmental catastrophes may occur. Those include potential pollution of surface and groundwater, disease spread by flies, bad odor, which leads to complaints from neighboring communities, and greenhouse gas emissions (ADB, 2022). In 2018, almost 50 commercial pig farms were using these systems in the form of simple covered lagoon digesters to treat and convert wastewater into energy for farm use (Hin et al., 2021).

Until now, there have been more than 500 officially recorded commercial pig farms across the country, while the unofficial number may be higher. So, there is a high potential for producing biogas from those farms, while eliminating issues related to wastewater, contributing to renewable energy production, and reducing greenhouse gas emissions (NBP, 2019). Year after year, the number of simply covered lagoon digesters is increasing without the latest data from the government, which means that wastewater treatment is not a concern anymore; then, a few local biogas suppliers have started to jump in, providing services such as covering lagoons to hold wastewater and to trap biogas and converting second-hand diesel generators into running on biogas. This is the main reason why the number of large-scale biodigesters keeps increasing. According to the studies conducted by Biogas Technology and Information Center (BTIC) between 2019 and 2023, 50-80% of pig farm electricity demand can be replaced by electricity produced from biogas. This is an enormous benefit because an average farm of 30,000 pigs can save 48000 USD per year. At the same time, the efficiency of dual generators in producing electricity from biogas and in reducing CO_2 emissions is poorly documented (BTIC, 2021).

OBJECTIVE

The goal of this research was to assess the efficiency of different biogas generators operated on pig farms. Thus, this research aimed to (1) determine biogas production and quality in two pig farms, (2) compare the working performance of a pure biogas generator and a dual generator, and (3) estimate CO_2 emission reduction in the two cases.

METHODOLOGY

The research was conducted from July 2022 and May 2023 on two large-scale pig farms that operated a full biogas system in the form of a covered lagoon digester. The first farm operated an all-in-all-out pig-raising system in Kampong Speu Province, raising 8,000 fattening pigs per cycle and two cycles per year (Table 1), while the second farm operated a full pig-raising system in Kampong Thom Province, raising 5,000 fattening pigs and 600 sows (Table 2). The biogas system run by the first farm consists of a 4,725 m^3 covered lagoon for accepting wastewater, a desulfurizing system for cleaning biogas, a flow meter for recording biogas consumption, and a second-hand dual 200 kW generator for producing electricity from biogas. The second farm had a biogas system that included a 2,560 m^3 covered lagoon, a desulfurizing system, a flow meter, and a second-hand 296 kW diesel generator modified to run on pure biogas. Because the second farm used only wastewater from fattening pig barns to produce biogas and then electricity, the study focused on all estimations based on the fattening pigs.

Biogas quality was measured by using a 5000-biogas analyzer, biogas flow rate by recording biogas flow rates on a biogas meter, and electricity generation by a Hioki power logger (Hin et al., 2021; Mean et al., 2023). Throughout the study, the inspection was made 5 times with an interval of 1-2 months, depending on the permission from the farms and when biogas is fully used.

Biogas quality was measured before and after desulfurization, and the collected parameters include methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), and hydrogen sulfide (H_2S). Each measurement was made three times to detect variations, and before every next measurement, the biogas analyzer was flushed out first to avoid the effects of previous samples. Biogas flow rates were also recorded when the generators were in full operation (Tippayawong et al., 2007). The measurement was done three times with an interval of 15 min to detect changes in consumption.

Output power produced by the generators were also recorded at any time that the biogas flow rates were recorded. In doing so, the total amount of time estimated to run generators based on the daily biogas production can be calculated using Eq. 1.

$$TW = WS + MP + UP \quad (1)$$

TW (m^3/day) accounts for the total wastewater generated in each farm daily. WS (m^3/day) represents the total daily water supplies for pigs on each farm, and it was calculated by multiplying the number of pigs by the average amount of water used per head, which is 30 L/head/day. MP (ton/day) represents the daily manure produced by a pig, being 1.5 kg/head/head (Mek et al., 2018). UP (m^3/day) accounts for daily urine excreted by a pig, estimated to be 2.5 L/head/day, while EV (m^3/day) represents daily evaporation from pig barns, which is 0.5 m^3 per barn (Hin et al., 2021).

Table 1 Information of the first farm

Farm	Type/Quantity	Description
Pig farm in Kampong Speu Province		Called the first farm
GPS location		11°16'55.8"N 104°36'51.4"E
Raising type	All-in-all-out	Piglets are supplied by a contracting company whenever new cycles come.
Fattening pig (head)	8,000	
Digester type	Simple covered lagoon	
Digester size (m^3)	4,725 m^3	
Generator type	Second-hand, dual-engine	30:70 (diesel:biogas)
Generator power (kW)	2 x 200	Two sets each with 200 kW
Desulfurizing system origin	V.W. gas	A local supplier
Desulfurizing system specifications	2 tanks and one cyclone without a blower	
Testing period	Oct 2021 – Jul 2022	

Table 2 Information of the second farm

Farm	Type/Quantity	Description
Pig farm in Kampong Thom		Called the second farm
GPS location		12°43'48.5"N 105°08'41.4"E
Raising type	Full production	Piglets are produced for own farm raising
Fattening pig (head)	5,000	
Sow (head)	600	
Digester type	Simple covered lagoon	
Digester size (m^3)	2,560	This pond accepts wastewater from fattening pig barns only
Generator type	Second-hand, modified from diesel to biogas	
Generator power (kW)	296	Two sets, 360 kW and 290 kW
Desulfurizing system origin	BTIC prototype	Called BTIC desulfurizing system in this study
Desulfurizing system specifications	2 tanks and one cyclone without a blower	
Testing period	May 2022 – May 2023	

In this study, the first farm had 10 barns, and the second farm had 8 barns. Likewise, the total quantity of biogas produced daily on the farms were calculated as Eq. 2 below.

$$Q_{biogas} = N \times MP \times DM \times BY \quad (2)$$

Q_{biogas} (kWh/day) represents the total quantity of biogas produced daily on each pig farm. N is the number of pigs, while MP is the daily manure. DM represents the content of dry matter present in the manure, and, in this study, DM is 20% (Department for Environment Food and Rural Affairs, 2021). BY stands for biogas yield, which is approximately 0.33 Nm^3/kg DM (Hin et al., 2021).

$$PE = CF \times Q_{biogas} \quad (3)$$

PE (kWh/day) represents daily amounts of potential electricity produced by the generators in each farm, and CF accounts for a conversion factor from biogas to electricity, which ranges from 1 to 1.7 kWh/Nm^3 biogas for second-hand generators, depending on the quality and age of the generator. In this study, CF of 1.5 kWh/Nm^3 biogas was used because the generators were large. Q_{biogas} (Nm^3/day) represents the total quantity of biogas produced daily from each pig farm.

$$LR = P_{output}/GP \quad (4)$$

LR (%) represents the loading rate of each generator when they were operated to produce electricity. P_{output} (kW) is the output power produced by individual generators, while GP is the generator power (kW).

$$CO_2 \text{ by avoidance of } CH_4 \text{ emission} = Q_{CH4} \text{ x } D_{CH4} \text{ x } CH_4\text{-to-}CO_2 \text{ equivalent} \quad (5)$$

$$CO_2 \text{ by avoidance of grid electricity use} = EM \text{ x electricity-to-}CO_2 \text{ equivalent} \quad (6)$$

Q_{CH4} (Nm^3/year) represents the amounts of CH_4 produced annually by the biogas systems on each farm, while D_{CH4} is the density of CH_4, which is 0.717 kg/m^3. The CH_4 - to - CO_2 an equivalent is 30 times more potential to cause global warming. EM (kW) represents the amount of electricity produced by biogas generator on an annual basis, and the electricity - to - CO_2 equivalent is 0.657 kg CO_2/kWh electricity. Total CO_2 emission reduction is calculated based on the addition of both CO_2 emission reductions in both of the above-mentioned cases.

Data analysis was made by using MS Excel to perform descriptive statistics. Meanwhile, graphs were created by using R Program and RStudio, which are free online software programs.

RESULTS AND DISCUSSION

Wastewater characteristics were studied and compared between the two farms (Table 3). It can be seen that all the studied parameters are 1.6 times higher in the first farm than in the second farm. This is because the first farm had more fattening pigs than the second farm did. On average, 12 tons of manure were produced by the first farm, while the second farm produced only 7.5 tons of manure per day. Urine production was 20 m^3/day on the first farm and 12.5 m^3/day on the second farm. Total dry matter for the first and second farms was 2.4 tons/day and 1.5 tons/day, respectively. With that, the total quantity of wastewater was 269 m^3/day and 171 m^3/day, respectively.

Table 3 Comparison of manure production, dry matter, and total wastewater in the two farms

Source	Unit	First farm*	Second farm*	Ratio
Fattening pigs	Head/cycle	8,000	5,000	1.6
Manure	ton/day	12	7.5	1.6
DM content	%	0.9	0.9	1.0
Total water use	m^3/day	240	150	1.6
Urine	m^3/day	20	12.5	1.6
Total DM	ton/day	12	7.5	1.6
Evaporation	m^3/day	5	4	1.3
Total wastewater	m^3/day	267	166	1.6

Biogas quality was inspected and compared before and after biogas was desulfurized in both farms (Table 4). The results show that there was no difference in CH_4, CO_2, and O_2, regardless of applied desulfurization and farms. On average, biogas had 62.8% CH_4, 32.0% CO_2, and 0.6% O_2. In contrast, H_2S decreased after desulfurization in both farms. Untreated biogas had a much higher H_2S concentration in the first farm than in the second farm. After treatment, H_2S was lower than 200 ppm, which is good enough for smooth generator operation.

Table 4 Comparison of biogas quality before and after desulfurization in both farms

Biogas quality	First farm		Second farm		Average
	Before	After	Before	After	
CH_4 (%)	63.0	62.5	63.0	62.7	62.8
CO_2 (%)	32.0	31.4	32.4	32.0	32.0
O_2 (%)	0.5	0.5	0.5	0.7	0.55
H_2S (ppm)	3,470	10	2,500	87	

Table 5 compares generator size, potential biogas production per day and pig head, biogas flow rate consumed by the generators, estimated generator-running time based on the estimated biogas production, estimated electricity production, output power produced by the generators, and their loading rate between the two farms. It is observed that the first farm (200 kW) had a smaller generator size than the second farm (296 kW) but produced more daily biogas. This is because the first farm had more pigs, thus having greater amounts of manure necessary to generate biogas. In our case, the size of generators suitable for daily biogas production was estimated to be 792 Nm^3/day for the first farm and 495 Nm^3/day for the second farm. Nevertheless, daily biogas production per head was the same, being 0.01 Nm^3/head/day. Because the first farm used a smaller generator, while producing more biogas, the estimated time that it could run the generator was more than a surplus. Meanwhile, the generator operated by the second farm might use up the daily produced biogas in 4.3 hours. After that, it depends solely on grid electricity. The reason why the first farm used much less biogas is because it operated a dual generator that ran on both biogas and diesel. In this regard, 90 L of diesel was consumed daily. The output power was 93 kW and 125.5 kW for the first and second farms, respectively. It can be noted that the total number of pigs raised in the second farm was much less than that of the first farm even with sows included, but more electrical power was required. This is because sow raising requires a considerable amount of energy, 3 times higher than the electricity needed for one fattening pig (39 kWh/year).

Table 5 Comparison of electricity production, generator efficiency, and loading rate by the two desulfurizing systems

Item	First farm	Second farm	Ratio
Generator size (kW)	200	296	0.7
Estimated daily biogas production (Nm^3/day)	792	495	1.6
Daily biogas production per head (Nm^3/head/day)	0.01	0.01	1.0
Biogas flow rate (Nm^3/h)	32	114.5	0.3
Estimated time for running generators by using biogas (h/day)	24.8	4.3	5.8
Potential Electricity production (kWh/day)	1,188	743	1.6
Diesel consumption (L/day)	90	0	
Output power (kW)	93	125	0.7
Loading rate (%)	47	41	1.1

Energy saving based on the utilization of biogas systems was calculated based on two different scenarios: when the farms did not use biogas and when they used biogas (Table 5). It was found that the first farm consumed 90 L of diesel on daily biogas when its generator was operated with a biogas mixture. However, diesel consumption rose to 450 L/day, when its generator was fully operated by using diesel. Thus, with the use of biogas, 80% of diesel consumption was reduced, which represents energy savings. These results are in line with a study by Leykun and Mekonen (2022) and Tippayawong et al. (2007) which suggested that using biogas with dual generator can reduce diesel up to 80%. Likewise, when biogas was used, the second farm reduced dependency on grid electricity from 2,784 to 2,256 kWh/year, a reduction of 24%. This result clearly indicated that using biogas can reduce electricity consumption that normally stems from the use of fossil fuel.

Table 6 Comparison of diesel consumption on the first farm and grid electricity consumption on the second farm when biogas is either used or not used

Description	First farm	Second farm
Diesel consumption mixed with biogas (L/day)	90	0
Diesel consumption without using biogas (L/day)	450	0
Grid electricity consumption mixed with biogas	0	2,256
Grid electricity without using biogas	0	2,748
Energy saving (%)	80	24

CO_2 reduction and CO_2 emission were compared on both farms when they use biogas in combination with diesel or grid electricity (Fig. 4). The results show that the first farm could reduce much more CO_2 emission (2,483 tCO_2equ) when biogas used, when compared with the second farm (1,552 tCO_2equ), which is equivalent to a 1.6-to-1 ratio. At the same time, the farms also used other sources of energy to meet the electricity demands. The first farm used diesel, while the second farm used grid electricity. As a result, they emitted 79.6 and 1,482 tCO_2equ, respectively. Despite that, they still had reduced carbon emissions, at 2,403 tCO_2equ for the first farm and 70 tCO_2equ for the second. It can be concluded that by using biogas to generate electricity, the farms can both save electricity costs and contribute toward CO_2 emission reduction, supporting the transition to a green economy.

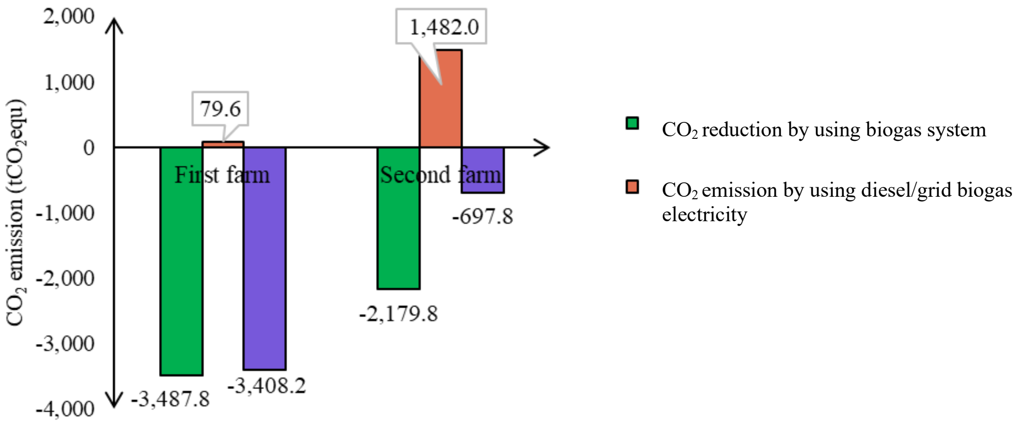

Fig. 1 Comparison of CO_2 reduction due to the use of biogas and CO_2 emissions due to the use of diesel and grid electricity in both farms

CONCLUSION

The study compared biogas production, biogas quality, energy production, and CO_2 emission reduction in two large-scale pig farms that used a pure biogas generator and a dual generator. Wastewater characteristics were also studied and compared. The findings show that the farm that has a larger number of pigs will produce more wastewater and manure on a daily or yearly basis, thus generating more biogas when biogas systems are operated. Despite that, electricity demand on the farms depends significantly on the purpose of electricity use. The first farm had more fattening pigs but used less electricity than the second farm that included 600 sows. This is due to the large quantity of electricity required to fulfil the electricity demand of raising sows. With the use of farm-generated biogas, diesel or grid electricity consumption is greatly reduced, which translates to energy and cost savings. Additionally, using biogas can lead to reduced carbon emissions, although the farms still depend on fossil fuel. This can in turn serve as an important contribution toward the green energy transition in the livestock sector. Nevertheless, future studies are needed to conduct a comprehensive cost-benefit analysis when the whole cost of a biogas system is included; it is expected such studies can reveal the full range of benefits provided by a biogas system.

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Research article

Evaluation of Agroecological Performance across Geographical Aspects and Agroecological Transition Levels in Battambang Province, Northwest Cambodia

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Abstract Agroecology (AE) is the application of ecological concepts and principles to agricultural systems to increase their sustainability. This study aimed to conduct a multidimensional evidence-based evaluation of AE performance in Battambang Province, using the Tool for Agroecology Performance Evaluation (TAPE). The study investigated two main criteria: geographical aspects in Sangkae (lowland) and Rotonak Mondol (upland) districts and AE transition levels. We preclassified 120 farms into two AE transition level categories (high-AE and low-AE) as well as a non-project farm category. Results indicated that the mean characterization of agroecological transitions (CAET) score was low (37.42%). Among ten elements covering technical and social aspects in AE, the technical performance was lower which emphasize the studied farms relied on external inputs (fertilizers, pesticides, seeds, labor, and services). Farms in the study area are increasingly used agro-inputs for increased productivity, particularly in lowland areas, using an average of 5.4 types of pesticides. The economic performance in the upland area resulted in negative total income due to climate change risks (drought and flood), pest-causing yield loss, rising agricultural input costs, loss of price of agricultural products, and difficulty in selling agricultural products. To improve the performance of agroecology transition, farmers need to save their seeds to maintain internal inputs at the farms. In addition, promotion of AE practices with technological techniques should be widely adopted at the national level, including encouraging farmers in the community to use less pesticides, adopt organic/natural fertilizers and pesticides, and apply ecological techniques.

Keywords agroecology, sustainability, TAPE, multidimensional, evaluation

INTRODUCTION

Agroecology (AE) is a comprehensive approach that considers ecological, and social principles and concepts in the development and management of food and agricultural systems. It aims to maximize interactions between plants, animals, humans, and the environment while taking into account the social issues that should be addressed for a sustainable and equitable food system (FAO, 2018).

In Cambodia, agriculture remains an important source of income for many Cambodians living in rural areas. Accounting for nearly 61% of rural people and 77% of rural households relying on agriculture, fisheries, and forestry for their livelihoods (USAID, 2024). There were some challenges in the Cambodian agroecological transition including a lack of knowledge and experience in AE, limited access to production factors and markets as well as policy support (ASSET, 2022). Cambodian farmers are particularly vulnerable to climate change including temperature rises, changes in precipitation patterns, and extreme weather events. To tackle the above challenges in the AE transition, this study aimed to generate evidence-based multidimensional knowledge for promoting the AE transition in Cambodia.

OBJECTIVE

This study aimed to conduct a multidimensional evidence-based evaluation of AE in Battambang province, northwest of Cambodia in terms of two main criteria, namely, geographical aspects and AE transition levels, using the Tool for Agroecology Performance Evaluation (TAPE) tool.

METHODOLOGY

By consulting with relevant stakeholders including the French Agricultural Research Center for International Development (CIRAD) team, currently implementing the project in the target area, the study was conducted in six targeted villages located in Sangkae (lowland with paddy rice production) and Rotonak Mondol (upland with cash and perennial crops) districts of Battambang province, northwest of Cambodia (Fig. 1).

The lowland area of Sangkae district is located near the Kanghot irrigation system which is used for two rice cultivation that allows for gravity-fed irrigation and pumping (Kong and Castella, 2021). Water availability is a major concern in some villages during the first or second rice cycle. Changing the rice cropping system has a significant negative influence on the ecosystem due to the increased use of chemical fertilizers and pesticides (Phoeurk et al., 2020). Approximately 98% of households use chemical pesticides for rice farming to protect pests and diseases while 90% of farmers use chemical herbicides (Kong and Castella, 2021). Rice is the main crop grown in this area and livestock farming is commonly raised.

In the upland area of Rotonak Mondol district, farmers can cultivate two cycles of crop each year. Farmers farmed annual cash crops (cassava and maize) and perennial crops (mango and longan). There has recently been an increase in the use of pesticides for off-season perennial crop production with polluted water sources and underground water (Kim and Peeters, 2020). Drought occurs frequently and has impacts on crop yields, particularly in 2015 and 2019 (Kong and Castella, 2021).

The study was conducted between May to August 2023 using the TAPE questionnaire installed in the Tablets for data collection in the fields by trained data enumerators. TAPE has four main steps (i) Step 0 – we organized focused-group discussions (FGDs) with relevant stakeholders and desk review; (ii) Step 1 – we surveyed the characterization of agroecology transition (CAET) to emphasize the 10 elements of AE; (iii) Step 2 – we surveyed the 10 core criteria of AE performance from five key dimensions to generate evidence on the multidimensional performance of AE; (iv) Step 3 – we organized a participatory analysis with relevant stakeholers in the study area to validate the results and explore potential levers to improve AE transitions.

The study covered two main criteria, namely, geographical aspects and AE transition levels, through a combination of qualitative and quantitative investigation. A total of 120 farms were predefined in geographical aspects such as lowland (Sangkae) and upland (Rotonak Mondol), including 60 AE farms and 60 non-project farms were selected as farmers of CIRAD and Water Resources Management and Agroecological Transition for Cambodia Program (WAT4CAM). For AE farms, we classified the farms into two AE transition levels including medium-high (high-AE) and low-medium (low-AE) based on the CIRAD project's data. These levels indicated the AE performance of each farm in the CIRAD project. For non-project farms, we selected the farms that have similar characteristics to AE farms for comparison (i.e., farm size and production system).

The data were analyzed using R-studio. Step 1 – the data analyzed the CAET scores and correlation. Step 2 – each criterion was calculated and scaled by using the traffic light approach where "3 = desirable", "2 = acceptable", and "1 = unsustainable". Step 3 – we analyzed by using a participatory analysis workshop with relevant stakeholders in the study area.

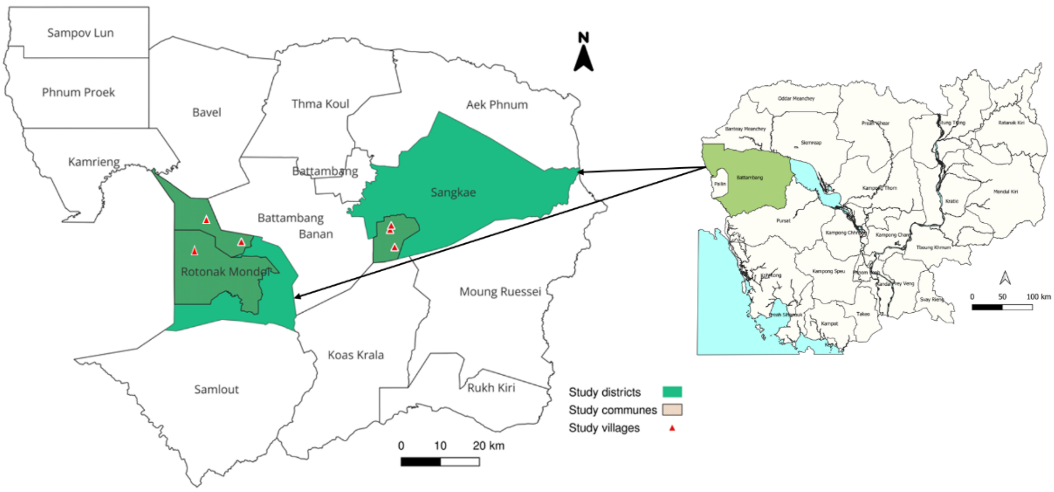


Fig. 1 Map of six targeted villages in Sangkae and Rotonak Mondol Districts of Battambang Province

RESULTS AND DISCUSSION

As shown in Table 1, the AE performance was low in the study area with a mean of CAET score 37.42%, except for a small number of farms (8.33%) obtaining a CAET score over 50%. Based on the classification of AE transitions made by Lucantoni et al. (2023), we could conclude that the overall CAET scores of this study are considered as non-agroecological transitions (less than 50%). The ranging from 50-60%, 60-70%, and higher than 70% are considered as incipient AE transition, in transition to AE, AE transition, respectively. According to similar studies conducted by Kim and Peeters (2020) and ECOLAND (2021), the CAET score was 55% and 45.23%, respectively. The overall CAET score in the study area has decreased by year since 2019.

The element of AE's social aspects performed better than the technical aspects, especially synergies, recycling, and efficiency elements (Table 1). In other words, most farms were dependent on external agricultural inputs including fertilizers, pesticides, seeds, labor, and rental services. Input expenditures (seeds, fertilizers, and pesticides) were 656.35 USD and 321.70 USD per hectare in lowland and upland, respectively. Its ratio was high, especially in the lowlands with around 45% of total expenditures.

Across geographical aspects and AE transition levels, predefined high-AE farms in both upland and lowland areas obtained an identical score while non-project farms in the lowland performed the lowest (Table 1). This could be explained by the predefined farms in the project practicing the Conservation Agricultural (CA) technique.

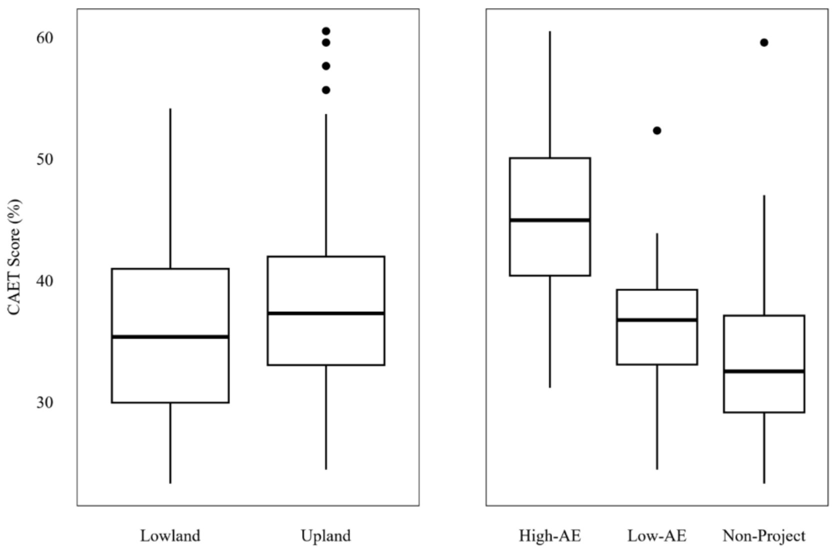
According to Table 1, the element of culture and food tradition and circular and solidarity economy in the lowland (high-AE) received better performance than the upland (high-AE). In the lowland, local markets were active and accessible where some products were produced and sold locally, providing farmers with access to a diverse diet of food groups.

Table 1 CAET score (%) based on geographical aspects and AE transition levels in Battambang province

Ten (10) Elements of AE	*AE performance	Upland			Lowland		
		High-AE	Low-AE	Non-project	High-AE	Low-AE	Non-project
Diversity	41.80	53.30	40.80	41.90	48.80	42.50	32.70
Synergies	35.30	44.60	37.10	34.20	44.60	35.80	26.00
Efficiency	24.50	35.00	20.80	24.00	32.10	25.40	17.50
Recycling	29.30	39.20	27.50	26.50	36.20	31.70	23.30
Resilience	33.50	42.50	29.00	32.10	41.40	33.10	28.80
Culture and Food Traditions	48.40	51.70	46.70	48.30	53.30	48.90	45.00
Co-creation and Sharing of Knowledge	39.40	51.70	35.60	35.80	56.70	37.20	31.10
Human and Social Values	49.10	55.40	47.90	49.40	50.80	48.80	45.60
Circular and Solidarity Economy	33.80	38.90	31.10	31.40	41.10	33.90	31.10
Responsible Governance	39.20	45.00	36.10	39.40	45.60	37.80	35.00
Overall CAET	37.42	45.70	35.30	36.30	45.10	37.50	31.60

*Source: Field survey, 2023; Explanation: *refers to the AE performance of all farm systems assessed.*

Figure 2 shows that the mean CAET scores of upland and lowland areas were distinct, but not significantly different. The upland score was higher at 38.40% than the score of the lowland at 36.50%. The predefined high-AE farms obtained higher CAET scores compared to low-AE and non-project due to the AE transition levels known as predefined samples from project partners with better AE performance.



a) Geographical Aspects **b) Predefined AE Transition Levels**

Fig. 2 Boxplots with mean CAET score

Based on the traffic light in Table 2, land tenure for men and women was obtained at an acceptable level in both criteria which suggested that most of them have either ownership or perception of their land security. The land tenure for men and women obtained acceptable levels in the high-AE while land tenure for women was higher than men for low-AE and non-project. Based on local authorities, land tenure in the lowland area is a certificate of exploitation (soft title) of land that is facilitated by village and commune chiefs.

Most farmers received an unsustainable level of pesticide exposure, meaning that they use highly hazardous pesticides (Class I) with less than four of the listed mitigation techniques (mask and protection gear) (Table 2). In addition, 78.33% of farmers thought that pesticides are important for agricultural production. According to FGDs, pesticide-based production was reported in both areas with an average of 6 applications and 5.4 types of pesticides. Local authorities reported that farmers have limited knowledge of the pesticide's application due to a lack of training, applying based on neighbors' experiences and instruction from input sellers.

For the dietary diversity dimension, farmer's households consumed an acceptable level in the lowland. From the AE transitional level, only those with high AE have accessed acceptable dietary status within the last 24 hours (Table 2). Only 25.80% of all respondents consumed 7 out of 10 food groups or desirable levels. In contrast to lowland farmers, upland farmers are more dependent on the self-produced food in their diverse farms as it was also reported of limited access to local markets.

The social and cultural dimensions consisted of women's empowerment and youth employment opportunities. Women's Empowerment in Agriculture Index obtained acceptable results across the two criteria (Table 2). However, youth employment opportunities were indicated at an unsustainable level for both criteria which means that young people were less interested in agricultural activities and willing to migrate for opportunities. According to FGDs, migration in the upland was higher than in the lowlands in the targeted villages interviewed. An estimated 30% of people in the upland migrated to Phnom Penh, Sihanoukville, and neighboring countries (Thailand) to find jobs, and only 10% to the lowlands.

In the environmental dimension, agricultural biodiversity was obtained at an unsustainable level for both criteria (Table 2). The upland and high-AE farms had better soil health at an acceptable level due to the CA technique that has been promoted in this area for almost 15 years to improve soil quality and better crop yield with reduced chemical inputs. Whereas, the lowland obtained traffic lights close to acceptable levels even though the CA technique was recently promoted in 2020.

Table 2 Seven of ten core criteria of AE performance from step 2 under geographical aspects and AE transition levels

Criteria	Governance		Health and nutrition		Society and culture		Environment	
	Land tenure for men	Land tenure for women	Exposure to pesticides	Dietary diversity	Women's empowerment	Youth employment	Agricultural biodiversity	Soil health
Upland	2.82	2.87	1.00	1.78	2.21	1.63	1.53	2.03
Lowland	2.60	2.72	1.02	2.07	2.50	1.27	1.08	1.97
High-AE	2.83	2.83	1.00	2.07	2.30	1.89	1.43	2.20
Low-AE	2.77	2.80	1.00	1.93	2.50	1.00	1.27	1.97
Non-project	2.62	2.77	1.02	1.85	2.32	1.39	1.27	1.92

*Source: Field survey, 2023; Explanation: *traffic light indication: 1 – unsustainable, 2 – acceptable, 3 – desirable*

According to Table 3, farms in the lowlands obtained a positive total income of 688.73 USD per hectare per year (in 2022) even though they faced environmental risks including flooding, insufficient water, and drought. However, upland farms received negative total income (-89.93 USD) due to unpredictable climate change (lack of rainfall and drought), the price of agricultural inputs increased in 2022, investment in insecticides, increased pests on maize with loss yields, declining product prices, and difficulty in finding markets. Nearly a quarter of farmers expressed having significantly reduced income. Some farmers (25%) reported increased income compared to the last three years, while 30% and 34.10% indicated that their income remained unchanged and decreased, respectively. Related to markets in the upland, most farmers sold raw maize and cassava to middlemen and traders with fluctuating prices. In 2021, the price of products was very cheap, e.g., 0.19 USD per kilogram of maize and 0.07 USD per kilogram of fresh cassava. In contrast, in the lowlands, there is an agricultural cooperative that actively facilitates contract farming with local rice millers with a guaranteed marketable price of 0.25 USD per kilogram of rice. Sok et al. (2022) reported that the income of farmers in 2020 remained low due to facing natural disasters and loss of rice yields.

The participatory analysis with local relevant stakeholders determined different activities including enhancing the ability of farmers to save the seeds and reduce the wasting of inputs, strengthening AE practices at the national level with reduced chemical use, and promoting new technological practices such as no-tillage technique, cover crops or resistant seeds to minimize the yield and cut loss.

Table 3 Economic performance (USD per hectare per year) under geographical aspects and AE transition levels in 2022

Criteria		Gross production	Gross added value	Net added value	Agricultural income	*Total income
Geographical aspects	Upland	793.88	75.33	7.70	-269.03	-89.93
	Lowland	1846.58	598.85	549.78	281.75	688.73
AE transition levels	High-AE	1357.73	451.75	379.43	144.28	337.48
	Low-AE	1480.70	521.48	402.35	160.30	268.93
	Non-project	1287.15	204.13	145.63	-119.20	245.63

*Source: Field survey, 2023; Explanation: *All the production costs of farming are included with other activities.*

CONCLUSION

The CAET score was low, meaning that agroecological performance remained low regardless of geography. Predefined high-AE farms in lowland and upland areas received higher CAET scores compared to low-AE and non-project farms due to they had adapted to AE practices with the CA technique. The majority of the farms relied on external inputs while there was limited productivity and income. With good governance of land and opportunities for AE's products, it could provide a promising alternative for youth employment. Based on the participatory analysis workshop with stakeholders, it was exploring themes to improve AE transition in the study area including technical, marketing, and policy aspects. An available and stable market for both inputs and products was critical for farmers to improve the AE production system. The study implies that intensification of production based on the chemical inputs poses concerns on the health and environment. It is a need for farmers to consider designing a farm with reduced expenditure of inputs. In addition, agroecological transition could be improved by tracking with climate change adaptation context and through holistic approaches and broader collective actions and networks.

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Research article

Design of a Two-Chamber Microbial Fuel Cell Without a Proton Exchange Membrane for Electricity Generation from Food Waste

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Abstract A conventional biomass-fired power plant requires substantial construction costs, making its implementation difficult in rural areas of developing countries. In contrast, microbial fuel cell (MFC) technology offers numerous benefits over conventional plants; however, its performance is currently inadequate and requires improvement before it can be deployed. This study proposed a new design for the anode chamber of a two-chamber MFC without a proton exchange membrane when food waste is used as a substrate. Different configurations of the anode chamber, including those with and without a soil layer and different anode positions, were investigated. The effects of each structure on MFC performance were investigated by measuring temporal changes in the cathode potential and examining the electrical conductivity (EC), oxidation–reduction potential (ORP) of the cathode water, and electrical current of MFC. The analysis of EC and ORP variations revealed that the introduction of a soil layer in the anode chamber resulted in lower EC values and higher cathode potentials, indicating that the soil layer acted as a filter to reduce the diffusion of ions from the anode chamber to the cathode chamber. However, this adsorption process increased the ohmic losses in the MFC system and decreased the current density. In the designs without a soil layer, when the anode was installed in the steelmaking slag (SS) layer, a higher cathode potential was observed compared with the design in which the anode was placed on the SS layer. Consequently, this higher potential induced a higher current density. However, without the exchange of cathode water, the current density decreased temporally, and no significant difference in the current density was observed between these designs during the first 7 days after generating electrical current. Therefore, placing the anode on the SS layer is a suitable design for recovering electricity from food waste.

Keywords electricity, food waste, diffusion, anode chamber, cathode water quality

INTRODUCTION

Electricity generation, particularly through coal-fired power plants, is a significant contributor to carbon dioxide (CO_2) emissions, exacerbating global warming concerns. Over the past few decades, efforts have been made to replace coal-fired power generation with renewable energy sources. Among these, biomass-based electricity generation plays a crucial role in reducing CO_2 emissions. Biomass-fired power plants are a conventional approach widely employed to convert biomass into electricity. However, this process involves converting chemical energy to thermal energy and then to electricity. As a result, substantial construction costs are required to construct a biomass-fired power plant. This cost barrier poses a challenge for achieving Sustainable Development Goal 7, particularly in the rural areas of developing countries.

The use of microbial fuel cells (MFCs) is an alternative approach for converting biomass into electricity, offering numerous benefits over conventional biomass-fired power plants, such as direct biomass-to-electricity conversion and a simplified structure. Previous studies have focused on converting organic waste, such as food or fruit waste, into electricity using MFCs (Li et al., 2016; Kumar et al., 2022; Zafar et al., 2023). However, the performance of MFCs remains low and must be improved before deployment. Furthermore, the cost-effectiveness of MFCs is affected using expensive proton exchange membranes (PEMs).

Following Touch et al. (2020), who demonstrated improved performance of sediment MFC through the addition of steelmaking slag (SS) with paddy soil, Shigetomi et al. (2022) succeeded in enhancing the performance of food waste by incorporating SS. Importantly, their MFC structure eliminated the need for PEMs, resulting in a new cost-effective approach for generating electricity from food waste. However, without the use of PEMs, the organic particles from food waste floated to the cathode chamber (Fig. 1) and decomposed, leading to a decrease in MFC performance. Shigetomi et al. (2023) proposed a new structure for the anode chamber of a single-chamber MFC; however, decreases in MFC performance still occurred. Therefore, the development of a new two-chamber MFC structure is required to mitigate the decrease in MFC performance.

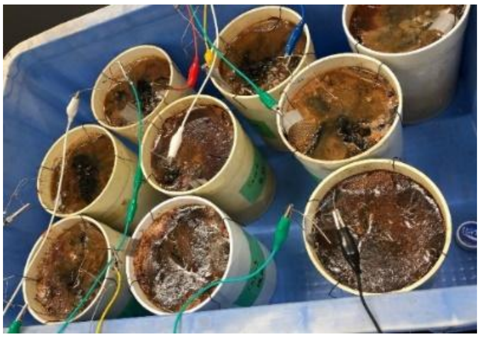

Fig. 1 Floating food waste particles into the cathode chamber

OBJECTIVE

This study proposes a new design for the anode chamber of a two-chamber MFC that can mitigate the decrease in MFC performance when food waste is used as a substrate. Different structures of the anode chamber, including those with and without soil layers and different anode positions, were examined. The effects of each structure on MFC performance were examined by measuring temporal changes in the cathode potential and assessing the electrical conductivity (EC), oxidation-reduction potential (ORP) of the cathode water, and electrical current of MFC.

METHODOLOGY

Experimental Materials and Procedures

The experimental setup comprised two connected cylindrical bottles (inner diameter = 12 cm and height = 14 cm). One bottle (the anode chamber) was filled with SS (diameter range of 5–40 mm) and food waste, and the other (the cathode chamber) was filled with tap water (Fig. 2). Three different designs of the anode chamber were made: (a) an 8-cm layer of SS was prepared, and the anode was then placed on the SS layer. A 3 cm layer of food waste was placed on the anode (Fig. 2a, DS1). (b) A 4-cm layer of SS was prepared, and the anode was then placed on the SS layer. Another 4 cm layer of SS was placed on the anode, followed by loading a 3 cm layer of food waste on the SS layer (Fig. 2b, DS2). (c) A 4-cm layer of dried upper land soils was prepared, and a 4-cm layer of SS was placed on the soil layer. Then, the anode was placed on the SS layer, and a 3-cm layer of food waste was loaded on the anode (Fig. 2c, DS3). DS1 and DS2 were designed to examine the potential of the anode, and DS3 was designed to examine the potential of the soil layer as a filter. The cathode chamber design was the same as that for DS1–DS3. This involved submerging a plastic net near the water surface on which the cathode was placed.

Carbon cloth (News Company, PL200-E) was used as the electrode material. Before use, the carbon cloth was heated at 500°C for 1 h to improve its performance, following the method described by Nagatsu et al. (2014). The heated carbon cloth, with a surface area of 0.1 m^2 (10 cm width and 10 cm long), was separated into carbon fibers to create a brush-type anode or cathode (Fig.1d). The food waste used was a commercially available product made by refining vegetable waste, mixing it with rice husk, and fermenting for 1 month (Fig. 2e).

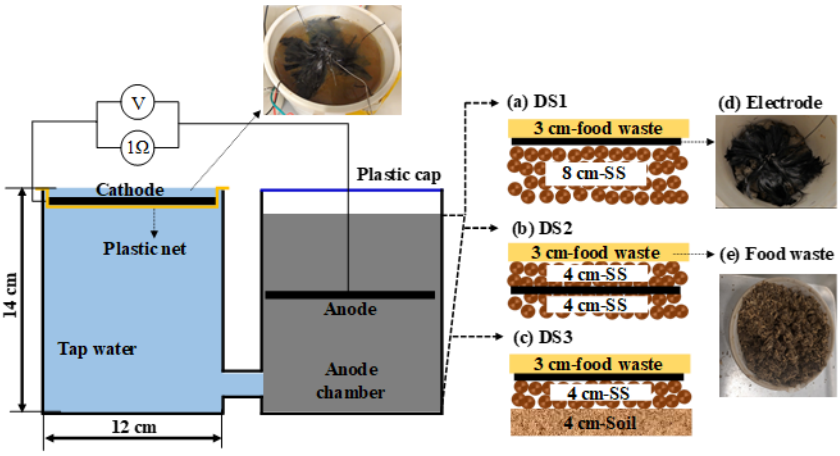

Fig. 2 Experimental procedures

Operations and Measurements

All MFCs were placed in an open-circuit (without electrical current flow) mode for 3 days. To generate electrical current, an external resistance of 1 Ω was connected between the anode and the cathode. The cell voltage was measured after 1 min of applying each external resistance and was used to calculate the current using Ohm's law: $I = U/R_{ex}$, where U [V] is the voltage, I [A] is the current, and R_{ex} [Ω] is the external resistance. The current density was determined by dividing the current by the electrode surface area, which was 0.01 m^2.

During the experiments, the ORP and EC of the cathode water were measured using an ORP/EC meter (Horiba, D-74). Furthermore, the cathode potential was measured by connecting the cathode and an Ag/AgCl reference electrode to the positive and negative terminals of the voltage meter.

RESULTS AND DISCUSSION

Temporal Changes in Electrical Conductivity of Cathode Water

Figure 3 shows a comparison of the EC of cathode water. EC increases when ions diffuse from the anode chamber to the cathode chamber. Thus, it enables us to understand the diffusion characteristics based on the variation trend of EC. Throughout the 35-day experimental period, the cathode water was exchanged twice, particularly on Days 14 and 22 (Fig. 3), where a significant decrease in EC was observed.

There was a slight difference in EC between DS1 and DS3, averaging less than 5 mS/m. Comparing DS3 with other designs was difficult because of the use of soil particles. However, by comparing DS1 with DS2, the EC of DS1 was higher than that of DS2, indicating that DS1 enables more ions to diffuse into the cathode chamber. From Days 0 to 14, the EC of DS3 was higher than that of DS2, which can be attributed to the diffusion of ions present in the soil layer. However, from Days 14 to 35, the EC in DS 3 was lower than that in DS1 and DS2, indicating the adsorption of ions from the food waste layer to the cathode chamber by the soil layer. In other words, the function of the soil layer as a filter was confirmed.

Based on the EC variations, it can be concluded that DS3, which incorporates a soil layer, is more effective in reducing ion diffusion into the cathode water. Without using a soil layer, the anode should be installed in the SS layer to minimize ion diffusion into the cathode water.

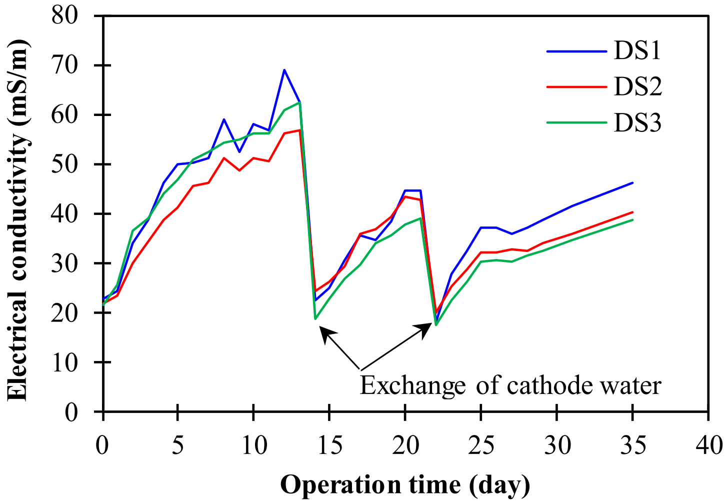

Fig. 3 Temporal variations in electrical conductivity of the cathode water

Temporal Changes in the Redox Potential of Cathode Water

The variation trend of the ORP of the cathode water can also provide insight into the diffusion of ions from the anode chamber to the cathode chamber. When ions diffuse into a water body, they consume oxygen and react with oxidants in the water body via oxidation-reduction reactions. Consequently, this decreases the ORP of the water.

Figure 4 depicts the decreases in the cathode water ORP. From Days 0 to 14, the decrease in ORP from DS1 to DS3 was of the same order of magnitude. However, from Days 14 to 25, decreases in the ORP of DS3 become lower, indicating a higher ORP than those of DS1 and DS2. This finding agrees well with the observations in Figure 2, indicating that the soil layer reduces diffusion.

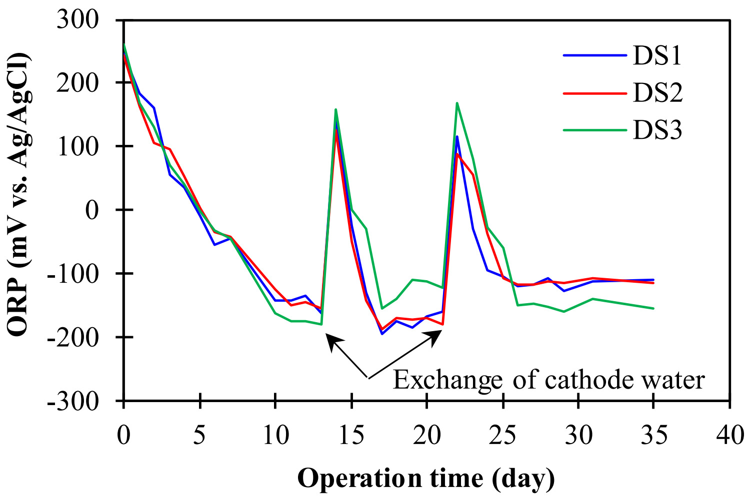

Fig. 4 Temporal changes in the cathode water ORP

Temporal Changes in Cathode Potential

Because cathode performance directly affects MFC performance, it is crucial to have a design that minimizes the decrease in cathode potential. The variation in the cathode potential during the experimental period is shown in Fig. 5.

As discussed earlier, DS2 outperforms DS1 in terms of reducing diffusion into the cathode chamber, resulting in a higher cathode potential for DS2. However, the decreasing trend in the first 2 days after the water exchange was the same for both designs. Figure 4 also shows that DS3 is more effective in reducing diffusion into the cathode water because a higher cathode potential was obtained. Furthermore, a different trend with a lower decrease in the cathode potential was observed compared with the other designs.

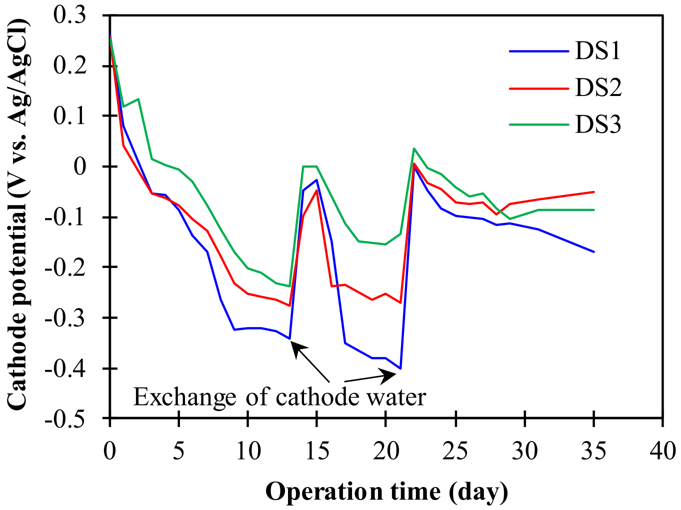

Fig. 5 Temporal changes in the cathode potential

Temporal Changes in Current Density

Although DS3 had a higher cathode potential than DS1 and DS2 (Fig. 5), its current density was lower than that of the other designs (Fig. 6). During the first 14 days, the average current density of DS3 was approximately 30 mA/m^2, which was half that of DS1 and DS1 (averaging 60 mA/m^2). The use of a soil layer as a filter reduces the current density. In other words, the adsorption of ions by the soil layer decreases the performance of the MFC. This decrease is attributed to the increase in ohmic losses in the MFC system because of the limitations of ion flow through the soil layer from the anode chamber to the cathode chamber.

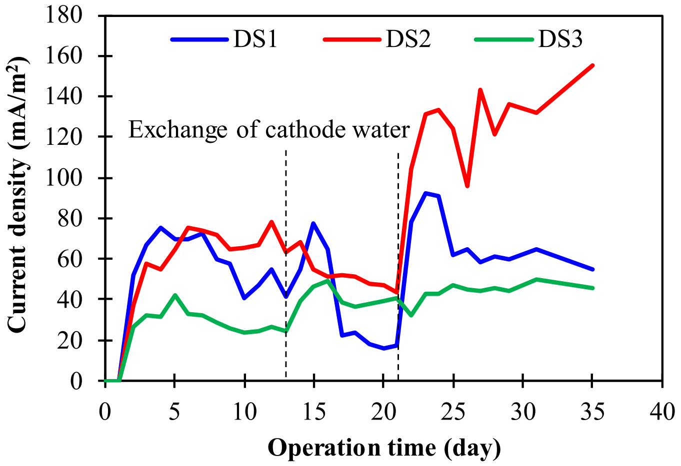

Fig. 6 Temporal changes in current density

By comparing the designs without a soil layer (DS1 and DS2), the current density of DS2 was found to be higher than that of DS2. The higher cathode potential of DS2 (Fig. 5) contributed to this increase in current density. Note that the current density decreased gradually without the exchange of cathode water. The decrease in current density began approximately 7 days after the current generation. During the first 7 days of the current generation, there was no significant difference in current density between DS1 and DS2. However, from a practical viewpoint, DS1 is better than DS2 because it allows the separation of food waste and SS by the anode, making it easier to replace the food waste after the experiment ends.

CONCLUSIONS

In this study, a new design was examined for the anode chamber of a two-chamber MFC for recovering electricity from food waste. Different anode chamber structures were proposed, and their effects were examined in terms of variation in cathode water quality and MFC performance. Analysis of the EC and ORP variations revealed that the use of a soil layer as a filter in the anode chamber (DS1) effectively reduced the diffusion of ions from the anode chamber to the cathode chamber. The adsorption of ions in the sand layer contributed to this reduction. However, this increased the ohmic losses in the MFC system and decreased the MFC performance. By comparing the placement of the anode on the SS layer (DS1) with the installation of the anode in the SS layer (DS2), it was observed that the DS2 maintained a higher cathode potential when the cathode water was exchanged, resulting in a higher current density. Unfortunately, without the exchange of cathode water, the current density decreased temporally, and no significant difference in the current density was observed between DS1 and DS2 during the first 7 days of electrical current generation. Therefore, DS1 should be a suitable design for the recovery of electricity from food waste because it facilitates the easy replacement of food waste at the end of the experiment. Even though DS1 could improve the SS-SMFC performance, the current density started to decrease after 7 days. Hence, the design of the cathode chamber needs to be considered for long-term electricity generation.

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Research article

Guidelines for Pesticide Risk Management at the Community Level in Northeast Thailand

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Abstract This study aimed to assess the risk of pesticide use and study guidelines for pesticide risk management at the community level in Northeast Thailand. From 2022 to 2023, data was collected by using semi-structured interviews and group discussions. Representatives of a group of farmers who use pesticides were purposively selected 10 per group with a total of 19 villages. Data collected from farmer interviews about pesticide use included substance type, application rates, spraying frequency, and plot size of plantations. This data was used in the EIQ Field Use equation to assess environmental risks. Group discussions included farmer representatives, community leaders, agricultural extension officers, public health officials, and researchers. It was found that the average Field Use EIQ of vegetable plots had a high-risk level, particularly in the case of villages growing chilies, tomatoes, and cabbage. From group discussions on guidelines for reducing the risk from pesticide use in each village, common guidelines identified included the following: 1) personal safety, requiring regulations on the use of appropriate spraying equipment, protective clothing and other personal protective equipment to prevent exposure to pesticides; 2) safety of people in the community, not spraying pesticides in villages or communities, schools, temples, and hospitals, and notifying the village headman with a spraying plan when spraying chemicals in areas close to the community or village; additionally, areas where pesticides are sprayed must have warning signs indicating the date and time; 3) safety for the ecosystem and public areas of the community; refraining from spraying chemicals, and leaving chemical bottles in public areas, water sources, and community forests; 4) food safety, ensured through compliance with the requirements outlined in the GAP standard; and 5) setting up a community committee to coordinate safe use of pesticides by the community's. These guidelines will be used as policy recommendations for reducing pesticide risk in commercial agricultural communities.

Keywords agriculture, environmental risk, community, pesticide, risk management

INTRODUCTION

Over the past few decades, agricultural activities have rapidly grown and diversified in Thailand. This creates new challenges in a variety of fields, especially the health and safety of agricultural workers and their families, as well as consumers. To meet global demand, the country relies heavily on pesticides to control pests in order to maintain high crop yields (Panuwet et al., 2012). In 2021, Thailand has pesticide use per area of cropland at 0.84 kg/ha, China 1.83 kg/ha, Philippines 3.37 kg/ha, Vietnam 4.28 kg/ha, Indonesia 5.29 kg/ha, Malaysia 5.51 kg/ha, and Japan 11.24 kg/ha (FAO, 2023). Although the rate of pesticide use is lower than in other countries in the region, they are also concerned about the behavior of using pesticides that are not yet correct. There are still problems such as applying higher concentrations than recommended and using adequate personal protective equipment (PPE) (Rivera et al., 2016). Their decisions regarding pesticide use are often based on information given by retailers, other farmers, agricultural extension service agents, and even the pesticide companies themselves (Tawatsin, 2015). Due to a lack of knowledge of availability and the affordability or inconvenience of wearing protective equipment, it was found that only a few farmers used PPE that was suitable for using pesticides (Kongtip et al., 2018). FAO's Code of Conduct article regarding pesticide selection as a risk management tool recommends that: ‘Pesticides whose handling and application require the use of personal protective equipment that is uncomfortable, expensive or not readily available should be avoided, especially in the case of small-scale users in tropical climates. Preference should be given to pesticides that require inexpensive personal protective and application equipment and to procedures appropriate to the conditions under which the pesticides are to be handled and used’ (FAO and WHO, 2020). The challenges to pesticide risk reduction have been identified by the Food and Agriculture Organization (FAO) of the United Nations: (a) the rapid expansion of pesticide trade in terms of total volume, number of products, and number of selling points, combined with a weak regulatory and enforcement capacity; (b) a high level of satisfaction among farmers with pesticides combined with low levels of risk awareness, lack of technical know-how about integrated pest management (IPM), and general unavailability of bio-control agents; and (c) no regular monitoring of pesticide risk, which makes it difficult for legislators, regulators, farmers and consumers to make rational decisions (Schreinemachers et al., 2015).

The Thai government has encouraged farmers to adhere to crop production standards, including GAP (Good Agricultural Practice) and organic farming. GAP's main principle in managing risks from the use of pesticides is IPM. IPM is the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations. It combines biological, chemical, physical, and crop-specific (cultural) management strategies and practices to grow healthy crops and minimize the use of pesticides, reducing or minimizing risks posed by pesticides to human health and the environment for sustainable pest management (FAO, 2024). Risk is a function of the probability of adverse health or environmental effect, and the severity of that effect, following exposure to pesticide. Risk assessment is an important tool to predict pesticide effects on human health or the environment. It is therefore widely used to justify registration decisions for reducing pesticide risks (FAO, 2017).

The Environmental Impact Quotient (EIQ) is a formula created to provide growers with data regarding the environmental and health impacts of their pesticide options, so they can make better informed decisions regarding their pesticide selection (Cornell University, 2024). The formula helps to calculate the environmental impact of the most common fruit and vegetable pesticides used in commercial agriculture. The values obtained from these calculations can be used to compare different pesticides and pest management programs to ultimately determine which program or pesticide is likely to have a lower environmental impact. The method addresses a majority of the environmental concerns that are encountered in agricultural systems including farm workers, consumers, wildlife, health, and safety (Kovach et al., 1992). Since 2000, the EIQ has been used in several IPM projects in Asia for different purposes ranging from impact assessment to pesticide selection (FAO, 2008). Assessing the risks from the use of pesticides is important for deciding how to manage pests. When farmers receive risk information, they will become aware of the dangers and reduce the use of highly toxic pesticides. Risk assessment is useful in warning of impacts to health, environment, and food safety and is used to set guidelines for risk management by government agencies in collaboration with farmers or people in the community who are stakeholders in the area.

OBJECTIVE

To assess the risk of pesticide, use by farmers and find ways to reduce the risk from the use of pesticides in commercial fruit and vegetable grower villages in Northeast Thailand.

METHODOLOGY

Data Collection

Data was collected by using semi-structured interviews and group discussions. Representatives of a group of farmers who use pesticides were purposively selected 10 per group with a total of 19 villages. Data from farmer interviews about pesticide use, including type of substances, application rates, spraying frequency, and plot size of plantations. Data from the interviews were used to assess risk using the EIQ equation (Eq. (1)). Once risk information was obtained, it was brought to a meeting with farmer representatives, community leaders, and government officials to clarify information on risks from the use of pesticides in each community. After that, it is a matter of finding ways to reduce the risk from the use of pesticides and reduce the impact on the community and the environment together. The commercial agriculture village in Northeast Thailand was purposively selected as a study site in this research. This village has a large vegetable and fruit production in the area where farmers have continued to grow vegetables or fruit for more than 10 years as it is the main source of their income. Pesticide application data were collected by using a semi-structured interview and making observations, from January 2022 to October 2023. Data were compiled for each pesticide compound, common name, active ingredient, % active ingredient, rate of application, frequency of application, and plot size were collected from sample plots. A guideline for pesticide risk management in community agriculture was obtained from group discussions including farmer representatives, community leaders, agricultural extension officers, public health officials, and researchers.

Risk Assessment of Pesticide Used by EIQ

The EIQ value for a particular active ingredient is calculated according to a formula that includes parameters of toxicity (dermal, chronic, bird, bee, fish, and beneficial arthropod), soil half-life, systemicity, leaching potential, and plant surface half-life are considered. The formula for determining the EIQ value of individual pesticides is listed below and is the average of the farm Worker, consumer, and ecological components. EIQ Eq. (1) is provided below (Kovach et al., 1992):

$$EIQ=\{C[(DT*5)+(DT*P)]+[(C*((S+P)/2)*SY)+(L)]+[(F*R)+(D*((S+P)/2)*3)+(Z*P*3)+(B*P*5)]\}/3 \tag{1}$$

Where DT= dermal toxicity, C= chronic toxicity, SY= systemicity, F= fish toxicity, L= leaching potential, R= surface loss potential, D= bird toxicity, S= soil half-life, Z= bee toxicity, B= beneficial arthropod toxicity, P= plant surface half-life.

Field Use EIQ is calculated by multiplying the table EIQ value for a specific chemical by the Percentage of the active ingredient in the formulation and its dosage rate per hectare, as in Eq. (2).

$$\text{Field Use EIQ} = \text{EIQ value} \times \text{\% active ingredient} \times \text{Dosage rate} \tag{2}$$

The risk level according to the EIQ Field Use Rating Levels; when EIQ Field Use less than 25= very low risk, less than 50= low risk, 50-99= moderate risk, 100-199= high risk, over 200= very high risk (Cornell University, 2024).

RESULTS AND DISCUSSION

Types of Pesticides that Farmers Use in Northeast Thailand

In cabbage vegetable plots, the most used herbicides are alachlor, atrazine, clethodim, haloxyfop-P-methyl, glyphosate, oxadiazon, and triclopyr, the most common fungicides used are mancozeb and metalaxyl, whereas the most used insecticide used are abamectin, carbaryl, cyantraniliprole, cypermethrin, dinotefuran, dichlorvos, emamectin benzoate, profenofos spinetoram, and tolfenpyrad.

In chilli plots, the most used herbicides are alachlor, atrazine, mesotrione, and quizalofop-P-ethyl. The most common fungicides used are azoxystrobin, cymoxanil, carbendazim, difenoconazole, etridiazole, mancozeb, metalaxyl, prochloraz, and pyraclostobin, whereas the most common insecticide used are abamectin, amitraz, beta-cyfluthrin, carbosulfan, clothianidin, chlorantraniliprole, cypermethrin, dinotefuran, emamectin benzoate, imidacloprid, spinetoram, and tebufenpyrad.

In tomato plots, the most used herbicides are alachlor, atrazine, clethodim, mesotrione, and glyphosate. The most used fungicide is metalaxyl, mancozeb, propineb, whereas the most common insecticide used are abamectin, carbaryl, emamectin benzoate, chlorantraniliprole, cypermethrin, lambda-cyhalothrin, deltamethrin, fipronil, imidacloprid, and thiamethoxam.

In mango plots, the most used herbicides are glyphosate, the most used fungicides are azoxystrobin, captan, carbendazim mancozeb, prochloraz, and propineb, whereas the most common insecticides used are abamectin, acetamiprid, carbaryl, carbosulfan, cypermethrin, dinotefuran, emamectin benzoate, fipronil, imidacloprid, lambda-cyhalothrin, spinetoram, and thiamethoxam. In jujube plots, the most used herbicides are glyphosate, the most used fungicide are azoxystrobin, carbendazim, captan, difenoconazole, mancozeb, and propiconazole, whereas the most common insecticide used are abamectin, buprofezin, cypermethrin, dinotefuran, fipronil, lambda-cyhalothrin, imidacloprid, propargite, and pyridaben.

Risk of Pesticide Use in Terms of the EIQ Equation

The information on the type of pesticides, the amount of active ingredient spraying rate, plot area, and spraying frequency from interviews with representatives from 19 communities is used to assess risk from the EIQ equation (EIQ Field Use Rating Levels). The EIQ Field Use was as follows (Fig. 1): cabbage grower average 67.64 (moderate risk); tomatoes grower average 116.01 (High risk); chilli grower average 86.65 (moderate risk); mango grower average 55.76 (moderate risk); and jujube grower average 59.20 (moderate risk).

Guidelines for Pesticide Risk Management in Community Agriculture

From the group discussion on guidelines for reducing the risk from pesticide use in each village, there were common guidelines: 1) Personal safety, requiring regulation of the use of appropriate spraying equipment. To prevent exposure to pesticides, applicators should wear protective clothing and personal protective equipment; 2) Safety of people in the community. Do not spray pesticides in villages or communities, schools, temples, and hospitals. Spraying chemicals in areas close to the community or village must notify the village headman with a spraying plan. Areas where pesticides are sprayed must have warning signs indicating the date and time; 3) Safety for the ecosystem and public areas of the community. Do not spray chemicals, and do not leave chemical bottles in public areas, water sources, and community forests; 4) Food safety. Farmers must comply with the requirements according to GAP standards; Also, 5) Set up a community committee to control the community's use of pesticides. The committee is responsible for coordinating the correct and safe pesticide use in the community. The guidelines will be used as policy recommendations for reducing the pesticide risk in commercial agricultural communities.

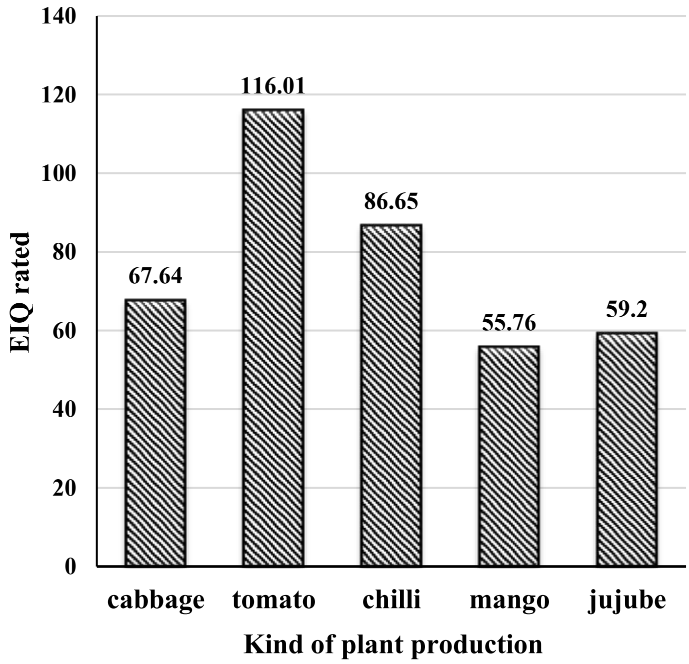

Fig. 1 EIQ Field uses rating of pesticide use in vegetable and fruit growers in the Northeast Thailand

CONCLUSION

For risk assessment from the use of pesticides using the EIQ equation, most of the information was obtained from interviews. Farmers may not yet be aware of risk reduction, so they should study other information, such as the results of testing for pesticide residues in the farmers' blood. Collection of plants, soil, and water samples for analysis. In this study, high-risk values will also be found in pesticide residues in the plants and soil of the planting plots. Analysis results are another factor that helps encourage farmers to improve their pest management methods to be more careful. Smallholders in the Northeast of Thailand, usually live within or near agricultural plots. For the guidelines for preventing the effects of pesticides used on communities and the environment, farmers must plan chemical spraying and inform those involved in the community and those living in nearby areas.

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Research article

Factors Influencing Agricultural Technology Adoptions by Vegetable Producers in Svay Rieng Province, Cambodia

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Abstract Efforts by extension workers to facilitate the adoption of climate-smart agriculture technologies are crucial. Document analysis reveals that vegetable producers adjust their production techniques based on the availability of technologies, influenced by two key determinants: Contextual Driving Factors (CDF) and Perceptual Force Factors (PFF) towards these technologies. Eight parameters were identified within CDF and eleven within PFF. This study aimed to assess the impact of these factors on technology adoption levels among 302 vegetable producers who are members of agricultural cooperatives in Svay Rieng Province. Utilizing Linear Multiple Regression analysis, this research identifies four CDFs – water shortage, resource scarcity, market competition, and water management challenges, and three PFF – result demonstration, anxiety, and perceived image, are significantly influencing the adoption of the technologies. These seven factors collectively contribute to the predictive model with an R-value of 0.612, explaining 36% of the variance in adoption levels. The findings suggest that successful technological adoption is influenced by the four CDFs, actually observed to be the external challenges, producers, and producers' positive perceptions towards these technologies. Effective extension strategies should be tailored to contextual realities, defined as CDFs, and aim to present technologies in a compelling and favorable light.

Keywords agricultural extension, farmer technology adoption, rural development

INTRODUCTION

Agricultural extension plays a vital role in improving agricultural productivity and cost-benefits for producers. Scientists, government agencies, commercial vendors, and extension workers aim to address technical shortcomings among producers by introducing various beneficial techniques and technologies (Cook et al., 2021). The primary goal is to influence behavioral changes in producers in response to production, economic, societal, and environmental challenges including sustainable development or climate changes (Cook, 2024). As reported by the Cambodian Ministry of Agriculture, Forestry, and Fisheries (MAFF) in 2019, the Ministry deployed 841 extension workers at the national, provincial, and district levels, serving 2.1 million agricultural households nationwide (MAFF, 2019). Given this widespread reach, the effectiveness and efficiency of designing extension strategies and techniques are crucial. The level of technological adoption is influenced by factors such as relative advantage, compatibility, complexity, trialability and observability, and socioeconomic factors of the households (Farquharson et al, 2013). As a result, we identified the internal and external factors relevant to technological adoption and we categorized them into two groups which we name as the contextual driving factors (CDF) and perceptual force factors (PFF). The former refers to the actual situation and challenges that vegetable producers are facing in their current situation while the latter refers to the perception-based factors which are the belief of the producers. As these factors are the drivers of technological adoption, understanding the most important factors that determine adoption by producers will be beneficial in formulating appropriate agricultural extension strategies contributing to the enhancement and maximization of adoption while minimizing efforts and ineffective strategies. This study aims to identify the relevant factors influencing producers' decisions to adopt agricultural technologies, serving as a foundational formula for the development of a more effective extension strategy for Cambodia.

OBJECTIVES

This study aims to establish the relationship between independent factors influencing the decision-making process of vegetable producers in Svay Rieng Province regarding the adoption of agricultural technologies within their region.

STUDY FRAMEWORK

The Farmer Technology Adoption Model (FTAM) emphasizes external variables as initiating factors that influence producers' perceptions, ultimately shaping their decisions to accept technologies, and leading to their actual application (Amin and Li, 2014). There are challenges in adopting available technologies that producers have been facing. The first group of factors were categorized as Contextual Driving Factors (CDF), directly attributable to their actual resources and challenges being faced. The description of the factors is provided in Table 1.

METHODOLOGY

Site and Sample

Svay Rieng province is located in the southeast part of Cambodia. According to the Provincial Department of Agriculture, Forestry, and Fisheries (PDAFF), 87% of the province’s population of 667,260 individuals live in rural settings with 68.5% of the population involved in agricultural production (PDAFF, 2020). In 2018, the province reported a land area for vegetable production of 1,760 hectares, generating 18,480 tons of vegetables per year, equivalent to 33% of the total demand in the province (SAAMBAT Project, 2020). The province is home to 86 agricultural cooperatives (ACs) of which 9 ACs are involved in vegetable production with a total membership of 933 households. These ACs actively produce and supply vegetables, to provincial and national markets, leveraging the benefits gained through the cooperative. Since the study focuses on vegetable producers who are members of the AC only, the members of the 9 ACs were selected for the study. To determine the sample of vegetable producers in the province, Cochran's formula was used to calculate the sample size with a margin error of 5%, a confidence level of 95%, and a response rate of 50%, resulting in a total sample of 273 individuals. The final population sample was 302 in which

92% were male gender, the majority were older than 45 years of age, and more than half completed primary school (Table 2).

Table 1 The study's variables

Independent variables	Definition / Description
AFF: Actual force factors	
AFF1: Lack of resources	Lack of resources includes a lack of capital for investment and labor forces that hinder producers' ability to expand production and invest in new technologies (Chuong, 2019)
AFF2: Water management challenges	The factor refers to the challenges that producers have excess water during the wet season while insufficient water during the dry season (Chhun et.al., 2021).
AFF3: Water shortage	This factor is critical to preventing producers from expanding production, either due to high expenses or unavailable water in certain areas (Chuong, 2019)
AFF4: Market prices	The low selling price of their products, resulting in minimal or no benefits due to market fluctuations discourages producers from continuing or expanding their production (Chuong, 2019; Muhammad, 2020).
AFF5: Pest and diseases	This is another significant concern, causing producers to hesitate in maximizing their production (Chuong, 2019).
AFF6: Competition	This factor refrains producers from expanding their production as the market is being competed by neighboring countries (Chhun et.al., 2021).
AFF7: High input cost	High input costs are an emerging barrier, preventing producers from experimenting with new technologies (Bhushan and Reddy, 2020).
AFF8: Poor quality inputs	This factor makes farmers concerned about low-quality inputs which can lead to poor results (Bhushan and Reddy, 2020).
PPF: Perceptual force factors	
PFF1: Job relevance	When producers have learned about new technologies, they assess the level of their relevance to their actual situation, called perceived relevance (Venkatesh and Davis, 2000).
PFF2: Output quality	Then, the quality of the product resulting from technology application is another factor driving their acceptance (Venkatesh and Davis, 2000).
PFF3: Result demonstration	The importance of tangible high-quality products (PFF3) (Venkatesh and Davis, 2000).
PFF4: Image	The potential positive image that producers expect from the result of the adoption is essential (Venkatesh and Davis, 2000).
PFF5: Perception of external control	This factor refers to the relationship that producers have with individuals who have technical expertise they are able to seek support, creating an expectation of successful technology application (Amin and Li, 2014).
PFF6: Self-efficacy	Another factor is the producers' personal level of knowledge adequacy regarding the technical knowledge of technology (Amin and Li, 2014).
PFF7: Innovation	This factor refers to producers' level of capability in innovating while adopting technologies to their specific situations (PFF7) (Amin and Li, 2014).
PFF8: Perceived enjoyment	Ease of use, in which producers feel that they can use the technologies joyfully is another driver of adoption (Venkatesh and Bala, 2008).
PFF9: Objective usability	The actual results from the adoption which can be transformed to be a benefit is another factor as well (Venkatesh and Bala, 2008).
PFF10: Anxiety	At the time of adoption, producers feel nervous regarding the technologies which can hinder producers from advancing to the next stage of application (Venkatesh and Bala, 2008).
PFF11: Subjective norm	This factor refers to the result from adoption that can be negatively influenced by social effects, impacting technology adoption positively (Venkatesh and Bala, 2008)
DVALL: Dependent variables	
DV1: Agricultural technology adoption	Referring to the level of adopting agricultural technologies including smart climate agricultural technologies and general technologies which are promoted for enhancing agricultural production of producers
DV2: Managerial and marketing knowledge adoption	Another type of technology is the managerial and marketing knowledge that producers are expecting to adopt to improve their production.

Construction of Survey Questionnaire

The construction of the items in the questionnaire followed the identified parameters in Table 1. The Likert Scale is revised for the intended questions. After completion of the questionnaire, validity, and reliability checking were conducted. First, it was sent to three agricultural extension experts in the rural development field to confirm the validity of the tool for revising. The revision was conducted until the questionnaire reached the level of satisfaction from the experts that they are valid as per the study objectives and contextual situation of vegetable producers in the province. Then, questionnaire testing was conducted with 36 households who are vegetable producers and members of the ACs to determine the reliability of the questionnaire. The result of the reliability calculation using Cronbach's Alpha was 0.795 which is acceptable to deploy for actual data collection.

Table 2 Profiles of respondents (*n=302*)

No	Variables		Frequency	%
1	Sex of household head			
		Male	279	92%
		Female	23	8%
2	Age of household head			
		< 31	6	2%
		31 - <45	44	15%
		45 - 60	162	54%
		> 60	90	30%
3	Education of household head (the % total = 93%)			
		Primary school or below	171	57%
		Secondary school	89	29%
		High school	18	6%
		Beyond high school	3	1%

Data Collection

The collection of data was conducted between May and August 2023, using a paper-based questionnaire by a group of four trained fourth-year students, who used the data as their study requirement. Each vegetable producer was requested to agree and sign before participating in the survey. The rejecting producers were recorded in the list to seek a replacement. Then, the questionnaires collected were entered into Excel and kept confidential by the research team.

Data Analysis

Analysis of the processed data includes descriptive statistics such as frequency, percentage, means, mode, and standard deviation to measure the tendency and variability of the observations in the data set. Pearson Product Moment Correlation was used to determine the correlation between independent and independent variables, and between independent and dependent variables, measuring the relationship between the influencing factors and technological adoption of producers through the calculation of multiple correlations. Lastly, Multiple Regression Analysis was conducted to remove a number of unnecessary factors through Stepwise Multiple Regression Analysis. The adoption level was interpreted into three key categories either in positive or negative adoption as per the absolute value: low (0.00-0.33), medium (0.34-0.66), and high (0.67-1.00).

RESULTS

Variable Reduction and Profile

Each variable can be covered by more than one question. In this regard, compiling those questions into the specific factors was conducted to obtain the final response to the questions. The result from the survey indicated that independent variables generally fell at medium and higher levels, except competition and poor-quality output which fell below the average. The result contrasts with dependent variables which fell into a below-average level indicating the level of adoption is quite low (Table 4).

Table 4 Profile of the study's variables (*n=302*)

Independent variable					
AFF	Means	SD	PFF	Means	SD
AFF1	3.06	0.68	PFF1	3.70	0.53
AFF2	3.53	0.81	PFF2	3.61	0.62
AFF3	3.09	0.99	PFF3	3.71	0.60
AFF4	3.19	0.80	PFF4	3.42	0.60
AFF5	3.42	0.84	PFF5	3.26	0.62
AFF6	2.91	0.68	PFF6	3.21	0.59
AFF7	3.11	0.78	PFF7	3.18	0.66
AFF8	2.71	0.66	PFF8	3.42	0.53
Dependent variables			PFF9	3.42	0.70
DV1	2.26	0.65	PFF10	3.27	0.69
DV2	2.32	0.68	PFF11	3.40	0.58
DVALL	2.32	0.68			

Correlation Analysis

To understand the relationship between the independent variable and dependent variable, Pearson Products' Moment Correlation r was used. The tests of the bivariate correlations indicated the relationship of testing of predictors themselves, predictors, and dependent variables.

Table 5 Correlation among all parameters within the study framework

Variables	AFF1	AFF2	AFF3	AFF4	AFF5	AFF6	AFF7	AFF8	DV1	DV2	DVAll
AFF1	1	.282**	.236**	.220**	.359**	.127*	.315**	.101	.051	.253**	.139*
AFF2		1	.332**	.177**	.413**	.175**	.200**	.162**	.108	.068	.107
AFF3			1	.407**	.337**	.394**	.048	.193**	-.299**	-.222**	-.310**
AFF4				1	.321**	.344**	.230**	.298**	-.179**	-.004	-.135*
AFF5					1	.253**	.380**	.174**	-.090	.004	-.065
AFF6						1	.131*	.292**	-.251**	-.193**	-.263**
AFF7							1	.234**	.016	.221**	.100
AFF8								1	-.158**	-.084	-.151**
DV1									1	.496**	.939**
DV2										1	.765**
DVAll											1

Variables	PFF1	PFF2	PFF3	PFF4	PFF5	PFF6	PFF7	PFF8	PFF9	PFF10	PFF11	DV1	DV2	DVAll
AFF1	-.116*	.014	.041	-.048	-.181**	-.129*	-.154**	-.121*	.063	.039	-.208**	.051	.253**	.139*
AFF2	.054	.132*	.088	-.012	.030	.023	-.007	.057	-.004	-.002	.058	.108	.068	.107
AFF3	.027	-.132*	-.152**	-.085	.097	-.090	.010	-.010	-.195**	.153**	-.004	-.299**	-.222**	-.310**
AFF4	.015	-.080	-.132*	-.115*	.062	-.045	-.026	.015	-.163**	.127*	-.042	-.179**	-.004	-.135*
AFF5	-.010	-.028	-.099	-.088	-.015	-.046	-.077	-.072	-.043	-.002	-.085	-.090	.004	-.065
AFF6	-.006	-.058	-.119*	-.047	.047	-.008	.022	.035	-.156**	-.017	-.016	-.251**	-.193**	-.263**
AFF7	-.174**	.052	-.004	.014	-.036	-.017	-.031	.006	.041	.022	-.047	.016	.221**	.100
AFF8	-.057	-.009	-.092	.052	.141*	.042	.054	.052	-.056	.055	.100	-.158**	-.084	-.151**
PFF1	1	.500**	.464**	.404**	.448**	.338**	.340**	.441**	.194**	.181**	.427**	.270**	.020	.208**
PFF2		1	.640**	.480**	.381**	.434**	.347**	.481**	.406**	.216**	.389**	.325**	.273**	.349**
PFF3			1	.539**	.291**	.426**	.237**	.446**	.421**	.178**	.345**	.394**	.385**	.445**
PFF4				1	.337**	.528**	.391**	.436**	.449**	.235**	.437**	.248**	.223**	.272**
PFF5					1	.409**	.353**	.441**	.171**	.350**	.487**	.030	-.137*	-.032
PFF6						1	.499**	.542**	.425**	.302**	.532**	.129*	.104	.137*
PFF7							1	.516**	.343**	.241**	.487**	.041	-.047	.012
PFF8								1	.462**	.335**	.593**	.117*	.096	.125*
PFF9									1	.319**	.473**	.137*	.256**	.203**
PFF10										1	.462**	-.148**	-.099	-.149**
PFF11											1	.058	-.027	.032
DV1												1	.496**	.939**
DV2													1	.765**
DVAll														1

*Notes: *p-value is below 0.05 and **p-value are below 0.01*

The statistics show that all of the factors except, six variables: AFF2, AFF7, AFF8, PFF5, PFF7, and PFF11, are significantly associated with the dependent variable. In addition, the correlation testing within the independent variables shows that cross-component (the AFF and PFF) variables are generally not statistically associated.

Analysis of the Variances for the Multiple Regression Analysis

The analytical results of the 19 predictors whether they can influence the agricultural technology adoption of vegetable producers indicated that the predictors could estimate the level of technological adoption of vegetable producers in Svay Reing Province.

Table 6 One-way ANOVA of the multiple regression analysis of the 19 variables predicting the level of technological adoption (*n =302*)

Source of Variation	df	SS	MS	F
Regression	19	56.434	2.970	10.119*
Residual	282	82.778	0.294	
Total	301	139.213		

*Notes: * = Significance, α = 0.05*

Analysis of Variance for the Stepwise Multiple Analysis

As the 19 variables contain the variables with limited association with the level of technology adoption, further analysis using stepwise multiple regression is conducted to determine the most appropriate predictors for technology extension. The results of the analysis are shown in Table 7.

Table 7 One-Way ANOVA of the multiple regression stepwise analysis of the 19 variables predicting the level of technological adoption (*n =302*)

Source of Variation	df	SS	MS	F
Regression	7	52.114	7.445	25.130*
Residual	294	87.098	0.296	
Total	301	139.213		

*Notes: * = Significance, α = 0.05*

Table 8 The parameters of the estimate equation of the level of technological adoption of vegetable producers in Svay Rieng province (*n = 302*)

Estimators	b	$SE._b$	β	t	β's Order
Constant	1.163	.316		3.677*	1
PFF3	.387	.064	.343	6.065*	2
AFF3	-.160	.038	-.234	-4.255*	3
PFF10	-.208	.048	-.212	-4.362*	4
AFF1	.179	.049	.178	3.635*	5
AFF6	-.175	.051	-.174	-3.450*	6
AFF2	.114	.043	.136	2.664*	7
PFF4	.135	.063	.119	2.138*	8
R =	0.612	F =	4.571*		
R^2 =	0.374	a =	0.156		
$SE._{est}$ =		± 0.544			

*Notes: * = Significance, p-value = 0.05*

Estimators of the Estimation Equation

From Table 8, the analytical results show that seven predictors significantly influence the level of technology adoption by producers in Svay Reing province at a 0.05 significant level. The prediction order of the predictors is PFF3, AFF3, PFF10, AFF1, AFF6, AFF2, and PFF4 at 0.05 significant level. The multiple regression strength as a whole is 0.612, and it can be stated that the level of technological adoption of vegetable producers in Svay Rieng province can be described by the seven predictors of 37.4 percent with the standard error of estimate of ±0.544. The Y intercepts of the unstandardized estimation equation which is 1.163.

DISCUSSION AND CONCLUSION

The study results indicate that vegetable producers are more likely to adopt technologies when they observe tangible results from specific demonstrations. However, the successful adoption of these technologies is contingent upon the availability of water for vegetable production. It is crucial to manage anxiety levels among producers by addressing concerns associated with technology adoption. This is reflected in the accessibility of resources for financial and labor investment, emphasizing the pivotal role of resource availability. Introducing technology effectively requires providing support and confirming that producers have sufficient manpower for trial implementation. Acknowledging that competition poses a barrier leading to hesitancy among producers to adopt technologies is important. Additionally, water management becomes a significant factor due to the highly fluctuating availability of water, necessitating effective management. The social image derived from technology adoption is crucial for producers who aim to showcase that they are knowledgeable and progressive regarding their adoption of technology.

RECOMMENDATIONS

In this context, it is recommended that extension workers tailor demonstrations to align with producers' available resources and ensure adequate water for production to facilitate technology adoption. Moreover, extension agencies can only promote technology in locations with sufficient water and water management capacity. At this juncture, agricultural extension strategies should prioritize providing adequate infrastructure to producers before investing in operations that may be inoperable. Addressing producers' anxiety requires constant monitoring and support to reassure them of the benefits at the trial's conclusion. This is essential for a smooth and warm application, ensuring the product's marketability and profitability. Therefore, introducing an appealing technology that enables producers to demonstrate and share their achievements with neighbors is vital.

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Research article

Influence of Copper and Cadmium Soil Pollution in Soybeans: Uptake, Growth, and Yield Pollution

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Abstract Food produced on polluted farmland often damages human health. Studying the various mechanisms through which agricultural products are polluted is crucial. This study investigated the influence of combined copper (Cu) and cadmium (Cd) soil pollution on soybeans and the Cu and Cd uptake and resultant soybean growth and yield. Our models comprised a layer of 14 cm gravel at the bottom of plastic containers, a layer of 20 cm non-polluted soil on top, and another layer of 20 cm polluted soil on the top. Eight soybean plants were cultivated for each model. Here, we used a cadmium-polluted soil sample (approximately 1.81 mg kg^{-1}) taken from a paddy field. We maintained the Cu concentration in the soil at 100 mg kg^{-1}, 250 mg kg^{-1}, and 400 mg kg^{-1}. The soybeans were seeded in early June and harvested in early October. Cd concentrations in soybean seeds in three different models were 0.48 mg kg^{-1}, 0.53 mg kg^{-1}, and 1.30 mg kg^{-1}, respectively, while the Cu concentrations in soybean seeds in the three models were 10.53 mg kg^{-1}, 15.40 mg kg^{-1}, and 20.18 mg kg^{-1} respectively. The levels of Cu and Cd pollution in the plants were highest in roots, medial in stems, and lowest in seeds. The growth and yield of soybeans were lower in models with a soil Cu concentration of 400 mg kg^{-1} compared to models with a soil Cu concentration of 100 mg kg^{-1}. The models with soil Cu concentration at 400 mg kg^{-1} yielded only three stumps. Thus, we conclude that changes in Cu concentration in soil polluted with both Cd and Cu have a considerable negative influence on the growth and yield of soybean plants.

Keywords soil pollution, Cadmium, rice, Copper, soybean

INTRODUCTION

It has been argued that soil pollution by heavy metals results in damage to human health. Several studies describing mitigation techniques have been reported (e.g. Toikawa et al., 2020). Specific to select heavy metals, Itai-Itai disease is widely known to damage human health as caused by cadmium (Cd) pollution of soil and water (Kobayashi, 1978). Most studies related to Cd pollution mention the oral ingestion of rice but rarely refer to ingestion of soybeans. Recently, it has been recognized that Cd is easily absorbed by soybeans (MAFF, 2006), and the amount of Cd uptake after soybean ingestion is similar to that of ingesting polluted rice (Hasegawa, 2013). Therefore, people in countries such as Japan who consume large amounts of soybeans are concerned about the damaging impact of Cd on their health.

To address this problem, Haque et al. (2014) and Li et al. (2017) attempted to minimize soybean Cd uptake by regulating the groundwater levels of these heavy metals in their fields. In Japan, copper (Cu), Cd, and arsenic (As) have been identified as toxic substances in agricultural land. However, most studies on soil pollution by these heavy metals have been conducted on rice and rarely on soybeans.

The Bordeaux mixture, a mixture of copper sulfate and calcium carbonate, has been used for a long time in apple orchards in Japan, and severe Cu accumulation on soil surfaces has been reported by Aoyama (2009). The Cu concentration in the soil of some apple orchards in Aomori Prefecture was higher than 500 mg kg^{-1} dry soil, whereas the paddy field soil criterion was 125 mg kg^{-1} dry soil in Japan (Yamane et al., 1997). Therefore, there is a concern about excess Cu accumulation in the soils of paddy fields around apple orchards. Fan et al. (2018) mentioned the possibility that some apple orchards in the lowlands that were once converted from paddy fields might have been restored to paddy fields.

Recently, soybeans have become a major crop for upland fields converted from paddy fields; therefore, Cu and Cd concentrations in soybeans are a major concern for consumers. Cd standards for soybeans have not yet been established. Haque et al. (2014) and Li et al. (2017) planted soybeans in Cd-polluted paddy soils and examined the growth, yield, and Cd concentrations in the plants. However, no study has examined the effects of the combination of Cd and Cu pollution in soil on soybeans.

OBJECTIVE

The aims of this study were to clarify the effects of combined pollution of Cd and Cu in farmland on the growth and yield of soybeans and to measure the concentrations of those heavy metals in them.

METHODOLOGY

Soil Properties and Experimental Design

In this study, we used polluted soil samples collected from Eastern Japan (where the location is secret) and non-polluted soil samples from the Kanagi Farm of Hirosaki University, Aomori Prefecture. Those two soils were collected from those two sites following the practice by Toikawa et al. (2020). The polluted and non-polluted soils were placed in plastic containers (41 cm × 61 cm × 63 cm). In addition, gravel (particle size 2–4 mm) was filled up to 14 cm from the bottom of the containers to maintain uniform drainage. Cu and Cd concentrations in Kanagi soil were 3.70 mg kg^{-1} and 0.14 mg kg^{-1}, respectively. However, Cu and Cd concentrations in the polluted soil were 12.2 mg kg^{-1} and 1.81 mg kg^{-1}, respectively. The organic matter content was 3.6% in the Kanagi soil and 5.1% in the polluted soil.

The Cd concentration levels in the two types of soils were left as they were at the time of soil sampling, whereas the Cu concentration levels were changed to three levels by adding copper chloride ($CuCl_2.2H_2O$) to them: 100 mg kg^{-1}, which is the standard in non-polluted soil of paddy fields; 250 mg kg^{-1}, which is approximately twice the standard; and 400 mg kg^{-1}, which is approximately four times the standard. We called the three different models with three different Cu concentration levels, 100 mg kg^{-1}, 250 mg kg^{-1}, and 400 mg kg^{-1}, M-①、M-② and M-③, respectively. The thicknesses of the two kinds of soil layers which were exact copies of a polluted field on-site were: the polluted soil layer (density: approximately 0.80 mg kg^{-1}) of 0-20 cm and the non-polluted soil (density: 0.89 mg kg^{-1}) of 20-40 cm.

A self-recording temperature sensor and an electrode for measuring the redox potential (Eh, Central Science Co., Ltd. UC-203) were inserted into the side walls of the containers to measure the soil temperature and Eh. The groundwater level was set to 40 cm by using Mariotte bottle, which has been reported to maximize soybean yield (Arihara, 2000).

Cultivation and Measurement Procedure

Soybeans were sown at four different places in plastic containers with five to six grains each. The soybean variety used in the experiment was Ryuhou (*Glycin Max* (L.) Merr. cv. Ryuhou). The prefecture in this area recommends the cultivation of it. Soybean seeding was performed on May 31, 2019, and June 1, 2020. Approximately two weeks after sowing, thinning was performed to leave two plants of average growth. Fertilizer recommended for Ryuhou was applied to soybean plants in a generally approved amount (Li et al. 2017). Water (2 L) was supplied to the soybeans every four days. Pest control was conducted as required. The experiments were conducted in a greenhouse at the Faculty of Agriculture and Life Sciences, Hirosaki University, Japan. The average daily temperature in the house ranged from 20 to 30 degrees.

A survey of soybean growth and yield (plant height, leaf age, number of nodes, number of pods, and weight of 100 beans) was conducted based on the survey standards of Kodama et al., 2004. We measured the Cu and Cd concentrations in the beans, stems, and roots. Analyses of these concentrations were performed using atomic absorption spectroscopy after extraction with HCI and HNO_3 (MAFF, 1979). These data were tested for significance using the Tukey-Kramer method.

RESULTS AND DISCUSSION

Oxidation-reduction Potential

The redox potential (Eh) values were in the range of 300–400 mV in models M-① and M-③ as shown in Figs.1 and 2. Moreover, the redox potential of M-② became the same range as M-①. The presence of Cd and Cu is affected by the redox state of the soil (Matsunaka, 2014). Thus, it was inferred that the polluted soil layers in all three models were in an oxidized state and that soluble Cd and Cu were absorbed by soybeans.

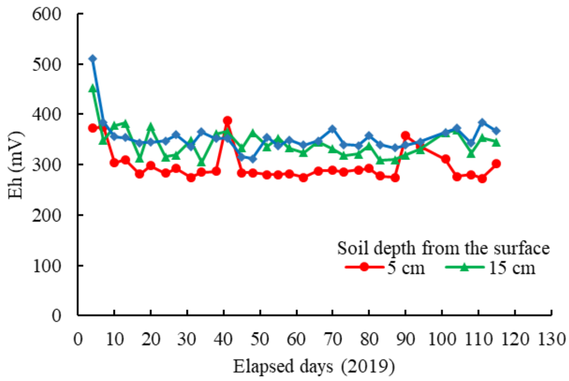

Fig. 1 Temporal change of Eh value with M-①

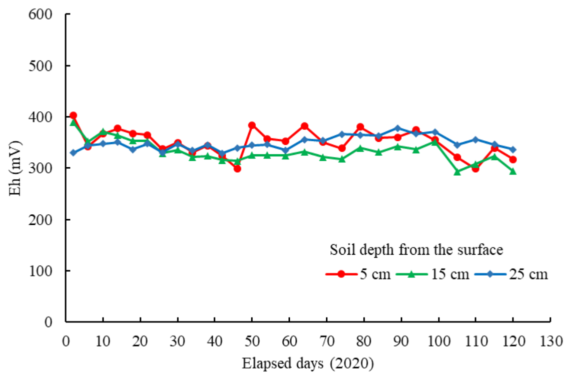

Fig. 2 Temporal change of Eh value with M-③

Cd and Cu Concentrations in Soybean Plants

Table 1below shows the Cd and Cu concentrations in the plants.

Table 1 Cd and Cu concentration in soybean plants in the three different models

Model	Seed-Cd*	Stem-Cd*	Root-Cd*	Seed-Cu*	Stem-Cu*	Root-Cu*
M-①	0.48±0.05^{a}	1.07±0.07^{a}	2.55±0.17^{a}	10.53±0.48^{b}	5.63±0.97^{b}	81.16±18.66^{b}
M-②	0.53±0.19^{a}	2.77±0.70^{a}	3.83±1.07^{a}	15.40±2.43^{ab}	21.78±7.10^{a}	365.60±43.68^{a}
M-③	1.30±0.73^{a}	7.40±5.76^{a}	29.23±26.43^{a}	20.18±0.62^{a}	21.87±12.10^{a}	374.27±140.93^{a}

*Notes: The two kinds of superscripts 'a' and 'b' indicates a statistically significant difference at a 5% level according to the Turkey-Kramer test; ± shows standard deviation. In all cases, three samples were used. * mg kg^{-1}*

(i) Cd concentration: Cd concentrations in soybean seeds were M-① (0.48 mg kg^{-1}) < M-② (0.53 mg kg^{-1}) < M-③ (1.30 mg kg^{-1}). However, these data varied so widely that there were no significant differences. The value of M-① (0.48 mg kg^{-1}) was less than half of the value (1.07 mg kg^{-1}) that Li et al. (2017) had reported by conducting a similar experiment. As the Cd concentrations in the sample soils used in the two experiments were almost the same, the difference in the Cd concentrations in seeds between the two experiments are most likely to have resulted from different Cu concentrations in the soil samples used in the two experiments. That is, the Cu concentration in the soil sample was 43.3 mg kg^{-1} in the experiment conducted by Li et al. (2017), which is less than half that (100 mg kg^{-1}) in our experiment. The Cd concentration we found in seeds in our experiment, 0.48 mg kg^{-1}, was well over four times of 0.11 mg kg^{-1}, which the Japanese Ministry of Agriculture, Forestry and Fisheries (2024) specifies as the mean Cd concentration in soybean seeds cultivated in non-polluted soils. The Cd concentration in the polluted soil sample in our experiment was 1.81 mg kg^{-1}, which was approximately five times higher than that in the non-polluted upland soil (0.373 mg kg^{-1}) reported by Asami (2010).

The Cd concentrations in soybean seeds and soils were positively correlated. Additionally, the Cd concentrations obtained in our experiment did not satisfy the standard value of 0.1 mg kg^{-1} set by the Codex Alimentarius Commission (MAFF, 2023).

Cd concentrations in stems were M-① (1.07 mg kg^{-1}) < M-② (2.77 mg kg^{-1}) < M-③ (7.40 mg kg^{-1}), which were similar to those in seeds, and they demonstrated no significant difference between them, compared to the Cd concentration in seeds. The Cd values in the stems in the experiment by Li et al. (2017) had been 1.48 mg kg^{-1}, whereas in our experiment they were much higher than in both our M-② and M-③. This difference can be attributed to the higher Cu concentrations in the soil, especially of the M-③, in which the Cu concentration was 400 mg kg^{-1}; a remarkable increase in Cd concentration was observed there.

Cd concentrations in the roots followed the same order as Cd concentrations in the seeds and stems, showing no significant differences among the three models. In M-③ Cd concentrations in seeds, stems and roots were far higher than those in the M-① and M-②. This difference was thought to have resulted from the fact that the Cu concentrations in M-③ soils were much higher than in the cases of the M-① and M-②, which may have affected the amount of Cd uptake from the roots.
The trend in Cd concentration in the soybean plants were as follows: seeds < stems < roots. In all three models, the same results were obtained by Haque et al. (2014) and Li et al. (2017). Toikawa et al. (2020), who experimented with paddy rice, reported that higher Cu concentrations in the soil caused lower Cd concentrations in brown rice. However, in the case of soybeans, we did not observe such a result.

(ii) Cu concentration: The Cu concentration in soybean seeds ranged in all three models from 10 mg kg^{-1} to 20 mg kg^{-1} and was in the order M-① (10.5 mg kg^{-1}) < M-② (15.4 mg kg^{-1})< M-③ (20.2 mg kg^{-1}), suggesting a positive correlation between the Cu concentrations in soybean seeds and soils, and there was a significant difference ($p<0.05$) between the M-① and M-③. In addition, Cu concentration in seeds in the M-① was almost the same as that found by Li et al. (2017), 9.96 mg kg^{-1}.

The Cu concentration in stems was 5.63 mg kg^{-1} in M-①, while those in M-② and M-③ were 21.8 mg kg^{-1} and 21.9 mg kg^{-1}, respectively. There was a significant difference between M-① and the other two models ($p<0.05$). The Cu concentration in roots was 81.2 mg kg^{-1} in M-① while those in M-② and M-③ were 365.6 mg kg^{-1} and 374.3 mg kg^{-1}, respectively. There was a significant difference between M-① and the others ($p<0.05$). The above-mentioned Cu concentrations were approximately 6 times in the case of M-① and 26 times in the case of M-② and M-③, greater than that found by Li et al. (2017), which was 14.11 mg kg^{-1}, suggesting an unusual Cu uptake mechanism in soybean plants that should be studied further.

The levels of Cu pollution in M-① were highest in roots, medial in seeds, and lowest in stems, while they were highest in roots, medial in stems, and lowest in seeds in both M-② and M-③, which was the same order as the Cd concentration in them. The Cu concentration distribution in soybean plants in M-② and M-③ was different from those reported by Haque et al. (2014) and Li et al. (2017), which may suggest a possible effect of higher Cu concentration in soil in our experiment on Cu transfer in the plant. Therefore, the threshold Cu concentration in the soil for the transfer process should be further studied.

In Japan, there is no regulatory value for Cu concentration in soybeans, while in China it is no more than 20 mg kg^{-1} (Li et al., 2017). The Cu concentration in seeds in our M-③, 20.18 mg kg^{-1}, does not satisfy that regulation value.

Soybean Yield and its Components

Table 2 lists the soybean yield and its components. In M-③, the number of stumps whose soybean grains reached the harvest was three out of eight. For the sake of comparison, we experimented with another model which was under the same experimental conditions as in this study but in which Cu concentration in the polluted soil was 500 mg kg^{-1}; the results demonstrated that the number of stumps whose soybean grains reached the harvest was zero.

Based on these results, the number of stumps for statistical analysis was set to three. The main stem length, the number of main stem nodes, and the stem diameter were significantly decreased in M-③ compared with the other two models. The M-③ stem thickness was approximately 50% compared to the other two models. This may have resulted from the possibility that Cu concentration became over 400 mg kg^{-1} during the growing stage.

Table 2 Soybean yield components of the three different models

Model	Stem height (cm)	Stem diameter (mm)	Node No.	Seed/Pod	100 seed wt. (g)	Good seed No. (g)
M-①	73.3 ± 2^{-1a}	12.0 ± 0.8^{a}	16.7 ± 0.6^{a}	1.8 ± 0^{-1a}	32.2 ± 1^{-1a}	197.7 ± 16.0^{a}
M-②	87.7 ± 7.2^{a}	11.9 ± 2.0^{a}	18.0 ± 0.0^{a}	1.4 ± 0^{-1b}	25.3 ± 8.8^{a}	86.7 ± 96.7^{a}
M-③	52.0 ± 7.0^{b}	6.1 ± 3.2^{b}	14.0 ± 1.0^{b}	1.5 ± 0^{-1b}	28.4 ± 4.9^{a}	72.0 ± 81.6^{a}

*Notes: The two kinds of superscripts 'a' and 'b' indicates a statistically significant difference at a 5% level according to the Turkey-Kramer test; ± shows standard deviation. In all cases, three samples were used. * mg kg^{-1}*

The number of seeds in a pod in M-① was significantly more than those in both M-② and M-③. The magnitude relationship between the number of good seeds and the weight of 100 seeds was M-③ < M-①; however, no significant difference was confirmed among the three models. This is perhaps due to considerable variations in the measured values. Compared to the results of Li et al. (2017), the stem height, stem diameter, number of soybean seeds per pod, and weight of 100 seeds tended to be lower. Thus, it can be concluded that an increase in the Cu concentration in the soil has an undeniable effect on growth and yield. However, further studies are required to confirm these findings.

CONCLUSION

The Cu concentration has a significant influence on the growth and yield of soybeans. An increase in Cu concentration in the soil of combined pollution has a significant influence on soybean growth and yield, as well as on Cd and Cu concentrations in soybean plants.

Through our research, we learned that introducing soil dressing can be very effective in alleviating Cu pollution in soil. It is not soybean plants alone, but many other plants are potentially polluted by Cu in soil. Therefore, it is important for us to extend our research to those other plants as well.

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Research article

Prospects of Nutmeg Industry Development in North Maluku, Indonesia

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Abstract This study describes the nutmeg industry in North Maluku Province, Indonesia, and includes definition of its current state and potential development opportunities. Primary data was collected in April 2019 and in September 2023, through interview surveys of local government officials and farmer groups in the Ternate Regency, North Maluku Province. The results demonstrate that 1) The nutmeg industry is deeply rooted in its long history and the farmers' strong connections to local wisdom and culture which are more highly valued than typical economic drivers, 2) the high market demand for nutmeg products offers promising prospects for the development of the nutmeg industry should the local industry wish to move in that direction, 3) the existence of genetically diverse natural resources of North Maluku nutmeg strengthen position of the industry for future development, and 4) more modern and scalable production and distribution systems are mandatory for the future development of the nutmeg industry and to support it becoming a sustainable and leading industry in the province.

Keywords nutmeg products, spice island, local culture, rural development

INTRODUCTION

Nutmeg fruits in Indonesia are processed into many types of products, including nutmeg spices, sweets, and oil. Generally, nutmeg seeds and mace are used for spices and oil, while nutmeg flesh is processed into food and beverage products, including sweets, syrup, and juice. The Indonesian nutmeg industry grew rapidly between 2010 and 2019 with an average year over year growth of approximately 9.5 percent. Indonesia produced 40,653 tons of raw nutmeg fruits in 2019, (Pakpahan et.al., 2020). Indonesia now meets more than 66 percent of the total global market demand (Sukarman, 2021) and is currently the largest producer of nutmeg oil in the world, meeting 75% to 80% of the global demand (Van Aroma, 2023).

North Maluku is one of the primary nutmeg - producing regions in Indonesia with a total cultivated area of 35,419 hectares which contributes 24.22% of the total national production. Nutmeg production in North Maluku is centered on three main islands of the province, namely Halmahera, Ternate, and Tidore islands. Farmers in North Maluku mainly produce nutmeg fruits and process those raw materials into nutmeg spices. Farmers usually sell nutmeg spices in two types of products, i.e. dried nutmeg seeds and dried mace. Despite its potential natural resources, the nutmeg industry in North Maluku is not fully developed and the nutmeg distribution system has not been well-established. Farmers have limited access to the market which most of them sell nutmeg spices to rural assemblers without proper sales regulations. Hence, nutmeg commodities from North Maluku currently face two main issues, namely unstable quality control and unclear traceability (Sulistiono et al., 2022). Regardless of its potential development, information on the current state of nutmeg industry in North Maluku is still very limited.

OBJECTIVE

This study aims to describe the nutmeg industry in North Maluku Province, Indonesia, including definition of current state and its strengths, weaknesses, threats, and opportunities related to potential development of nutmeg industry in the province.

METHODOLOGY

Primary data was collected through sequential interview surveys of government officials from the Assessment Institute of Agricultural Technology (AIAT) of North Maluku Province representing the central government, officials from the Ternate City Agriculture Agency representing the local government, extension workers, and three farmer groups from Ternate City, North Maluku Province, Indonesia. The first interview survey was conducted using a semi-constructed questionnaire in April 2019 and sought to clarify the characteristics of nutmeg industry in North Maluku Province. The second survey was delayed due to the COVID-19 pandemic and was completed in September 2023 by conducting focus group discussion with government officials and leaders of the same three farmer groups visited during the first survey. This survey was mainly focused on collecting data on the current state of nutmeg production and distribution system in North Maluku, specifically questioning problems and challenges faced by local farmers. A SWOT analysis is applied to analyze the prospects of nutmeg industry development in North Maluku, specifically from farmers' perspectives, based on qualitative data collected during both interviews. SWOT stands for **S**trengths, **W**eaknesses, **O**pportunities, and **T**hreats (Peterdy, 2023).

RESULTS

Characteristics of Nutmeg Production in North Maluku

Nutmeg cultivation in North Maluku is mainly conducted by family farmers in mixed-cropping home gardens or agroforestry lands where they combine nutmeg with other crops such as clove, coconut, cacao, and other horticulture crops (i.e. vegetables, fruits, and medicinal plants). Currently, there are 1,893 family farmers in Ternate Regency with a total production area of 1,975 hectares (North Maluku Provincial Agriculture Agency, 2023). Table 1 shows production of fresh nutmeg fruits by area in 2021.

Table 1 Production of nutmeg fruits in North Maluku by regency/municipality (2021)

Regency / Municipality	Production (ton)	Productivity (kg/ha)
West Halmahera	653	560
Central Halmahera	1,831	435
Sula Islands	89	220
South Halmahera	608	418
North Halmahera	1,852	560
East Halmahera	184	123
Morotai Island	102	278
Taliabu Island	104	377
Ternate	326	324
Tidore Kepulauan	314	400
North Maluku	6,062	419

Source: Ministry of Agriculture Directorate General of Estates (2023)

Moreover, nutmeg cultivation in North Maluku is strongly connected to the local wisdom and culture that passed through generations, tracing back to the long historical background where tradition of nutmeg production in the community has begun since the 14th century. Hence, for years land management has still continued to be conducted in community-based system where farmers share knowledge and use tools collectively as communal property (Sidayat and Fatmawati, 2019).

Meanwhile, nutmeg processing in North Maluku is focused on spices production. As mentioned in above Introduction, generally nutmeg fruits in Indonesia are processed into spices, oil, and foods and beverages products, such as sweets, syrup, and juice. Hence, farmers in North Maluku mainly process nutmeg fruits into nutmeg spices and sell them in two types of products, i.e. dried nutmeg seeds and dried mace. There are some farmers who process nutmeg fruits into sweets and syrup, but generally food and beverages are still limitedly processed for family consumption.

To escalate the Indonesian agricultural industry, the central government launched the 5-year Strategic Plan of the Ministry of Agriculture 2020-2024 that aimed to increase productivity and efficiency through research and development (R & D) and technological innovation in order to achieve a developed, sustained, and modern agriculture in Indonesia (Secretariat General of Indonesian Ministry of Agriculture, 2021). The strategic plan includes farm rehabilitation and production expansion of high-value commodities, that is hoped not only to boost national production but also to improve farmers' livelihood as source of income. Thus, as one of the targeted high-value commodities from the central government, the strategic plan for nutmeg industry is implemented in five main producing areas, including North Maluku, Maluku, Aceh, Papua, and North Sulawesi.

In North Maluku, the above strategic plan is specifically focused on expanding nutmeg cultivation areas and increasing productivity. The interview survey to the AIAT and Ternate City Agriculture Agency clarified that the strategic plan consists of providing seeds, fertilizers, tools, and necessary assistance for farmers in target areas. In order to supply high quality seeds, the local government began the strategic plan by identifying high yield block (HYB) and selected parent trees (SPT) under the assistance of AIAT. Then, selected farmers are assigned to become seeds breeders to provide necessary seeds for farm rehabilitation and expansion programs. Currently, there are nine nutmeg varieties in Indonesia certified as superior seeds by the Ministry of Agriculture, of which five varieties are originally indigenous nutmeg seeds from the North Maluku region, namely *Ternate 1, Tidore 1, Tobelo 1, Makian,* and *Patani*. However, due to the small land size and limited areas available at Ternate Island, currently, the expansion program is mainly implemented by farmers in Halmahera Island. On the other hand, farmers in Ternate Island are encouraged to become seeds breeders for supplying seeds to Halmahera Island. These implementation efforts were then legalized by the issuance of the Ministry of Agriculture Decree in 2022 that divided nutmeg development in North Maluku into the following directions; firstly, targeting Ternate and Tidore Islands for conservation of superior seeds and parent trees, and secondly, targeting Halmahera Island for conservation and expansion. In 2022, the Ministry of Agriculture distributed 200,000 nutmeg seeds to two areas in Halmahera Island, namely North Halmahera and South Halmahera for land expansion.

Current State of Nutmeg Distribution System in North Maluku

In general, nutmeg spices produced in North Maluku are mainly distributed to the international market. The second interview survey clarified that the distribution system for nutmeg spices starts from farmers level, where farmers conduct the following production processes: cultivation, harvesting, selecting and drying nutmeg seeds and mace. Then nutmeg spices will go from farmers to the market through the following distribution channels, namely rural assemblers, regency assemblers, regency processors, and domestic manufacturing and trading companies. Farmers explained that this distribution channel has actually been conducted for centuries. Although farmers are aware that they can get higher prices if selling directly to buyers at a regency level than selling to rural assemblers, there are two reasons why they still choose to sell to rural assemblers: trust and convenience. Rural assemblers are usually people among farmers themselves who play roles in gathering nutmeg spices from surrounding farmers in the same village. Then, the rural assemblers will collectively distribute these products into bigger assemblers in the regency, called regency assemblers. Most farmers have a very strong connection and trust with rural assemblers because those assemblers are basically fellow farmers from the same village. Hence, selling to rural assemblers is easier and can cut farmers' transportation cost instead of bringing them directly to the market. Meanwhile, the interview survey also revealed that many rural assemblers conduct "pre-payment", which they pay for the products in advance before harvest season begins. Although this practice can be helpful for farmers who are in need of cash money for their daily expenses, unfortunately it can also tie farmers and limit their access to sell to other potential buyers. Currently, the selling price of dried nutmeg seeds and dried mace at the regency level are 90,000 IDR and 225,000 IDR per kilogram, respectively.

On the other hand, the regency assemblers, who usually own a warehouse in the regency's central market or near the port, will distribute nutmeg products to two types of buyers, namely regency processors or domestic exporters, depending on their connection and transaction deals with the target buyers. Regency processors are the ones who directly process dried seeds and make them into packaged products, while domestic exporters usually play both roles as domestic manufacturers and trading companies. Lastly, the exporters will ship nutmeg species through trading ports and sell them to the international market. For North Maluku, although nutmeg production is conducted on three islands, i.e. Ternate, Tidore, and Halmahera, nutmeg spices will first be transported to Ternate Island where it is equipped with proper infrastructures, such as an airport and shipping ports. Hence, those spices will be distributed from Ternate Island into warehouses of exporting companies that are mainly located in three official trading ports in Indonesia, namely Surabaya in East Java, South Sulawesi, and North Sulawesi. Figure 1 shows the illustration of nutmeg distribution system in North Maluku.

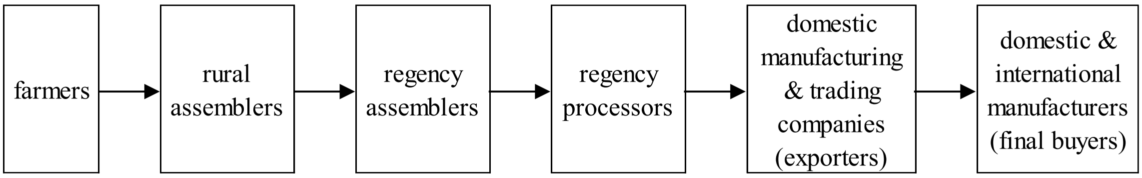

Fig. 1 Nutmeg distribution channel in North Maluku

DISCUSSION

SWOT Analysis on Prospects of Nutmeg Industry Development in North Maluku

The previous section summarized the current state of nutmeg production and distribution system in North Maluku. In this section we conducted SWOT Analysis by elaborating information gathered during interviews and categorizing them into four aspects, strengths, weaknesses, threats, and opportunities to describe the prospects and challenges for the development of nutmeg industry in North Maluku. Figure 2 summarizes the four aspects based on the SWOT Analysis.

In terms of strengths, nutmeg production in North Maluku is strongly favored by the rich natural resources and large areas of cultivated land. As mentioned above, currently five indigenous varieties originally from North Maluku have been classified as superior seeds by the Indonesian Ministry of Agriculture. The field survey and interviews with farmers highlighted potentials of more varieties existing in the North Maluku forests, which farmers believe to be different from other varieties that have been certified by the Ministry. Hence, this knowledge and local wisdom preserved in farmers' communities can be considered as important sources of information that may lead to the discovery of new potential raw materials for the nutmeg industry, which in advance requires a thorough empirical study. With the support and assistance of the local government and research institutions, technical training and knowledge sharing can be actively promoted to provide opportunities for exchanging valuable information with local farmers. Having a vital position as the origin of nutmeg with genetically diverse varieties, combining local knowledge and wisdom preserved in farmers' community with a comprehensive empirical study is important to unfold potential nutmeg resources in North Maluku.

In terms of weaknesses, three aspects can be identified as limitations of nutmeg industry development in North Maluku, namely limited knowledge and technology application at the farmers' level, low productivity, and long distribution channels. As mentioned above, currently most farmers in North Maluku process their nutmeg fruits into nutmeg spices. The processing of nutmeg spices in farmers' level consists of harvesting fruits, separating flesh, and drying seeds and mace to make nutmeg spices. However, these processes are mostly conducted in traditional ways without high technology. Farmers harvested fruits and separated each part manually then sun-drying seeds and mace naturally outside their houses. Some farmers have built drying racks to preserve the quality of dried seeds and mace, but many are still drying on the sheets that lay on the road in front of their houses. Since all the processing steps are still conducted manually, nutmeg spices produced are assumed to be less than available resources when compared to the scale of cultivated land, hence productivity is considerably low. Moreover, the long distribution channels are also identified as a weakness in the development of nutmeg industry in North Maluku. Many farmers are still relying on rural assemblers, especially with the current "pre-payment" practice that is also limiting farmers from finding new buyers. Moreover, with no information on what is going on in the nutmeg market outside their producing areas, farmers have no idea of the value of their products. Hence, farmers tend to stay in stagnant conditions and have no courage to improve their production and distribution system for higher productivity and better bargaining positions in sales.

Strengths	**Opportunities**
･Rich natural resources	･Sustainable production
･Potential raw materials	･Products diversification
･Historical& cultural assets	･Increasing market demand
Weakness	**Threats**
･Limited knowledge and technology implementation in farmers level	･Quality problems
･Low productivity	･Price drop
･Long distribution channels	･Export restriction

Fig. 2 SWOT analysis of the nutmeg industry in North Maluku

In terms of opportunities, there are three aspects that can be considered as advantages for the development of nutmeg industry, namely sustainable production, product diversification, and increasing market demand. Considering potential natural resources such as large cultivation areas and the existence of diverse varieties, North Maluku is a very prospective region to achieve sustainable nutmeg production. Currently farmers may still focus on producing nutmeg spices which only use seeds and mace from the nutmeg fruits and throw away the flesh. However, with proper knowledge and technical training, farmers can get information on quality improvement and product diversification. Those thrown away flesh have already been processed into foods and beverages but still limited for family consumption. Information on the prospective market for these nutmeg foods and beverages can encourage farmers to try processing different products, hence expanding their production and opening market opportunities for various nutmeg products. At this moment, the local government of Ternate has initiated the establishment of a souvenir shop in the city center. Although it only comes from two producers, some nutmeg foods and beverages such as candy, juice and syrup that are made from the flesh have been exhibited and sold at the shop. Meanwhile, seeing the current trend where Indonesia is serving as the largest nutmeg oil producer and supplying 66% of the total global market demand, it is foreseen by the AIAT that the international demand for Indonesian nutmeg products may also increase in the future considering more industries (e.g. cosmetics and medicines) are using chemical compounds derived from nutmeg as raw materials. Hence, trends in both domestic and international markets can be prospective opportunities for the development of the nutmeg industry.

Conversely, the development of the nutmeg industry in North Maluku faces several threats that must be taken into consideration. For years, quality management has been the largest issue in expanding sales of Indonesian nutmeg. As an export commodity, Indonesian nutmeg products must meet the quality requirements mandated from the international market. The government of

Indonesia has set quality standards and regulations for nutmeg products at both the local and national levels to address the quality problems. However, the quality regulation system has not been effectively functioning at any level. A study by AIAT in 2022 confirmed that the current nutmeg seeds and mace drying process of using open sunlight is still inappropriate and can affect the quality of the products. This inappropriate process may then result in a domino effect on the distribution channels. Once the nutmeg seeds and mace are not completely dried and/or if they are partly damaged, they can cause fungi contamination to other products when kept in the same storage. Furthermore, the current rural level distribution system in North Maluku, demonstrates that farmers may sell to specific rural assemblers which can be traced to the source farmers for assuring the production quality. However, once the nutmeg products are distributed to regency and other distribution channels, it will be mixed with products from many farmers and traceability of the products becomes unclear. Without proper quality control from local authority, specifically in regency level, the quality problems seem to remain unsolved, and traceability will remain unclear. Hence, if the quality issue continues, it can further lead to price drops and export restrictions from international markets thus limiting potential expansion of the nutmeg industry in North Maluku.

CONCLUSION

This study explained the current state of the nutmeg production and distribution system in North Maluku and analyzed the prospects and challenges of nutmeg industry development in North Maluku using SWOT Analysis. The results demonstrate that 1) the nutmeg industry in North Maluku is deeply rooted in its long history and the farmers' strong connections to local wisdom and culture which are more highly valued than typical economic drivers, 2) the high market demand for nutmeg products offers promising prospects for development of the nutmeg industry should the local industry wish to move in that direction, 3) the rich and genetically diverse natural resources of North Maluku nutmeg strengthen position in the industry for future development, 4) however, more modern and scalable production and distribution systems are mandatory for the future development of the nutmeg industry and to support it becoming a sustainable and leading industry in the province. Hence, actively exchanging information with farmers community through knowledge sharing and technical training becomes essential to build strong relations between farmers and related key players, including local government and research institutes. As export commodities, the market demands a sustainable supply of high-quality nutmeg products, thus collaboration among related parties to establish a proper management and control system on production and distribution in the producing areas under legal entity, e.g. Farmers Corporation or Regionally Owned Enterprise (BUMD) should be seriously considered for future development of nutmeg industry in Indonesia.

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Research article

Performance of a Covered Lagoon Digester on Wastewater Treatments Obtained from Mango Processing in Kampong Speu, Cambodia

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Abstract: Cambodia exported more than 163,400 tons of fresh mangoes and 18,490 tons of processed, dried mangoes in 2022., Approximately 250–300 tons of dried mango are processed daily throughout the country. Mango processing produces wastewater which is a major concern and requires proper handling and treatment. This study aimed to assess the utilization of a lagoon digester on the mango processing wastewater including (1) ascertain the physio-chemical characteristics of mango processing wastewater; (2) estimate the biogas production and its quality; and (3) determine the potential greenhouse gas emission reductions available through this technology. The lagoon digester had a volume of 6,000 m^3. The study was carried out from July to November2023, at a mango processing factory located in the Kampong Speu province in Cambodia. The factory produced up to 300 m^3 of wastewater per day, which was diverted to the lagoon and then treated with NaOH and powdered calcium carbonate to raise the pH before feedstock was released into the lagoon pond. Three wastewater samples were obtained from the discharge pond of lagoon digester after a month of treatment to measure chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS) and pH. The biogas production was estimated and measured using the vortex flow meter, while a portable biogas analyzer was used to measure the biogas quality. The COD concentration of the wastewater before use of the digester was 35,000 mg/L which was above the standard of Ministry of Environment, Cambodia (<70 mg/L of COD for a public water discharging) which was reduced to 12,000 mg/L, or 65%, after treatment. It was estimated that the biogas yield from the lagoon digester was, on average, 2,296.9 Nm^3/day. While the H_2S concentration was over 5,000 ppm (above the permittable standard < 200 ppm) and the CH_4 content was 52%. In conclusion, this factory can lower the COD concentration of mango wastewater after discharging from the lagoon digester and further benefit from using biogas instead of LPG gas for cooking; by using the lagoon digester, the factory may be able to reduce greenhouse gas emissions by 1,5415.6 tCO_2eq/year.

Keywords lagoon digester, biogas, wastewater, treatment, Greenhouse gas, COD

INTRODUCTION

Mango is the highest produced and most valuable fruit grown by farmers in Cambodia. Over 100,000 hectares are cultivated for mango. Among Cambodia's 25 provinces, Kampong Speu produces the highest amount and the best quality mangoes in the country. (Pisei, 2019). In addtion to this, over 163,400 tons of fresh mangoes exported abroad. However, it decreased 30 percent of fresh mangoes export from the same period in 2021. According to the Ministry of Agriculture, forestry and fisheries, 99,800 tons were exported to Vietname whereas, China imported only 27,400 tons from Cambodia in 2022 (Socheata, 2023a).

Cambodia processed and exported 18,490 tons of dried mangoes in 2022 which was over 3 percent increases compared to last year. Among the top three buyers, China imported 15,800 tons of dried mango from Cambodia (Socheata, 2023b). On a daily basis, 300 tons of mango are processed in five mango processing factories in Cambodia.(Vireak, 2020). This amount of processing capacity produces a large amount of wastewater which requires proper management and treatment. One case study showed that 50-100 tons of mango processing produced approximately 150-300 m^3 of wastewater with a high concentration of chemical oxygen demand (COD) which must be reduced below the permittable standards of Cambodia (Hin et al., 2023).

Wastewater treatment is a significant concern in Cambodia. Wastewater management appears to include discharge of treated wastewater, discharge of untreated wastewater, or by run off and natural purification processes in natural ponds or rivers in accordance with the environmental standards. In one study, the treated effluent had BOD and COD values (mg/L) that complied with the Ministry of Environment's regulations for wastwater effluent discharged into public waters and sewers, the standards of which are below 100 mg/L of COD and 80 mg/L, respectively (Prak and Savath, 2013). Generally, there are many options to remove COD from wastewater with both biological and chemical treatments. However, most livestock farms used the anaerobic digestion (AD) technology in terms of wastewater management and climate changes mitigation (Achinas et al., 2017).

A covered lagoon digester is a popular AD method in Cambodia, In 2019, 44 units were reported to be in use for the treatment of wastewater mostly for commerical pig farms with some agro-processing factories using this method by construction of this type of lagoon digester inside their factory for wastewater management (NBP, 2019). With low construction costs, ease of usage, and suitability for wastewater with a dry matter (DM) level of 0.5-2%, lagoon digesters are popular (Rahman and Borhan, 2012) while the amount of DM in the wastewater from Cambodian pig farms is 0.9%, according to Hin et al. (2021). A cassava starch factory discharged the total wastewater about 800 m^3 for 50 tons of cassava starch processing daily and COD was analyzed on at least 3-4 times before construction and this results varied from 1,600 to 6,800 mg/L of COD and the covered lagoon digester was constructed to treat it properly and can be possibly 80% COD removal and it benefits the factory to generate biogas for electricity and boiling instead using of LPG gas. Our review demonstrates that only one mango processing factory in Kampong Speu attempted to solve their wastewate management problem after the existing systems were deemed inefficient at pollutent removal in wastewater. By installing and using a covered lagoon digester to treat approximately 200-300 m^3 of wastewater per day and generate 1,584 Nm3 of biogas for their daily consumption as well as it can reduce CO_2 emission by 9,540 tCO_2eq/year (Hin et.al, 2023).

Biogas, a byproduct of the lagoon digester, is a mixture of gases that consists of 60-70% of CH_4, 30-40% of CO_2 and other trace compositions (Okoro and Sun, 2019; Safferman et al., 2007). Methane (CH_4) is the main energy resource that can generate both heat and power generation. Nevertheless, biogas has a high content of hydrogen sulfide (H_2S) up to 3,500 ppm (Dumont, 2015). H_2S is poisonous to people and damaging to engines. H_2S levels for generator operation must be kept between 200 and 500 ppm (Rodriguez et al., 2014).

Given the importance of processing and exporting dried mangoes and in managing the resultant wastewater, the study aimed to (1) ascertain the physio-chemical characteristics of wastewater; (2) estimate the biogas production and its quality; and (3) determine the greenhouse gas emission reductions throughout the installation of the lagoon digester.

MATERIALS AND METHODS

The study was carried out between May and December 2023, at a mango processing factory located in the Treng Trayoeung commune, Phnom Srouch district, Kampong Speu province. This factory processes an average of 50-60 tons of fresh mango per day while the maximum processing is up to 100 tons daily.

The factory had applied two procedures to treat and manage the wastewater which had a chemical treatment and an anerobic digestion system or a simple lagoon digester. In principle, this mango-factory produced approximately 300 m^3 of wastewater daily with a high concentration of chemical oxygen demand (20,000 mg/L of COD) before being treated. A covered lagoon was a total volume of 6,000 m^3 for generating mango processing wastewater into biogas. In contrast to this, the factory used nitrogen hydroxide (NaOH) powder with an amount of 200 kg into a chemical treatment tank before discharging into lagoon digester.

Table 1 General description of the mango processing factory

Factory	Description
Name	Mango processing factory at Kampong Speu
GPS	11°19'50.0"N and 104°12'53.7"E
Years in operation	5
Daily processing capacity (tons)	50-60 tons
Operational period	10 months per year
Number of staff (persons)	140
Wastewater treatment	A Covered Lagoon Digester
Volume of digester	6,000 m^3
Maximum wastewater (per day)	300 m^3

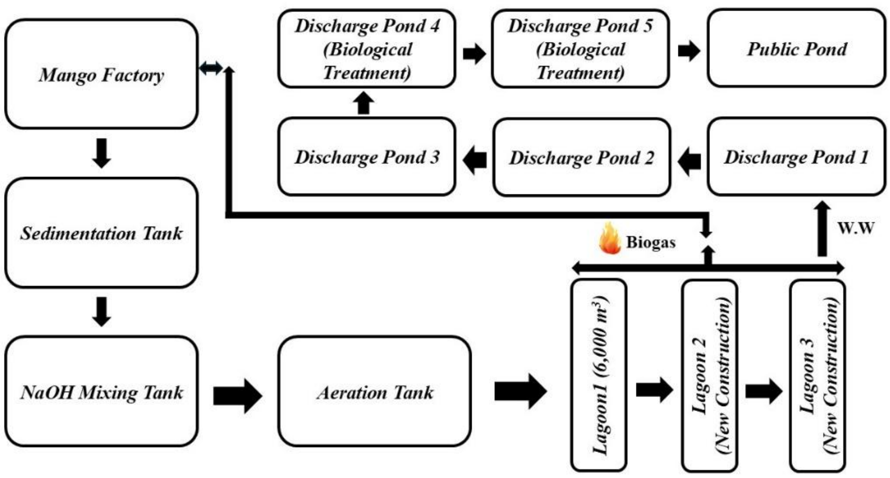

Fig. 1 Diagram of wastewater treatment at the mango processing factory

Materials

A Geotech 5000 biogas analyzer was used to measure biogas quality (Hin et al., 2021; Mean et al., 2022). A vortex flow meter (was used to measure what?) with a range of 20-880 Nm^3/hr. was connected to the main pipeline of the lagoon. The desulfurizing system consisted of 4 desulfurizing tanks which stored and used iron oxide (Fe_2O_3) with an amount of 30 kg in each. Iron oxides replacement occurred monthly to make sure that H_2S concentration remained below 200 ppm.

Data Sampling

To determine the physio-chemical properties of wastewater (COD, BOD, TS, TSS, pH and TOC), there were three samples of wastewater taken from different sites including, the first sample was collected in sedimentation tank; the second sample was collected in a NaOH powder mixing tank and the third sample was taken from a discharge pond 1. For daily biogas consumption was recorded twice per day from the vortex flow meter whereas, the biogas quality was measured by Geotech 5000 biogas analyzer for three times per month before and after desulfurized when biogas was consumed for boiling and cooking.

Total Biogas Estimation

Technically, 1kg of COD can be removed from 1 liter of wastewater converted into 0.35 $Nm^3$of methane volume (CH_4) and mainly the methane concentration varied from 50-60% in biogas from mango processing factory (Deublein and Steinhauser, 2010). Additionally, to estimate the total biogas production was based on the efficiency of COD removal from the total wastewater after discharging from the lagoon digester.

$$TBP\ (Nm^3) = TW(m^3/day) \times COD(kg/m^3) \times 0.35 \times COD_{removal}\ (\%)/\ \%CH_4 \quad (1)$$

Whereas, TBP represents the total biogas production and TW presents the total wastewater and COD removal represents the efficiency of COD reduction in biogas production.

The Estimation of GHG Emission Reduction

To calculate CO_2 reduction equivalent (tCO_2 eq.) by avoidance of CH_4 emission reduction throughout the operation of lagoon digester for the wastewater treatment is based on the CH_4 density which is 0.717 kg/m^3 whereas, the conversion of CH_4-to-CO_2 is 30 times more potential in causing the global warming (Mean et al., 2022).

$$CO_2 \text{ by avoidance of } CH_4\ (tCO_2eq./year) = Q_{CH4} \times D_{CH4} \times CH_4\text{-to-}CO_2/1{,}000 \quad (2)$$

Where Q_{CH4} represents the total methane production annually (Nm^3/year), D_{CH4} represents the methane density (kg/m^3).

Data Analysis and Interpretation

Data were prepared in table and bar charted in Microsoft Excel and Descriptive statistics were employed in each parameter to determine mean, standard deviation (SD), standard error (SE) and p-value in R studio version 4.3.1.

RESULTS AND DISCUSSION

The Physio-chemical Characteristics of Wastewater

The wastewater primarily originates from various stages of mango processing, including washing fresh mangoes, syrup production, steaming, mango pearl processing, and other operations along the production line. For laboratory analysis, the wastewater quality was considered with three different sites in anaerobic digestion. Table 2 showed the physio-chemical characteristics of wastewater in this factory contained 3.6-4.2 pH in acidity state which was strongly affected by the fermentation of the wastewater in the covered lagoon. Additionally, the COD reduced from 35,000 mg/L to 19,400 mg/L after being treated with NaOH powder while it further decreased to 12,000 mg/L after discharged from the lagoon digester for which we compute a COD removal efficiency of 65%. However, the COD standard for water area and sewer was lower than 300 mg/L in Cambodia whereas, the COD standard for protected public water was below 120 mg/L according to (MoE, 2018).

In contrast, one study found that mixing NaOH with wastewater was effective in reducing COD from 5,000 mg/L to 1,200 mg/L, while also adjusting the pH from 6.5 to 9.5 with a 0.5 M NaOH concentration (Amor et al., 2019). Additionally, the BOD_5 concentration in wastewater before treatment was 17,540 mg/L, which decreased to 7,810 mg/L and further reduced to 6,030 mg/L after treatment in the lagoon digester. However, the permissible BOD_5 standard for sewage discharge pond is set below 200 mg/L (MoE, 2018).

Table 2 The Physio-chemical characteristics of wastewater (WW)

Parameters	Units	Testing results		
		WW before treatment	WW + NaOH before treatment	WW after treatment
pH	-	3.6	3.8	4.2
Chemical oxygen demand (COD)	mg/L	35,000	15,600	12,000
Biochemical oxygen demand (BOD_5)	mg/L	17,540	7,810	6,030
Total organic carbon (TOC)	mg/L	1690	6,990	5,995
Total nitrogen (TN)	mg/L	112	228	346
Total suspended solids (TSS)	mg/L	480	188	64

The Estimation of Biogas Production from Mango Processing wastewater

Table 3 shows the potential biogas produced from mango processing, and it was estimated to produce approximately 2,296.9 Nm^3/day with an average of 150 m^3wastewater treatment daily. For full processing, the factory produced a maximum of 300 m^3 wastewater and treated it in the lagoon digester. So, the biogas potentially produced 4,593.8 Nm^3/day daily in terms of 65% COD reduction efficiency in this lagoon digester. Additionally, Table 4 described the biogas quality and it resulted as 52% of CH_4, 40.8% of CO_2, 1.1% of O_2 and 4.1% of N_2, respectively whereas, it was observed that H_2S concentration contained above 5,000 ppm or an average of 5,040 ppm in biogas which needed to treat it properly and reduce below 200 ppm if the factory preferred to generate it with a cooking stove, boiling and electricity generation in avoidance of erosion and a short life-time of uses.

Table 3 Description of biogas potential produced from mango processing

Description	Unit	Average
Total wastewater	m^3/day	150
Daily Biogas Production	Nm^3/day	2,296.9

Table 4 Description of Biogas quality in lagoon digester

Biogas compositions	Unit	Mean	S. E
Methane (CH_4)	%	52	0.5
Carbon dioxide (CO_2)	%	40.8	1.2
Oxygen (O_2)	%	1.1	0.3
Hydrogen sulfide (H_2S)	ppm	5,040	150
Nitrogen (N_2)	%	4.1	0.2

In the meantime, biogas production from cassava wastewater in the same anaerobic digestion (covered lagoon digester) found that the biogas potential was estimated to produce 5,500 Nm^3/day within amount of 400 m^3 wastewater treated daily in terms of 80% COD removal efficiency after discharged from lagoon. Furthermore, its biogas quality contained 50% of CH_4, 41.7% of CO_2, 0.1% of O_2 and 3.8 of N_2, respectively whereas, H_2S varied from 260-450 ppm (Hin and Sokhom, 2020). In contrast, the biogas production in fattening pig farms was an average of 415 Nm^3/day in terms of 140 m^3 wastewater treatment in a covered lagoon digester daily. Meanwhile, its biogas quality resulted 59.5% of CH_4, 31.5% of CO_2, 1.3% of O_2 and 2,256 ppm of H_2S, respectively (Hin et al., 2021).

Biogas Desulfurization (H_2S) Reduction

Figure 2 illustrates the comparison of H_2S concentration before and after desulfurization between one week and four weeks of full biogas consumption. It was observed that H_2S gas decreased dramatically from over 5,000 ppm to 37 ppm (below standard) within a week of use whereas H2S increased gradually by 4,700 ppm over a month. Similarly, a few commercial pig farms use iron pellets to treat H_2S and normally, they prefer to change iron pellets monthly with a flow rate of 150-250 Nm^3/hr. (Mean et al.,2022). Meanwhile, this amount of H_2S dramatically increased after a month of full consumption (cooking and boiling) with a flow rate of 30-80 Nm^3/hr. which caused the iron pellets (120kg) in the desulfurizing tanks to be less efficient to remove H_2S from biogas. Technically, According to Lor et al. (2021), H_2S removal was observed with 4 kg of pellets, as H_2S levels decreased to above 2,500 ppm.

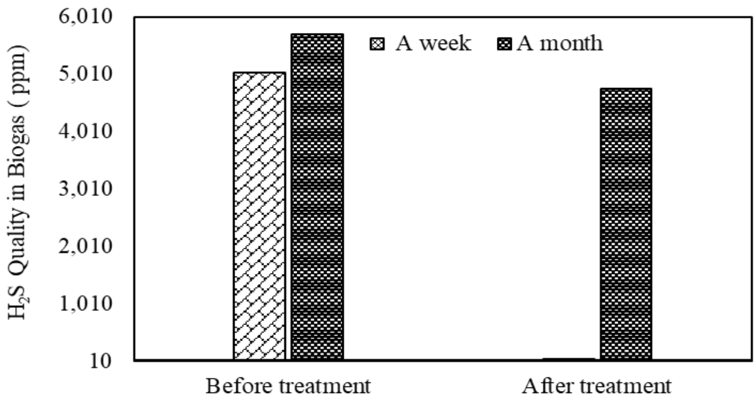

Fig. 2 Comparison of H_2S concentration after desulfurization between a week and a month

Estimation of Annual CO_2 Emission Reduction

Table 5 shows that the annual biogas production was 1,378,125 Nm^3/year, with methane production at 716,625 Nm^3/year. The factory's full biogas utilization can significantly reduce CO_2 emissions by 15,415.6 tCO_2eq/year. Compared to commercial pig farms, this represents a substantial reduction in CO_2 emissions. Hin et al. (2021) reported that CO_2 emissions from pig farm wastewater treatment can be reduced by 2,832 tCO_2eq annually.

Table 5 The avoidance of CO_2 emissions throughout the promotion of lagoon digestion

Description	Unit	Value
Annual biogas production	Nm^3/year	1,378,125
Annual methane production	Nm^3/year	716,625
Annual CO_2 reduction	tCO_2eq./year	15,415.6

CONCLUSION

The lagoon digester was the most effective option for wastewater treatment, as it not only reduced COD concentration but also generated biogas for on-site use. Additionally, it helped the factory mitigate foul odors and minimize complaints from neighboring villagers. Furthermore, the treatment process contributed significantly to CO_2 reduction. However, the COD levels remained above the standard even after treatment. To enhance wastewater treatment efficiency and further reduce pollutants, it is recommended that the factory construct two additional lagoon digesters. This would also increase biogas production, which could replace LPG and diesel for boiling and electricity generation.

ACKNOWLEDGEMENTS

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Research article

Local Awareness and Perception of Fertilizers: A Case Study in Anuradhapura District, Sri Lanka

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Abstract For many decades, the agriculture sector in Sri Lanka has been dependent on chemical fertilizers, providing near-term benefits but posing substantial long-term environmental impacts. This practice underscores the challenge of transitioning to more sustainable farming strategies. Through structured questionnaires and in-depth discussions, we explored the awareness and perception of fertilizer application practices among paddy farmers in the Tisa Wewa irrigation scheme in the dry zone of Sri Lanka. Most farmers (78%) relied solely on inorganic fertilizers, while an approach of mixed inorganic and organic fertilizers was adopted by 19%. Only 3% of farmers used solely organic fertilizer. Of the respondents utilizing inorganic fertilizer, 44.1% applied the recommended amount set by the Department of Agriculture, Sri Lanka, while 42.6% applied greater than the recommended amount, and 13.2% applied less than the recommended amount. The survey and interview data indicated that the current practice and high reliance on inorganic fertilizer is due to the limitations of organic fertilizers governed by the large amount needed, the longer necessary to release nutrients, and the limited manure availability. Most farmers (87.1%) expressed a strong preference for adopting mixed organic and inorganic fertilizer applications in the future, emphasizing the use of high-quality input products, reflecting a forward-looking approach to sustainable agriculture, combining the benefits of both organic and inorganic fertilizers. The statistical results strongly indicate that education and awareness reduce the over-dependency on inorganic fertilizers and significantly influence the adoption of sustainable fertilizer practices.

Keywords fertilizer application, paddy farmers, awareness, perception, Sri Lanka

INTRODUCTION

Sri Lanka's monsoon climate supports two annual paddy seasons (Yala and Maha), with rice farming occupying about 29% of the country's total cultivated land (Department of Census and Statistics, Sri Lanka, 2023). The government's fertilizer subsidy program established in 1962 encourages farmers to adopt high-yielding rice varieties responsive to inorganic fertilizers. This program has made inorganic fertilizers affordable, with the unintended consequence of farmers' overuse (De Silva et al., 2020). As such and for several decades, the agriculture sector in Sri Lanka has been dependent on inorganic fertilizers. Studies indicate significant inefficiency in inorganic fertilizer application for paddy cultivation, with 50-70% of fertilizer inputs being lost through volatilization, leaching, or other pathways (Sirisena et al., 2016). Hence, excessive use of inorganic agricultural inputs results in serious environmental and health effects (Siriwattananon et al., 2014). Fertilizer runoff causes water pollution, especially eutrophication since the excess nitrogen and phosphorus from fertilizers increase algae growth and deteriorate water quality. Furthermore, repeated inorganic fertilizer degrades soil quality by altering pH and depleting essential micronutrients and organic matter contents, leading to a vicious circle of dependence on synthetic inputs. Moreover, water bodies and soil become contaminated with nitrates, cadmium, and fluoride, which are harmful to human health.

Hence, sustainable agricultural practices become necessary for environmental integrity and human health (Siriwattananon et al., 2014).

The abrupt shift to an exclusive organic agriculture policy in Sri Lanka in April 2021, which banned synthetic fertilizers and pesticides, was implemented by the Sri Lankan government. Though The policy aimed to reduce chemical dependency and promote environmental sustainability, it was reversed within months due to severe crop yield declines (Wijerathna et al., 2024). The crisis underscored the need for phased transitions, thus in October 2022, a new approach was introduced recommending a balanced use of 30% organic and 70% inorganic fertilizers for paddy cultivation. (MALLI, 2022). Farmers were encouraged to obtain an organic certificate or Good Agricultural Practices certification. However, still, it remains unclear whether Sri Lankan paddy farmers apply sufficient amounts of organic matter or effectively utilize specific sources. Therefore, this study aimed to assess farmers' awareness and perceptions of fertilizer application to identify issues and/or gaps in current practices, explore the barriers to adopting more balanced fertilizer application strategies, and generate and propose practical recommendations facilitating the transition towards sustainable fertilizer practices.

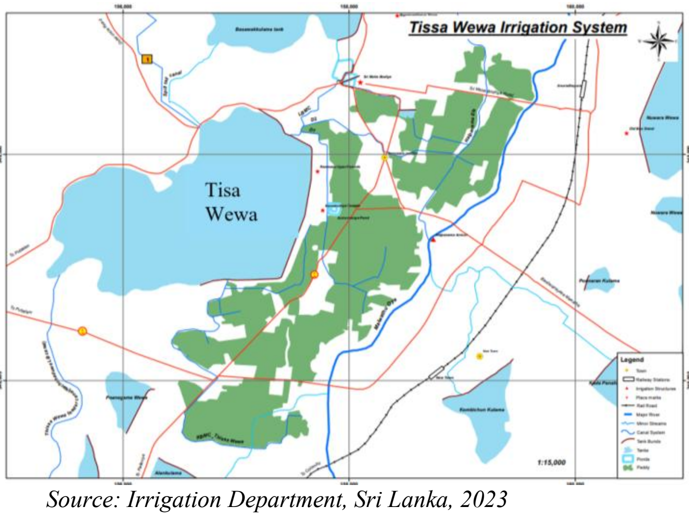
OBJECTIVE

This research aimed to measure and analyze local awareness and perceptions regarding fertilizer application among paddy farmers in Sri Lanka's dry zone.

METHODOLOGY

Study Area

Anuradhapura District in the north, central plain of Sri Lanka, is identified as one of the major paddy farming districts, with high productivity and production accounted for 12% of Sri Lanka's paddy production during the 2023 Yala season (Department of Census and Statistics, Sri Lanka, 2023). The study was conducted in the Tisa Wewa irrigation scheme in Anuradhapura District (Fig. 1), using a local paddy farming community. This area was selected as a representative site due to its significant role in supporting paddy cultivation in the region and its practical feasibility. The long-standing agricultural history of Tisa Wewa and a wide range of farming practices allowed for a comprehensive understanding of local awareness and perception of fertilizer application. By selecting this area, the study could capture diverse perspectives on fertilizer application, providing a representative context for examining fertilizer application behavior within Sri Lanka's paddy farming sector and facilitating the development of recommendations applicable to similar regions.



Source: Irrigation Department, Sri Lanka, 2023

Fig. 1 Scheme map of Tisa Wewa irrigation scheme

Data Collection

The primary data were collected from August to September 2023, through a structured questionnaire survey with close-ended questions supplemented by informant discussions. The study was focused on the farmers involved in paddy cultivation under the Tisa Wewa irrigation scheme, which was organized into five major farm organizations. Stratified random sampling was employed to ensure reliable representativeness by dividing the population into five strata, corresponding to the five farm organizations, and proportionally randomly selecting farmers from each stratum. The minimum sample size was determined as in Eq. (1), assuming a success or failure proportion of 0.5, with a 95% confidence level and a 10% margin of error. Seventy farmers were selected from a total of 220, for the study based on the calculated minimum required sample size (67). The list of registered farmers in the study area was provided by the Department of Agrarian Development in Sri Lanka.

$$n=\frac{96N}{N+96} \tag{1}$$

Where N = population size and n = sample size.

Data Analysis

The survey questionnaire was developed based on a review of existing literature on agricultural practices and fertilizer use.-Before finalizing the questionnaire, a preliminary survey was conducted with 10 farmers to ensure clarity and relevance. It provided valuable feedback that helped refine the final questions used in the study. The main areas covered in this survey include demographic and farming characteristics, awareness and perception of fertilizer application, and future preferences. Purpose and survey questions related to each category are shown in Table 1. Data collection was conducted using pencil-and-paper surveys administered through face-to-face interviews to accommodate rural farming communities. The data were descriptively analyzed using Microsoft Excel and SPSS, employing frequency distributions, percentages, and correlation analysis to interpret and present the findings. In addition, relevant secondary data regarding the fertilizer application were also reviewed.

Table 1 Survey questions associated with categories

Category	Purpose	Survey question
Demographic and farming characteristics	Define Age	What is your age?
	Define the highest educational level	What is your highest level of education?
	Define farming experience	How long have you been paddy farming? (Years)
	Define farm area	What is the current paddy cultivated area (in ha)?
Awareness and perception of fertilizer application	To define the current fertilizer type	What kind of fertilizer do you add to the field? (Inorganic/Organic/Both)
	To define the current inorganic fertilizer amount	How do you add inorganic fertilizer to the field? (Recommended amount/higher or less)
	To evaluate the awareness of the environmental impact of inorganic fertilizer	Do you think the usage of inorganic fertilizers results in adverse effects on the environment and health? (Yes/No)
	To define organic fertilizer type usage	What kind of organic fertilizer do you add to the field? (open-ended or pre-configured list.?)
	To measure farmer knowledge of organic fertilizer benefits	Advantages of organic fertilizers (open-ended or pre-configured list.?)
	To rank order practical issues when using organic fertilizer	Rank the given constraints (need large quantities, more time taken to release nutrients, high cost of manure, limited supply of manure, unable to self-produce)
Future preference of fertilizer application	To identify the farmer's preference for future fertilizer practices	What is your preferred method for future fertilizer applications? (Inorganic/Organic/Mixed application)

Source: Questionnaire survey in August to September 2023

RESULTS AND DISCUSSION

Demographic and Farming Characteristics of Farmers

Table 2 shows the demographic and farming characteristics of the respondents (N=70). Most respondents (85.7%) were male, with a mean age of 54.2 years (SD=12.56). Notably, only 2.9% of respondents were less than 30 years of age reflecting the younger generation's minimal involvement in paddy cultivation.

Most farmers (44.3%) completed secondary education and sat for the General Certificate of Examination (GCE) Ordinary Level, which most respondents (74%) passed. The second largest proportion (32.9%) completed their GCE Advanced Level. A small proportion (8.6%) obtained a bachelor's degree in any field. According to the findings, there is potential for agricultural development and knowledge-based improvements in rural farming communities due to many farmers having reached at least a foundational level of secondary education.

Most farmers (47.1%) had over 15 years of experience. Most farmers (60%) were small-scale farmers cultivating less than 1.2 hectares (ha) of paddy land, 22.9% cultivated medium-scale farmlands (1.21-2 ha), and the remainder cultivated larger-scale farms.

Table 2 Demographic and farming characteristics of respondents

Factor	Category	Frequency	Percentage (%)
Gender	Male	60	85.7
	Female	10	14.3
Age (years)	Less than 30	2	2.9
	31 - 44	17	24.3
	45 - 60	29	41.4
	More than 60	22	31.4
Highest educational level	Primary	2	2.8
	Grade 6 - 8 (Middle Level)	8	11.4
	Grade 9 - 11 (up to GCE Ordinary Level)	31	44.3
	GCE Advanced Level	23	32.9
	Degree	6	8.6
Farming experience under Tisa Wewa irrigation scheme (years)	Less than 5	7	10.0
	5-10	11	15.7
	11-15	19	27.1
	More than 15	33	47.1
Cultivating paddy area under Tisa Wewa irrigation scheme (ha)	<1.2	42	60.0
	1.21-2	16	22.9
	2.01-4	5	7.1
	> 4	7	10.0

Source: Results from the questionnaire survey in August to September 2023

Current Fertilizer Application Behavior

The primary inorganic fertilizers used for paddy cultivation included Urea, Triple Super Phosphate (TSP), and Muriate of Potash (MOP). Organic materials such as rice straw, green leaves, compost, and biofertilizers were also utilized by respondents in the region. Manuring applications in the paddy fields were notably limited to only cow manure.

As shown in Figure 2(a), most farmers (78%) relied solely on inorganic fertilizers, while a mixed approach of inorganic and organic fertilizers was adopted by 19%. Only 3% of farmers used solely organic materials. This outcome aligns with previous findings, such as by Senanayaka (2022), that only organic fertilizer usage in the country was limited to 1% of the rice farmers. 44.1% of respondents applied the recommended amounts for inorganic fertilizer applications defined by the Department of Agriculture, Sri Lanka (2013), while 42.6% used a greater than the recommended amount. Fig. 2(b). 13.2% of farmers used less than the recommended amounts and the same category also included the farmers who incorporated organic matter into their practices. Over-application still practiced by farmers, indicates potential misuse of inorganic fertilizer, influenced by the belief that more fertilizer equates to higher yields. Some respondents mentioned that they had to apply higher quantities of inorganic fertilizers due to the poor quality of inorganic fertilizers, to achieve the desired crop yield.

These behaviors govern a vicious cycle of soil quality degradation, reduced crop yield, and the need for more fertilizer. Therefore, targeted strategies are required to promote greater adoption of sustainable agricultural practices.

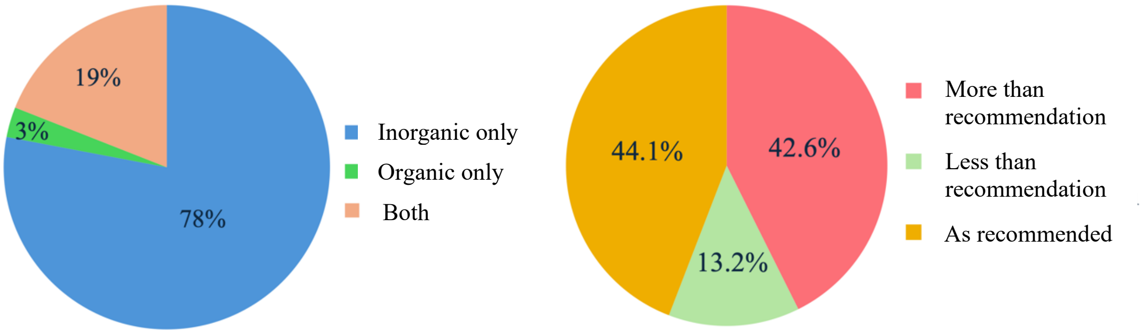


Fig. 2 Fertilizer application practices (a) and application rate of inorganic fertilizer (b)

Perceived Environmental and Health Risks Associated with Inorganic Fertilizers

Respondents (68.6%) revealed a general awareness of the potential negative environmental and human health impacts of inorganic fertilizers. The main perceived risks entail soil degradation, water pollution, loss of biodiversity, and chronic diseases such as cancers. Perceptions are formed based on self-observation, local knowledge, and information shared within the farming community. Despite this awareness, respondents hesitate to avoid or reduce inorganic fertilizer usage due to a perceived lack of other efficient and effective alternatives. Consequently, a recommendation is made to related organizations to act on enhancing the use of organic or integrated nutrient management practices, bringing knowledge to farmers on how to effectively and safely use fertilizers which could help mitigate some of the perceived risks while maintaining agricultural productivity.

Current Usage and Knowledge of Organic Fertilizers

Results revealed that among farmers applying organic materials to their fields, 60% used rice straw with green leaves. Gliricidia (*Gliricidia sepium*) leaves were used most often due to their high availability. Additionally, 40% of farmers utilized self-prepared compost, 20% relied on commercial compost, 6.7% used cow manure, and 6.7% used bio-fertilizers. However, some farmers expressed concerns about the perceived lower quality of commercial compost products. Cow manure was the sole animal waste used by respondents since the shortage of animal manure has resulted in significantly higher costs.

Key advantages of organic fertilizers mentioned by the respondents were improved plant growth (75.7%), improved soil fertility (52.9%), enhanced soil water holding (27.1%), and reduced soil erosion (12.9%). Such a consensus reflects the belief in organic matter's positive impact on crop development. However, a notable percentage (22.9%) expresses uncertainty, which might indicate an awareness gap. Targeted educational initiatives are essential to bridge this gap, improving farmers' understanding of the significance of organic matter in agriculture.

Constraints Associated with Organic Fertilizers

The average ranking method (Eq. 2) according to Yusufi and Yamada (2019), was used to determine influential constraints to organic matter application. Which have the lowest average ranks, indicating they are critical issues to address. Table 3 revealed that the most significant constraint was the need for large quantities of organic materials compared to inorganic fertilizers.

$$\text{Average rank} = \frac{X_1P_1+X_2P_2+\ldots+X_nP_n}{\text{Total response count}} \tag{2}$$

Where X_n = response count for each choice, P_n = ranked position.

Table 3 Average ranking for constraints of organic fertilizer application

Constraints	1st	2nd	3rd	4th	Average rank
Need large quantities	41	21	8	0	1.5
More time is taken to release nutrients	27	41	1	0	1.6
High cost of manure	2	2	24	14	1.9
Limited supply of manure	0	5	29	33	3.3
Unable to self-produce	0	1	8	23	4.5

Source: Results from the questionnaire survey in August to September 2023

Farmers face challenges in obtaining adequate quantities of necessary materials, either because they are not available at reasonable prices or because they lack the means to prepare by themselves. The second important constraint was more time to release nutrients primarily due to challenges in obtaining standard or quality materials. Additionally, the high cost and limited availability of manure further compounded the issue. The inability to produce self-produce due to time and space was identified as a lesser constraint. Previous studies also revealed that limited availability and poor quality of organic materials were the most severe barriers to organic farming (Wijerathna et al., 2024). Therefore, to make it viable there is an urgent need to address the availability of quality organic products.

Future Preference of Fertilizer Application

The majority (87.1%) preferred a mixture of inorganic and organic fertilizers in the field, while 10%, favored only organic application, and 2.9% preferred solely inorganic fertilizers. This is an increase from previous reports, in which only 58% preferred mixed systems, while 31% and 11% preferred fully inorganic and fully organic applications six months after the 2021 policy shift to exclusive organic fertilizers (Wijerathna et al., 2024). The increased uptake of mixed systems (87.1%) reflects a pragmatic response to the shortcomings of the organic-only policy, which had led to severe yield losses and economic hardship. This change reflects a positive evolution towards more sustainable forms of agriculture. Farmers expressed a high preference for this mixed approach with high-quality organic and inorganic materials under proper guidance. Additionally, this finding aligns with the previous research of Silva et al. (2020). Therefore, integrating organic fertilizers and reducing the overuse of chemical fertilizers would be more widely accepted by farmers, and offering significant support through the government and private sector involvement is highly recommended.

Pearson Correlation Analysis

Pearson correlation and Sig. (2-tailed) p-values help determine the strength and significance of relationships between variables, with significant relationships indicating that the variables are meaningfully related. The correlation analysis revealed several significant relationships between the variables in the study, providing valuable insights into farming practices and the factors influencing them. A low negative correlation between the age group and cultivated area was observed where older farmers tend to cultivate smaller paddy areas ($r = -0.332$, $p = 0.005$). This trend suggests that older farmers may reduce the size of their paddy fields, possibly due to several factors such as retirement, health issues, or the transfer of land to younger generations. Interestingly, age alone did not have a strong influence on fertilizer preference.

Educational qualifications showed significant moderate positive correlations with several farming variables such as fertilizer type used ($r = 0.448$, $p < 0.001$), awareness of impacts of inorganic fertilizers ($r = 0.662$, $p < 0.001$), and preferred fertilizer method ($r = 0.478$, $p < 0.001$). Specifically, it had a significantly strong negative correlation ($r = -0.707$, $p < 0.001$) with the application rate of inorganic fertilizer, which is preferred for the recommended amount or less. These findings highlighted that farmers with higher educational qualifications are more likely to choose organic fertilizers and adopt more sustainable farming practices, suggesting that education influences the choice of fertilizers and farming practices.

Awareness of the impacts of inorganic fertilizers demonstrated a significant moderate negative correlation with inorganic fertilizer application rate (IFR) ($r = -0.609$, $p < 0.001$), suggesting that those more aware of the environmental impact of fertilizers are less likely to use inorganic methods or preferred for recommended rates or less. There was a significant positive relationship with the preferred fertilizer method ($r = 0.468$, $p < 0.001$), suggesting that awareness of fertilizers is associated with preferences for organic fertilizers. These results strongly indicate that both education and awareness significantly influenced the adoption of more informed and sustainable fertilizer practices.

Table 4 Results of Pearson correlation analysis

		AG	EQ	FD	CA	FT	IFR	IFI	PFM
AG	Pearson Correlation	1	-0.006	0.223	-0.332**	0.169	-0.117	0.088	0.006
	Sig. (2-tailed)		0.958	0.064	0.005	0.161	0.334	0.471	0.957
EQ	Pearson Correlation		1	-0.313**	0.124	0.448**	-0.707**	0.662**	0.478**
	Sig. (2-tailed)			0.008	0.308	0.000	0.000	0.000	0.000
FD	Pearson Correlation		**	1	-0.193	0.268*	-0.216	0.105	-0.143
	Sig. (2-tailed)				0.109	0.025	0.073	0.386	0.239
CA	Pearson Correlation	**			1	-0.220	0.098	0.035	0.136
	Sig. (2-tailed)					0.068	0.418	0.774	0.261
FT	Pearson Correlation		**	*		1	-0.620**	0.335**	0.131
	Sig. (2-tailed)						0.000	0.005	0.280
IFR	Pearson Correlation		**			**	1	-0.609**	-0.190
	Sig. (2-tailed)							0.000	0.115
IFI	Pearson Correlation		**			**	**	1	0.468**
	Sig. (2-tailed)								0.000
PFM	Pearson Correlation		**					**	1
	Sig. (2-tailed)								

*Note: AG= Age group, EQ= Educational qualifications, FD= Farming duration, CA=Cultivated area, FT=Fertilizer type (inorganic, organic, both), IFR=Inorganic fertilizer rate (recommended, less or more), IFI=Inorganic fertilizer impact, PFM=Preferred fertilizer method (**p < 0.01, * p < 0.05)*

Recommendations

Government and private sector efforts should focus on promoting organic fertilizer use, ensuring the availability of compost and manure at subsidized rates, improving supply chains, and supporting local production. Training and education in effective utilization and home composting should be provided to address farmer constraints while exploring more efficient application methods. Policymakers should encourage organic and inorganic fertilizers mixed approach, ensuring sustainable soil fertility and crop productivity. Given the strong link between education, awareness, and fertilizer practices, agricultural extension programs should focus on improving farmers' knowledge of efficient fertilizer use and integrated nutrient management. Practical workshops, field demonstrations, and research-based information dissemination will support sustainable paddy farming practices in Sri Lanka.

CONCLUSION

The study found that education and awareness of the effects of inorganic fertilizer greatly influence farmers' intentions to adopt organic-based practices. Farmers with at least secondary levels of education were more likely to apply integrated nutrient management and showed greater environmental awareness. However, insufficient availability and low quality of organic materials, coupled with inadequate animal manure, were the key factors limiting farmers from adopting organic farming. Although 87.1% of the farmers preferred a mix of organic and inorganic fertilizers, this would show a gradual change toward sustainable practices. It also points to the opportunity to promote environmentally friendly, balanced fertilizers to improve productivity without harming the environment.

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Research article

Enhancing Soil Productivity for Sustainable Agriculture in Afghanistan: The Impact of Organic Amendments on Soil Water Holding Capacity and Grapevine Growth in Kabul, Afghanistan

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Abstract Afghanistan's sandy loam soils hold significant agricultural potential; however, they face challenges such as low water-holding capacity, poor organic matter content, and high infiltration rates, which hinder plant growth and productivity. This study aimed to evaluate the effects of organic amendments on soil volumetric water content, water-holding capacity, and grapevine performance. A controlled pot experiment was conducted in a glasshouse at Tokyo University of Agriculture, using five different treatments (T), each applied at a rate of 7.5%: T0 (control), T1 (sawdust), T2 (compost), T3 (chicken manure), and T4 (a combined treatment). Delaware grapevine seedlings were planted in each pot, and volumetric water content and matric potential data loggers were connected to sensors to monitor soil moisture and water suction. Additionally, leaf area index and chlorophyll content were measured using ImageJ software and a chlorophyll-measuring device. The results showed that organic amendments sawdust, compost, chicken manure, and the mixed treatment significantly improved soil water-holding capacity, and overall soil productivity, all of which are essential for sustainable agriculture in water-scarce regions like Afghanistan. Chicken manure and the mixed treatment demonstrated the highest volumetric water content, while sawdust and compost provided the greatest water-holding capacity. Moreover, these amendments enhanced grapevine growth, as indicated by increased leaf area and chlorophyll content. The findings suggest that incorporating organic amendments into sandy loam soils can improve water efficiency, plant growth, and soil sustainability, contributing to the long-term viability of Afghanistan's agricultural sector.

Keywords organic amendments, soil productivity, water holding, plant growth

INTRODUCTION

In Afghanistan, agriculture is the backbone of the economy, with most of the population relying on it for food, income, and livelihood. Even though only 12% of Afghanistan’s total land is arable and only about 6% is currently cultivated (Yousufi, 2016). Among all fresh fruits, grapes hold the highest economic importance, covering 50% of the total horticulture crops (Yusufi and Yamada, 2017), with a production volume of 993,382 tons in 2020 (MAIL, 2020). Despite the 87,593 hectares (ha) of vineyards cultivated across the country, less than 1% of the vineyards are located in highly suitable areas, while another 22% of suitable land remains available for potential expansion of grape farm (Arab and Ahamed, 2022). Water scarcity is a primary barrier for agriculture in Afghanistan’s arid and semi-arid regions, with irrigation accounting for 85% of water use to sustain the country's agriculture (Aini, 2007). However, the prevalent sandy loam soils in the region are limited by low water-holding capacity, high infiltration and evapotranspiration rates, and minimal organic matter content with a range from only 0.02 to 2.1 percent, factors that collectively restrict soil moisture and productivity for plant growth. These base problems are especially challenging during frequent droughts impacting overall agricultural productivity (FAO, 2020). The challenges of low water retention, poor organic matter content, and rapid infiltration limit soil productivity and its ability to support plant growth (Yusufi and Yamada, 2019).

OBJECTIVES

To evaluate the effectiveness of organic amendments in improving soil water-holding capacity, enhancing soil productivity, and assessing their impact on grapevine cultivation, with the goal of developing sustainable agricultural practices for arid regions of Afghanistan.

STUDY AREAS AND METHODOLOGY

The study areas are Shakardara, Kalakaan and Mir Bacha Kot districts of Kabul, Afghanistan, have a semi-arid to arid climate, characterized by low precipitation, hot summers, and cold winters. The soil in these regions is generally sandy loam to loam, with low organic matter, poor water retention capacity, and limited fertility. One of the major challenges for agriculture in these areas is the scarcity of irrigation water, as precipitation is insufficient to support reliable crop production. Additionally, climate variability, high temperatures, and soil degradation further reduce productivity. My study focuses on improving soil water-holding capacity and fertility using compost, chicken manure, sawdust, and their combinations as potential amendments to enhance sustainable agriculture in these water-limited environments.

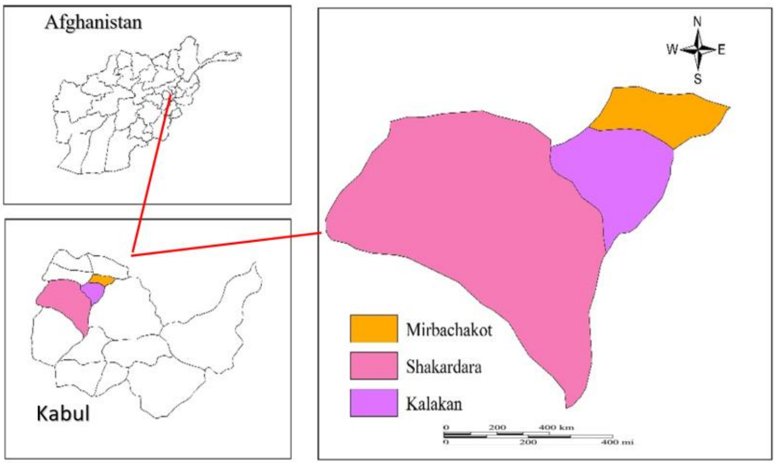


Fig. 1 Map of the study area

Materials

A pot experiment was conducted in a controlled environment at the Tokyo University of Agriculture from August 2023 to December 2024. After the preparation of 15 pots, two-year-old Delaware grapevine seedlings were transplanted into each pot. Irrigation was provided during the growing season as necessary. Weed control and other management procedures were regularly undertaken by standard protocols, especially at the early stages of seedling growth. Plant growth parameters such as the chlorophyll content of leaves and leaves areas of grapevine were assisted. Testing five organic amendments to assess their effects on soil water holding and grapevine growth.

Experimental Layout

The study tested under five treatments and three replications as shown in Table 1.

Table 1 Experimental layout with five treatments

Number		Treatments
(i)	T0	Control/no amendment: sandy loam soil 9,000 g (100% of soil weight)
(ii)	T1	Sandy loam soil 8,325 g (92.5%) + sawdust 675 g 1 mm (7.5%) (8325 + 675 = 9000 and % figures would be 92.5% and 7.5%)
(iii)	T2	Sandy loam soil 8,775 g (92.5%) + compost 675 g (7.5%) (8775 + 675 = 9450 and % would be 92.5% and 7.5%)
(iv)	T3	Sandy loam soil 8,775 g (92.5%) + chicken manure 675 g (7.5%) (8775 + 675 = 9450 and % figures would be 92.5% and 7.5%)
(v)	T4	Sandy soil 8,775 g (92.5%) + mixed 675 g (7.5%) (8775 + 675 = 9450 and % figures would be 92.5% and 7.5%)

The selection of a specific ratio (7.5%) of organic soil amendments was based on several scientific and practical criteria (Bot and Benites, 2005). This ratio falls within a range commonly used in agricultural research, where moderate amendments are tested to evaluate their impact on soil properties without causing nutrient imbalances. Further, higher rates may be more costly and labor-intensive.

Installation of Sensors

Matric potential and volumetric water content sensors were placed in each pot at a depth of 10 cm because it provides the most valid and representative data and many plants have a significant portion of their root system within the top 10-15 cm of soil, where they absorb most of the water and nutrients. Additionally, two software tools, Zentra Utility and HOBO Ware, were used for automated data collection. For measuring chlorophyll, we used SPAD-502Plus, a portable device used to measure leaf chlorophyll content. For leaf areas index, we used ImageJ software.

RESULTS AND DISCUSSION

The soil moisture-irrigation relationship relies on balancing the timing and amount of water application to maintain soil moisture within an optimal range for plant uptake. After irrigation or rainfall, the soil reaches its field capacity. At this point, the soil has enough moisture for plants to absorb easily. If soil moisture falls below the permanent wilting point, plants are unable to extract adequate water, leading to wilting and, ultimately, death in the absence of irrigation. In an experimental context, sandy loam soil treated with chicken manure and mixed at a ratio of 7.5% by total mass demonstrated a significantly higher volumetric water content compared to other treatments.

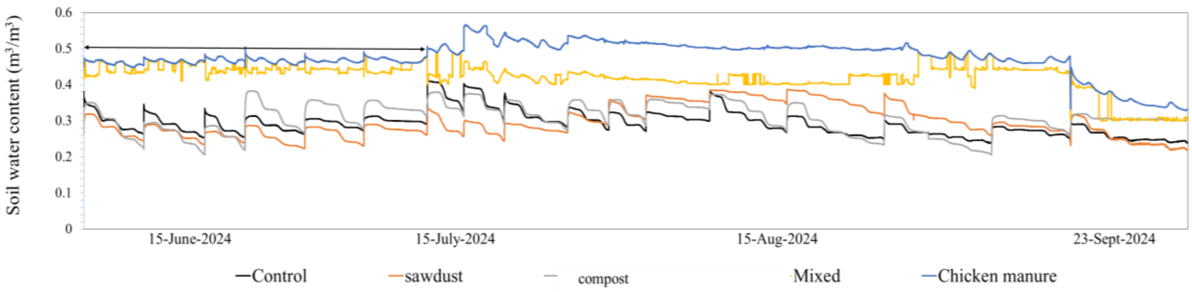


Fig. 2 Effects of organic amendments on soil volumetric water content

The data, as shown in Fig. 2, reveal that the moisture content of this treatment (represented by the blue and yellow lines) remained higher than that of untreated soils. This improvement in water-holding capacity may be attributed to increased cohesive forces, which enhance soil structure by attracting water particles. Consequently, the water-holding capacity of the treated soil exceeds that of untreated soil, indicating improved soil moisture availability for plant growth.

According to Figure 3 when soil is wet, the matric potential is near zero because water is easily available. As soil dries, water becomes more tightly bound to the soil, increasing the negative value of the matric potential (e.g., -50 kPa to -800 kPa), indicating that plants need to exert more effort to extract water. In this line graph, matric potential is monitored using sensors to measure soil water suction, which helps determine irrigation needs and optimize water use. Each line corresponds to a different organic amendment treated with soil. The blue, yellow, and orange lines remain higher and less steep than the others, indicating that these soil types retain water better at lower tensions, making it easier for plants to access water. Understanding matric potential helps optimize irrigation by providing a guide to when soil water content is too low and needs to be replenished to ensure plants receive adequate moisture for growth. This information aids in making informed decisions about irrigation practices.

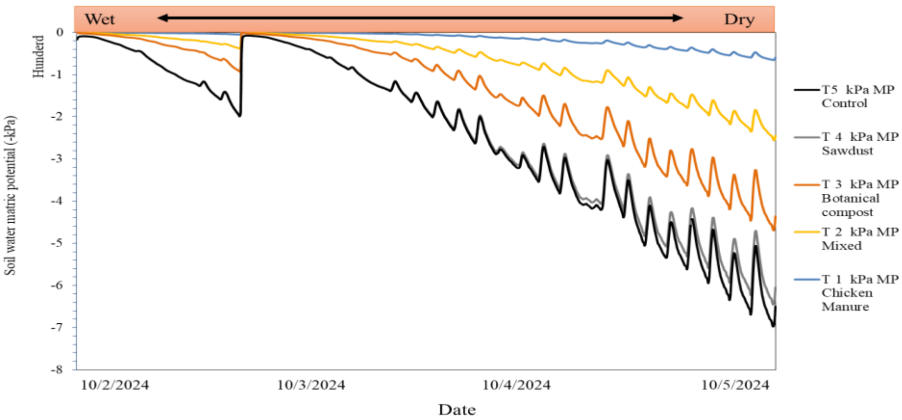
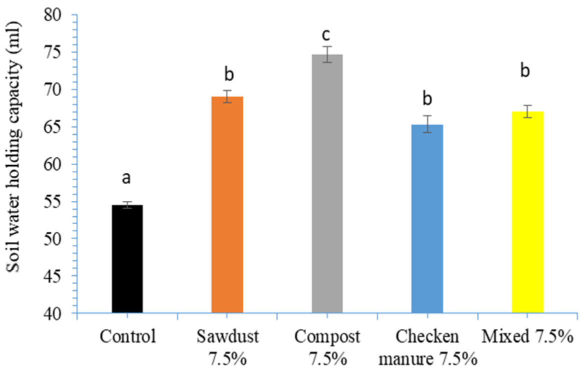


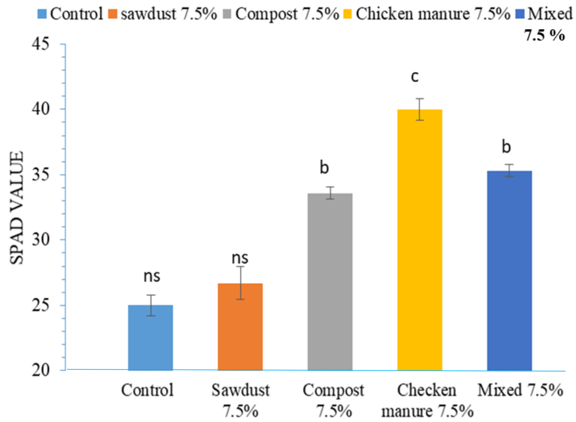
Fig. 3 Effects of organic amendments on soil matric potential

The bar graph suggests that different soil treatments have a significant impact on soil water-holding capacity. Compost at 7.5% has the highest water retention, followed by sawdust Figure 4. When added to soil, sawdust improves soil structure by increasing its porosity, allowing the soil to hold more water and nutrients. Sawdust has relatively low nutrient content and decomposes slowly compared to other organic materials, but it helps improve soil texture by increasing the proportion of finer particles. This creates more micropores that can retain water, unlike the larger macropores typical of sandy loam soils, which allow water to drain quickly. However, the grapevine leaves chlorophyll content significantly increased soil treated with compost, chicken manure and mixed at 7.5% (Fig. 5).



Notes: Error bars indicate the standard deviation of the mean; p < 0.01, ns: not significant compared to the control one way ANOVA.

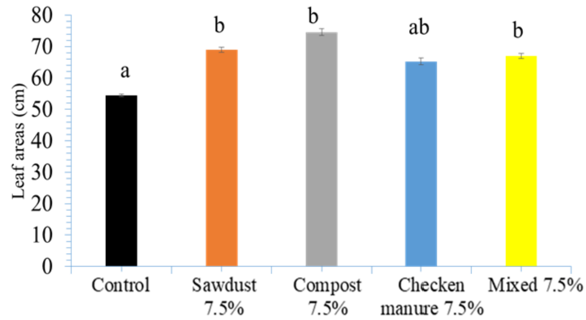
Fig. 4 Changes on soil water holding capacity at saturation with addition of organic amendments in sandy loam soil



Notes: Error bars indicate the standard deviation of the mean; p < 0.01, ns: not significant compared to the control one way ANOVA.

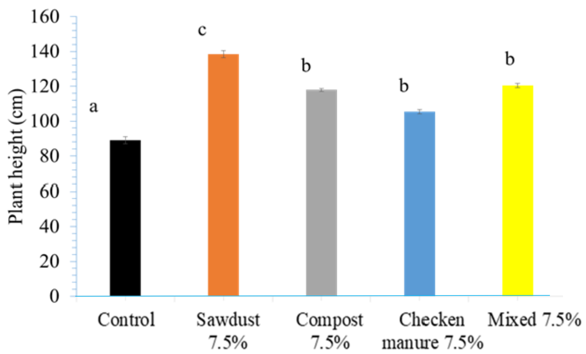
Fig. 5 Changes on grapevine leaves chlorophyll content with addition of organic amendments in sandy loam soil

According to the bar graph in Fig. 4, the nutrients and improved soil properties resulting from organic amendments promote overall plant growth and leaf area expansion. Larger and healthier leaves tend to produce and maintain more chlorophyll, enhancing photosynthesis and boosting vine productivity. According to Fig. 5, the amendments notably enhanced the chlorophyll content in grapevine leaves. Previous studies have also shown that chlorophyll content is a useful indicator for assessing nitrogen uptake in plants (Bojović and Marković, 2009).



Notes: Error bars indicate the standard deviation of the mean; p < 0.01, ns: not significant compared to the control one way ANOVA

Fig. 6 Changes on leaf area with addition of organic amendments in sandy loam soil



Notes: Error bars indicate the standard deviation of the mean; p < 0.01, ns: not significant compared to the control one way ANOVA

Fig. 7 Changes on plant height with addition of organic amendments in sandy loam soil

Leaves are one of the most important organs that plants have. Leaves enable photosynthesis, the process by which plants produce food using light, carbon dioxide (CO_2), and water. Leaves are essentially responsible for the productivity of a plant. Therefore, understanding the leaf area is important (Trimble, 2020). According to Figure 6, the effects of organic amendments on the leaf area of plants vary depending on the specific type of amendment used, the ratio of soil amendments, and the overall health of the grapevines. The addition of sawdust, compost, and chicken manure, mixed at a ratio of 7.5%, contributed essential nutrients to the soil and promoted healthy grapevine leaf area and growth compared to the control. As shown in Figure 7, adequate nutrient levels are crucial for photosynthesis and overall plant development. Soil amendments can influence factors such as nutrient availability, soil structure, water retention, and microbial activity, all of which can impact grapevine height and growth.

CONCLUSION

The experiment demonstrated that organic amendments significantly enhanced volumetric water content, soil water-holding capacity, and overall soil productivity, all are key factors for sustainable agriculture in water-scarce regions like Afghanistan. Chicken manure and the mixed treatment showed the highest volumetric water content and soil water matric potential, while sawdust and compost contributed the most to water-holding capacity due to their ability to modify pores distribution compared to control and promote with larger pores, which retain more water. Decomposition of organic matter releases essential nutrients in plant-available forms, as reflected in increased leaf area and chlorophyll content both indicators of improved plant health and photosynthetic efficiency as evidenced by increased leaf area and chlorophyll content. Thus, the application of organic amendments to sandy loam soils not only enhances water efficiency and plant growth but also promotes soil sustainability, supporting the long-term viability of Afghanistan's agricultural sector.

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Research article

Personal Hygiene Practices: Impact of Hygiene Education on Preschool Students in Phnom Penh, Cambodia

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Abstract Pathogenic microorganisms that cause severe infections in humans are primarily spread due to poor personal hygiene practices, such as inadequate handwashing and toothbrushing. Proper handwashing with soap and effective toothbrushing are recognized as essential defences against upper respiratory, gastrointestinal, and diarrheal diseases, as well as dental plaque, periodontal disease, and dental caries. This study implemented a comprehensive personal hygiene program aimed at preschool students, focusing on delivering hygiene education and incorporating pre- and post-education surveys to assess the program's effectiveness and impact. The personal hygiene activities were specifically defined as handwashing and oral hygiene. Participants included preschool students aged three to five years from Samdach Hun Sen Dangkor Primary School. The findings showed that pre-education personal hygiene scores for handwashing were below 1%, which significantly increased to 93% following the educational intervention, as verified by the "Hand washing training unit LED UV light." Similarly, pre-education scores for toothbrushing were 9%, with a notable improvement to 57%, as measured by the Qscan Plus device. An awareness survey conducted with 10 selected preschool students who participated in the training indicated a substantial enhancement in daily handwashing and toothbrushing practices post-training, with an improvement rate exceeding 50% for each question in the hand hygiene session (except for two questions) and over 80% for tooth hygiene after waking and post-meals. These results underscore the effectiveness of the training program in enhancing students' daily hygiene practices.

Keywords hygiene, hand wash, teeth cleaning, survey of awareness, preschool student

INTRODUCTION

The implementation of hand and oral hygiene among preschool students is crucial for promoting overall health. In Cambodia, improving handwashing and oral care for children is a priority, especially by raising awareness of the importance of proper hand hygiene and oral care. According to a previous report (UNICEF Cambodia, 2020), during the COVID-19 pandemic, hand hygiene plays an important role in protecting children from viral infection. However, the lack of handwashing facilities and appropriate washing methods are significant barriers. These challenges lead to children rarely washing their hands and ending up being infected with the virus. In 2020, contributing to improving handwashing for preschools in Cambodia, UNICEF Cambodia provided hygiene supplies and other safety education materials to 13,482 schools and 3,064 preschools throughout Cambodia (UNICEF Cambodia, 2020).

From the perspective of the researcher, washing hands with soap using the correct method could reduce the incidence of diarrhea by up to 50% (WHO,2001) and the risk of respiratory illnesses, such as colds, by 16–21% (Aiello et al., 2006; Aiello et al., 2008). In alignment with the Sustainable Development Goals (SDG 4.3 and SDG 4.7), the "Leading University Project for International Cooperation" (LUPIC project) established the Department of Food and Nutrition at the Royal University of Agriculture in 2022. This initiative focuses on acquiring knowledge and skills by strengthening the university's educational and teaching capacities. Therefore, supported by the LUPIC project, this research aims to develop a personal hygiene model for schools across Cambodia, promoting better personal hygiene practices nationwide.

OBJECTIVES

Following objectives were set in this research.

1. To define the current knowledge and practice of hand hygiene and oral care in a sample of preschool students
2. To deliver context / age-appropriate education and training programs for hand hygiene and oral care for the preschool students
3. To measure post-education knowledge and practices for hand hygiene and oral care in the preschool students
4. To provide recommendation how this program may be implemented throughout Cambodia

METHODOLOGY

Sampling and Scope of the Study

A randomized selection was made to select primary schools very close to the RUA. As a result, Samdach Hun Sen Dangkor Primary School in Phnom Penh was selected for the training. A total of 180 registered preschool students were selected as respondents and invited to participate in the training (personal hygiene education). Approximately 50% of the total respondents (100 students of 180 students) were selected for the pre-testing and post-testing to evaluate the improvement of the respondents' awareness of hand and teeth hygiene using the prepared questionnaire.

For this reason, a 3-sessions series training was conducted with preschool students in Samdach Techo HUN SEN Dangkor Primary and Secondary School in 2023 under the teaching and instruction from department staff and assisted by the 1st generation student from this department. The training aimed to link the department staff and students to share hygiene knowledge with the students in the hope of improving the hand hygiene and oral hygiene situation of the preschool students and guide them to keep this good habit for protecting them from infection of the disease and other pathogens that penetrate through the dirty hand or unhealthy teeth. The training provided the children with the theory and real practice of correct way for hand washing and teeth cleaning and verified the kids result practice with the equipment as a tool for strengthening their acceptance of the knowledge from the training.

Survey on the Awareness of Body Hygiene

A "personal hygiene awareness questionnaire for preschool students" was designed by the research team to evaluate the awareness level of personal hygiene (hand, teeth, and mouth hygiene) of the respondents. The questionnaire consisted of two main questions: (1) Knowledge of hand hygiene at different times, such as before and after meals, after sneezing, after toilet time, after play time, after touching with pet, and before helping the mother to prepare food were used for the pre- and post-evaluation of the research. Two additional questions about hand hygiene, how often they washed their hands, and how well they knew about the correct washing step, were also included (asked and confirmed the result of their practices with both devices for post-test). (2) Knowledge of oral hygiene at different times, such as before sleep, after sleep, after meals, how often they brush their teeth, and how well they know about correct brushing of their teeth were used in the questionnaire.

During the survey, 18 students from the Department of Food and Nutrition were assigned as facilitators to a group of 40-45 students. Facilitators responded by asking and collecting answers from students.

Education on Hand Hygiene

A series of educational programs of the "personal hygiene education" contained 4 weeks session. The details of the activities in each session are described as follows.

Session 1 Conduct pre-testing: For the academic year 2022-2023 students, the total number of kindergarten students was 180, which were divided into four classes and selected for personal hygiene education. Pretesting was conducted with approximately 50% of the total number of kindergartens (100 students). The pre-test aimed to show how well the students knew about personal hygiene before the training was provided. The results from this pre-testing were used for comparison with the post-testing results.

Session 2 Conduct hand hygiene training: The respondents watched a video illustrating the relationship between germ and disease. The video was designed using content related to the children and the current real situation of personal hygiene. The other activity was to teach which part of our hand should perform hand hygiene. This session focused on the awareness of the right time to perform hand hygiene. Facilitators play an important role in explaining the right region of the hand for performing suitable hand hygiene practices. Then, a traditional Khmer game called "hot potato" was played to enhance the children's learning effect. The "Hot potato" refers to the penalty paper ball made by rolled several papers together and each paper contained a question (the question related content just learnt). The game was played by letting the kids gather in the cycle and listen to the music while passing the ball from one to another. The kid passing the ball when the music stopped the one who got the ball received the penalty by answering the question (right part of the hand to perform hand hygiene).

In the same section, the facilitator demonstrated the correct conduct of handwashing with soap. After the class demonstration, the trainers divided the students into groups and conducted real demonstrations using tap water and soap on the school campus. Then, all students followed the trainer's steps one by one. Then, the knowledge was stimulated with practice using an LED UV light hand wash training unit. In order to assume a virtual bacterium, per the unit's best practice methodology, a fluorescent lotion for plant testing that is harmless to the human body to act as bacteria was used. Similar to real bacteria are invisible to the naked eye, the lotion used for testing is also invisible to the naked eye. However, when the hand is placed into the equipment, contamination can be detected with the naked eye. These conditions were assumed to represent the presence of infectious bacteria.

The practices of hand wash with the LED UV light hand wash training unit were practiced as follows.

(1) Apply the lotion evenly to the hands as much as a bean and let it dry for a while
(2) Put the hand on the viewpoint to check the level of contamination
(3) Wash your hands as usual
(4) Put the washed hand on the checker again, check the residual contamination level

(5) Wash the hands properly and wash hands with the method just learnt
(6) Check the result can compare with (4)

In addition to the demonstration by hand LED UV light wash training unit, I-stand, poster, and leaflet showing the right hand washing and when they should conduct it were also used to enhance the understanding. After all students finished their performance with the equipment, a post-test survey was conducted. The awareness survey used the same questionnaire as the pretest survey.

Session 3 Conduct oral hygiene training: Before starting the new section, the facilitator reviewed the “right practices” for hand hygiene and then started oral hygiene education. After that, the facilitator taught how to practice correct tooth brushing. The facilitator showed a video on “Brush Your Teeth” and explained it using the I-stand, poster, and leaflet. The contents of all the teaching materials showed how to brush our teeth correctly and how often they should be brushed. Moreover, some students were invited to demonstrate the correct method of cleaning their teeth in front of their friends. Subsequently, the facilitator provided them with toothpaste and toothbrushes and allowed them to do it by themselves. Then, the Qscan Plus Device was used to demonstrate and check their practices. This device was used to check the oral hygiene status. According to the device’s best practice method, four steps were performed as follows.
(1) The device was positioned on the mouth so that the LED could illuminate the respondent's teeth
(2) Turn on the device
(3) The respondents’ teeth were checked through a filter. During self-inspection, check the teeth using a mirror
(4) Turn off the device

Data Analysis

The data were analyzed using SPSS statistical software (version 25). The data of the pre-test and post-test surveys were expressed as percentages (%) through “Cross-tab analysis. Differences in the outcomes of each question between the two groups (“pre-test” and “post-test”) were tested using Pearson’s chi-square test. The significance of all results was set at $p < 0.05$.

Fig. 1 Hand sanitation check-up before/after hand wash training with Unit LED UV light (A) and teeth sanitation check-up with Qscan Plus equipment (B)

RESULTS AND DISCUSSION

Hand Hygiene

The hand hygiene training provided aimed to guide the students on the proper method of handwashing and make it a habit for their lives. Because actual germs are invisible, many people overlook them and wash their hands roughly in their daily lives or even avoid hand washing.

From the pre-test results (Table 1), seven situations were raised to observe how much the respondent was aware of the right time for washing hands. As a result, before and after eating and after sneezing, only 25%, 10%, and 18% of the respondents washed their hands, respectively. After toilet time, playing time, touching the pet, and food preparation, 5%, 7%, 5%, and 8% washed their hands before food preparation, respectively. During the pre-test survey, respondents were less likely to wash their hands because they did not know when to do so. They mentioned that they washed their hands whenever they saw dirt on their hands or were asked by their parents/teachers. Surprisingly, some respondents even washed their hands before and after eating or after sneezing, but the chance of them using soap every time they washed their hands was very low. Only 4% of them used soap every time they washed their hands because they did not see any dust or dirt on their hands, so they used only water without soap most of the time. Moreover, the pre-test results showed that only 4% of the respondents knew the correct way of washing their hands. In addition, the results showed that the respondents had very low awareness of handwashing.

Table 1 Result of the awareness of hand hygiene from pre-test and post-test survey

N	Questions: When do you need to wash your hands?		Respondents answer (n=100)			
			Yes (%)	No (%)	Don't know (%)	p value
1	Before eating					0.000***
		Before training	25.00	75.00	0.00	
		After training	99.00	1.00	0.00	
2	After eating					0.000***
		Before training	10.00	90.00	0.00	
		After training	93.00	6.00	1.00	
3	After sneezing					0.000***
		Before training	18.00	81.00	1.00	
		After training	94.00	6.00	0.00	
4	After toilet time					0.000***
		Before training	5.00	95.00	0.00	
		After training	91.90	7.10	1.00	
5	After play time					0.000***
		Before training	7.00	93.00	0.00	
		After training	99.00	1.00	0.00	
6	After touching pet					0.000***
		Before training	5.00	61.00	34.00	
		After training	63.00	3.00	34.00	
7	Before preparing food (for helping mother)					0.000***
		Before training	8.00	69.00	23.00	
		After training	74.00	3.00	23.00	
8	Using soap every time for washing hands					0.000***
		Before training	4.00	96.00	0.00	
		After training	98.00	2.00	0.00	
9	Washing hands correctly					0.000***
		Before training	4.00	96.00	0.00	
		After training	95.00	5.00	0.00	

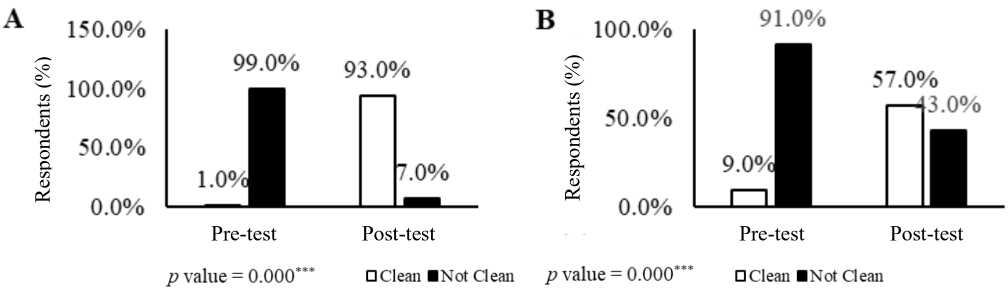
*Note: Pearson Chi-square test for p value: *** Statistically significantly different at $p < 0.001$.*

Handwashing training was provided to improve respondents' awareness of hand hygiene. After the training, a post-test survey (Table 1) was conducted to evaluate the effectiveness of the training on respondents' perception of hand washing. Consequently, their awareness of handwashing changed dramatically in all aspects. Before and after eating, and after sneezing, up to 99%, 93%, and 94% of the respondents washed their hands, respectively. Moreover, after toilet time, after playing time, after touching the pet, and before food preparation, the results showed that 91.9%, 99%, 63%, and 74% of the participants, respectively, washed their hands correctly.

According to the chi-square test table, the p-value of Pearson chi-square was < 0.001, providing evidence of significantly difference in each question (question 1-7) between the pre-and "pre-test" result and "post-test" results. The training resulted in 74 the improvement in hand wash awareness before eating, 83% after eating, 76% after sneezing, 86.9% after using the toilet, 92% after playing, 58% after touching pets, and 66% before preparing food (help their mother). Additionally, in the "after touching pet" situation, 34% of respondents did not show any improvement because they did not raise any pets at home or play with pets in their free time. In the "before preparing food" situation, 23% of respondents still did not show any improvement because they did not help their mothers prepare food because they were too young to cook.

The demonstration of hand washing with LED UV light in the hand wash training aimed to allow the respondents to clearly see how germs contact their hands. As shown in Fig. 2A, before learning the correct handwashing method, up to 99% of the respondents had unclean hands. This result indicates that with respondents' own habit of hand washing, there is a very high chance of germs still attached to their hands, which easily leads to many infections. A total of 99% of the respondents showed unclean hands when displayed with the equipment because they did not wash their hands with soap or used soap but did not scrub their hands correctly. By following the correct hand washing method from the trainers, the respondents practiced and checked the equipment again. The results showed that the number of unclean hands was only 7%, and that of clean hands increased to 93% of total respondents.

According to chi-square tests, the p value of Pearson chi-square is < 0.001 give the evidence of significant difference of "Hand sanitation check-up" between "pre-test" and "post-test" results. With a 92% improvement in clean hands, the outcomes showed a positive effect of the training on the respondents' hand hygiene habits. The demonstration with this equipment also correlated with the increase in their habit of using soap every time of washing and awareness of the correct way of hand washing.



*Note: Pearson Chi-square test for p value: *** Statistically significantly different at $p < 0.001$*

Fig. 2 Results of checking before/after hand wash training with Unit LED UV light (A) and of checking with Qscan Plus equipment (B)

Teeth Hygiene

The mouth-teeth hygiene training aimed to guide the students on the proper method of mouth-teeth cleaning and make it a habit for their life. Neglecting mouth-teeth cleaning can lead to many mouth-teeth health problems.

Table 2 Result of the awareness of teeth hygiene from pre-test and post-test survey

N	Questions: when do you need to wash your hand?	Respondents answer (n=100) Yes (%)	No (%)	Don't know (%)	*p* value
Situations to clean the teeth					
1	After waking up				0.000***
	Before training	4.00	96.00	0.00	
	After training	94.00	6.00	0.00	
2	After meal				0.000***
	Before training	9.00	91.00	0.00	
	After training	89.00	11.00	0.00	
3	Before bedtime				0.100
	Before training	87.00	11.00	2.00	
	After training	95.00	5.00	0.00	
Awareness of teeth cleaning					
4	Do you know how to brush teeth correctly?				0.000***
	Before training	0.00	100.00	0.00	
	After training	96.00	4.00	0.00	

*Note: Pearson Chi-square test for p value: *** Statistically significantly different at $p < 0.001$.*

From the pre-test survey (Table 2), three situations were raised to test the respondents' awareness of mouth-teeth cleaning. The results showed that 4% of the respondents cleaned their teeth after waking up, 9% cleaned their teeth after meals, and 87% cleaned their teeth before going to bed. The low result of cleaning after waking up and after meals is because the respondents only brush their teeth when their parents told them to do so, or their parents sometimes cleaned their teeth for them. Additionally, before mouth-teeth hygiene training was provided, none of the respondents (0%) knew the correct method of tooth cleaning.

After the training, a post-test survey was conducted to evaluate the effectiveness of the training on respondents' awareness of mouth-teeth cleaning. As a result, their awareness of mouth-tooth hygiene dramatically changed in all three situations. The post-test results in Table 2 show that 94% of respondents brushed their teeth after waking up, 89% brushed their teeth after meals, and 95% brushed their teeth before going to bed.

According to the chi-square test table, the p-value of Pearson's chi-square for cleaning teeth after waking up "after waking up" and "after meal" situation is < 0.001 give the evidence of significantly different between "pre-test" result and "post-test" results. However, the p-value of Pearson's chi-square for cleaning teeth at "before bedtime" situation is > 0.05 give the evidence of non-significantly different between "pre-test" result and "post-test" results. Comparing the results of the pre- and post-tests, the training effect on mouth and teeth hygiene awareness showed an improvement in cleaning teeth after waking up (90 %), cleaning teeth after meals (80 %), and cleaning teeth before bedtime (8 %).

Checking teeth after cleaning with the Qscan Plus Device provides evidence of how respondents can acquire knowledge from training. As shown in Fig. 2B, before receiving training, 9% of the respondents were able to clean their teeth correctly, and 91% of the respondents cleaned their teeth incorrectly. After receiving training, 57% of respondents had clean teeth.

According to the chi-square test table, the p-value of Pearson's chi-square for "teeth check-up" result is < 0.001 give the evidence of significantly different between "pre-test" result and "post-test" result. Comparing the results between the pre- and post-tests, a 48% improvement was found among the respondents regarding tooth cleaning. The demonstration with this equipment also correlated with an increase in the frequency of tooth cleaning before and after training.

When asked, 'How many times do you brush your teeth per day?' Twelve% of students said that they did not or rarely brush their teeth, and 79% brushed once per day (some brushed in the morning, while some brushed in the evening as ordered by their parents). Only 9% of the students brushed their teeth twice daily before the training. Moreover, none of the respondents brushed their teeth three times per day or did not know about tooth cleaning.

Table 3 Result of frequency of cleaning teeth from pre-test and post-test survey

Questions: How many times do you brush your teeth in a day?	Respondents answer (n=100) Pre-test (%)	Post-test (%)
None	12.00	1.00
1 time	79.00	1.00
2 times	9.00	17.00
3 times	0.00	81.00
4 times	-	-
P value	0.000***	

*Note: Pearson chi-square test for p value: *** Statistically significantly different at p < 0.001.*

According to chi-square tests table, the *p* value of Pearson chi-square for "frequency of cleaning teeth" result is < 0.001 give the evidence of significant difference between "pre-test" and "post-test" results. There were 81% improvement for brush teeth 3 times per day and 8% improvement for brush teeth 2 times per day, and these were very positive results from the training for changing the habit of the student from not clean their teeth or clean in a very low frequency (1 time per day) to clean their teeth in high frequency (2 or 3 times per day).

According to the "Piaget's four stages of cognitive development" raise by Swiss philosopher and psychologist, children at the age of 4-7 are categorized into "Intuitive thought" of the second stage (pre-operational). In this stage, the children can learn the object through "image, word, and drawing" and able to build the stable concepts, reasoning, and magical beliefs (The Neurotypical Site, 2023). By using the poster, I-stand, video for teaching the correct way of hand wash and real demonstration by the trainer made the respondents easy to understand well about the content of the teaching. This can be verified by the increasing data for "clean hands" from hand sanitation check-up. The increasing data of cleaning hand is the evidence that the respondent agreed that the using soap and water equipped with correctly way of hands wash is the best way for them to protect their hands from germs, these results were consistent with some other previous studies (Lopez-Quintero et al, 2009; Hazazi et al, 2018; Assefa and Kumie, 2014; O'reilly et al., 2008; Aziz et al., 2012) . This result showed that training had a positive effect on student awareness regarding hand hygiene. Furthermore, evidence from a previous study (Leal) showed that children at the age–5-6 years old can perform the ability to wash their teeth better than younger children. This evidence could explain why the children improved their awareness regarding teeth hygiene in a very short period after receiving the lecture from the training. This result showed that training had a very positive effect on student awareness of mouth-teeth hygiene

CONCLUSION

After 3 sessions of three training sessions, the results showed improvement in hand washing for all aspects (before eating for 74%, after eating for 83%, after sneezing for 76%, and after playing time for 92%, after touching pets for 58%, and before preparing food for 66%). As for the improvement in teeth hygiene awareness, the results showed a positive increase for all three raised situations (cleaning teeth after waking up for 90%, cleaning teeth after meals for 80%, and cleaning teeth before bedtime for 8%). These results showed that training had positive effects on improving students' awareness regarding hand hygiene and teeth hygiene. This program should be considered as a way to reduce the burden of infectious diseases in Cambodia. The program could be used to reduce the incidence of infectious diseases by teaching children the importance of handwashing, proper food handling, and personal hygiene. However, owing to the evaluation of the improvement conducted after the training was completed, ensuring long-term effectiveness remains difficult to prove. Therefore, further research should focus on the sustainable effectiveness of training and spread to rural areas in Cambodia. Furthermore, for this education to be effective and sustainable, personal hygiene education should be the same for parents and teachers, as it plays a key role in monitoring and motivating children to practice properly and consistently.

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Research article

Assessing Land Use Change and Causes of Deforestation in the Last 30 Years Using Satellite Images in the Municipality of Cobija, Pando Province, Bolivian Amazonia

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Abstract This study employs advanced Geographic Information System (GIS) techniques and satellite imagery to conduct a comprehensive analysis of land use and land cover changes and deforestation trends over the course of three decades within the Cobija Municipality, situated in the heart of Bolivian Amazonia. The research focused on light on the intricate relationship between human activities, environmental alterations, and socio-economic conditions, particularly emphasizing Cobija city's susceptibility to illegal logging, heavily influenced by the region's low economic income. Within this geographic expanse, characterized by rich biodiversity and vast forest cover, Cobija grapples with pivotal challenges. Dominated by agroforestry (51.04%) and Amazonian fruit cultivation (29.16%) as primary economic activities, the area faced persistent hurdles in converting pastures into agriculturally viable fields. This struggle is compounded by socio-economic disparities, with 26.04% of the population earning the Bolivia's minimum wage, and a striking 61.45% subsisting on incomes below this threshold. Notably, Cobija, despite being a significant timber supplier, stands as one of Bolivia's poorest cities. The role of timber extraction significantly contributed to deforestation trends in Cobija, exacerbating the region's socio-economic challenges. The lure of profits from the timber trade amplified the pressures on forested areas, rendering Cobija highly susceptible to deforestation practices. The outcomes of this research underscore the urgent need for nuanced policy interventions. By integrating economic incentives into conservation strategies, policymakers can address the intricate interplay between socio-economic conditions and environmental conservation in Cobija. This holistic approach is essential to foster sustainable land management practices, mitigate deforestation, reduce erosion risk and preserve the ecological integrity of the Bolivian Amazonia.

Keywords land use and land cover, deforestation, satellite imagery, socio-economic conditions, Amazonia

INTRODUCTION

Tropical deforestation is an important issue because of its possible ecological, environmental, economic, and agronomic effects (Myers, 1995). Deforestation has occurred in the tropics throughout history (Tucker and Richards, 1983; Hecht and Cockburn, 1989; Williams,1989) and has accelerated recently, particularly in areas of seasonally deciduous tropical forests (Schmink and Wood, 1984; Janzen, 1986; Fearnside, 1986, Houghton, 1991; Skole and Tucker, 1993; Maass, 1995). Accurate information on the extent of tropical forests and deforestation is essential for estimation of changes in surface energy balance and atmospheric greenhouse gas emissions (Cook et al., 1990; Gash and Shuttleworth, 1991).

An important consideration among several factors affecting agricultural sustainability of land converted from rainforest to arable or pastoral land uses is adverse changes in soil properties that influence the soil's quality and productivity. Deforestation and intensive agricultural land use can lead to land degradation, with drastic adverse changes in soil properties such an increase in bulk density, a decrease in aggregation and aggregate size distribution, a reduction available water-holding capacity, a decrease in macro porosity and infiltration capacity (Lal and Cummings, 1979; Alegre et al., 1986), and an increase in susceptibility to erosion (Lal, 2003). These effects are exacerbated by a reduction in the activity and species diversity of soil fauna, a decrease in the quantity and quality of soil organic matter content, and a possible reduction in the formation of organic mineral complexes, etc. Intensive burning can also alter aggregate size distribution (Ghuman and Lal, 1989).

The research area of Cobija Municipality is in Bolivian Amazonia, serving as the capital of the Department of Pando and the Province of Nicolás Suárez. Over the past two decades, Cobija has experienced substantial deforestation rates (Bolivian National Statistical Institute, 2015). The progress of this phenomenon was significantly shaped by the prevailing socio-economic characteristics within the area, with this region standing out as one of the most economically deprived areas throughout Bolivia.

OBJECTIVE

The study aims to comprehensively analyze and quantitatively assess the evolving patterns of land use and land cover changes and deforestation within the specified region over the past three decades, concurrently investigating and discussing the causative factors driving deforestation trends.

METHODOLOGY

Site Description

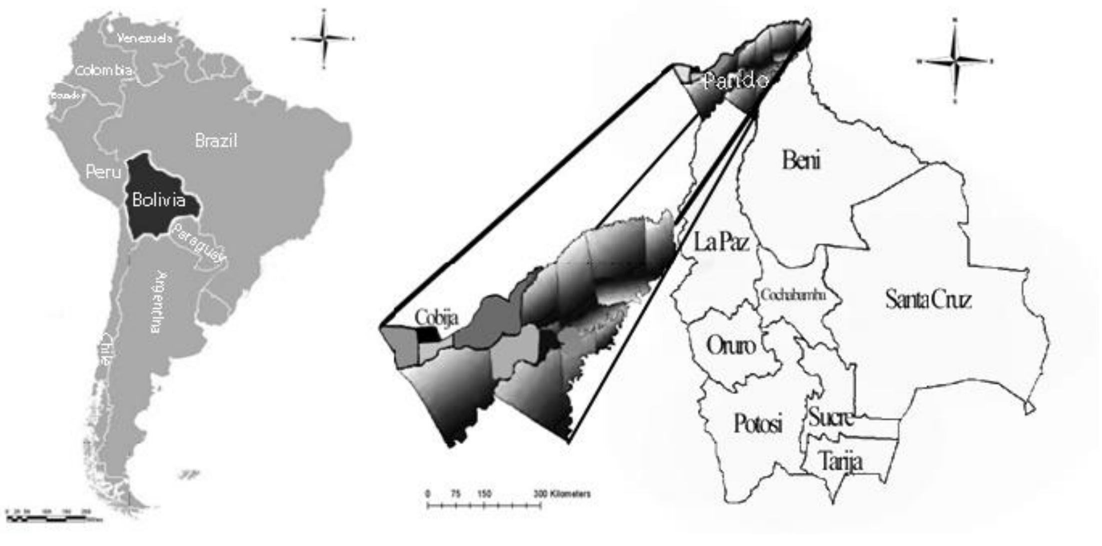

Fig. 1 Location of study area in Cobija, Bolivian Amazonia

The land uses were greatly influenced by the regional development strategy initiated by the Bolivian Government in 1989. Local farmers gradually transformed the forested landscape into other land uses. The climate in the study area is classified as equatorial, characterized by hot and humid conditions with a tropical transition. There is a distinct dry season from June to August, and the average annual precipitation is 2,016 mm (Mayoralty of Cobija, 2022). The research area spans 401 km^2, with an average annual temperature ranging from 32˚C to 24˚C. The monthly average air moisture ranges from 80 to 85 percent. The terrain is undulating, with elevations ranging from 100 to 120 meters above sea level.

Data Collection Strategy

The data was collected using Landsat satellite imagery from 1992 to 2023, strategically chosen to cover a three-decade timeline, facilitating a comprehensive analysis of temporal land use changes. Specifically sourced from Landsat 5, 7, and 8 satellites, ensured temporal consistency and access to diverse spectral bands essential for detailed land cover analysis. By meticulously curating these temporal intervals and satellite sources, this study dealt with the evolution of land use patterns within the Cobija Municipality over the last 30 years. This dataset empowered an in-depth examination of land cover dynamics.

Preprocessing Steps

Preprocessing of the Landsat imagery included radiometric and geometric corrections, using the Dark Object Subtraction (DOS) method in ArcGIS to mitigate atmospheric distortions. The annual selection of the best available image minimized cloud influence and atmospheric variability. This process standardized the dataset, harmonizing spectral responses across different sensors and acquisition dates, which facilitated a reliable analysis of land use dynamics and deforestation trends in Cobija Municipality.

Pixel-Level Analysis Preparation

Preprocessed Landsat imagery, prepared using ArcGIS, formed the basis for pixel-level analysis, including spectral analysis and classification, to assess land use and land cover changes and the causes of deforestation over the last 30 years in the Municipality of Cobija, Pando Province, Bolivian Amazonia. The preprocessing workflow in ArcGIS involved radiometric calibration, atmospheric correction, geometric alignment, and cloud masking to ensure the imagery was free from artifacts and distortions that could compromise accuracy. These steps harmonized spectral data across different acquisition dates and sensors, enabling precise pixel-by-pixel comparisons.

Land Cover Classification

Utilizing unsupervised classification techniques, this study delineated distinct clusters and patterns within the satellite imagery, facilitating the identification of varied land cover classes solely based on spectral characteristics. Not reliant on prior training data, this approach enabled a comprehensive exploration of the multifaceted land cover types prevalent in Cobija Municipality. This study used unsupervised classification algorithms like K-means and ISODATA to cover land map in Cobija using only the spectral information from satellite imagery.

These algorithms group similar pixels into clusters representing different land use and land cover types. ISODATA, specifically, refines these clusters by merging or splitting them based on statistical thresholds, effectively adjusting the number of classes to better capturing the complex spectral variations in the imagery and produce a more accurate land use and land cover map.

Socio-economic Analysis

In accordance with data sourced from the National Institute of Statistics in Bolivia (INE), the estimated population of Cobija city stands at 46,267 individuals. Of this population, 25.3% reside in rural areas, constituting a total of 11,708 rural inhabitants. Employing a confidence interval of 95% and a margin of error of 5%, the sample size utilized for the study was determined to be 96 individuals.

To those 96 individuals, socio-economic survey was conducted focusing on age, gender, farming experience, education, occupation, land size area, annual income, household size, agricultural activity, type of farming, in addition to deforestation reason.

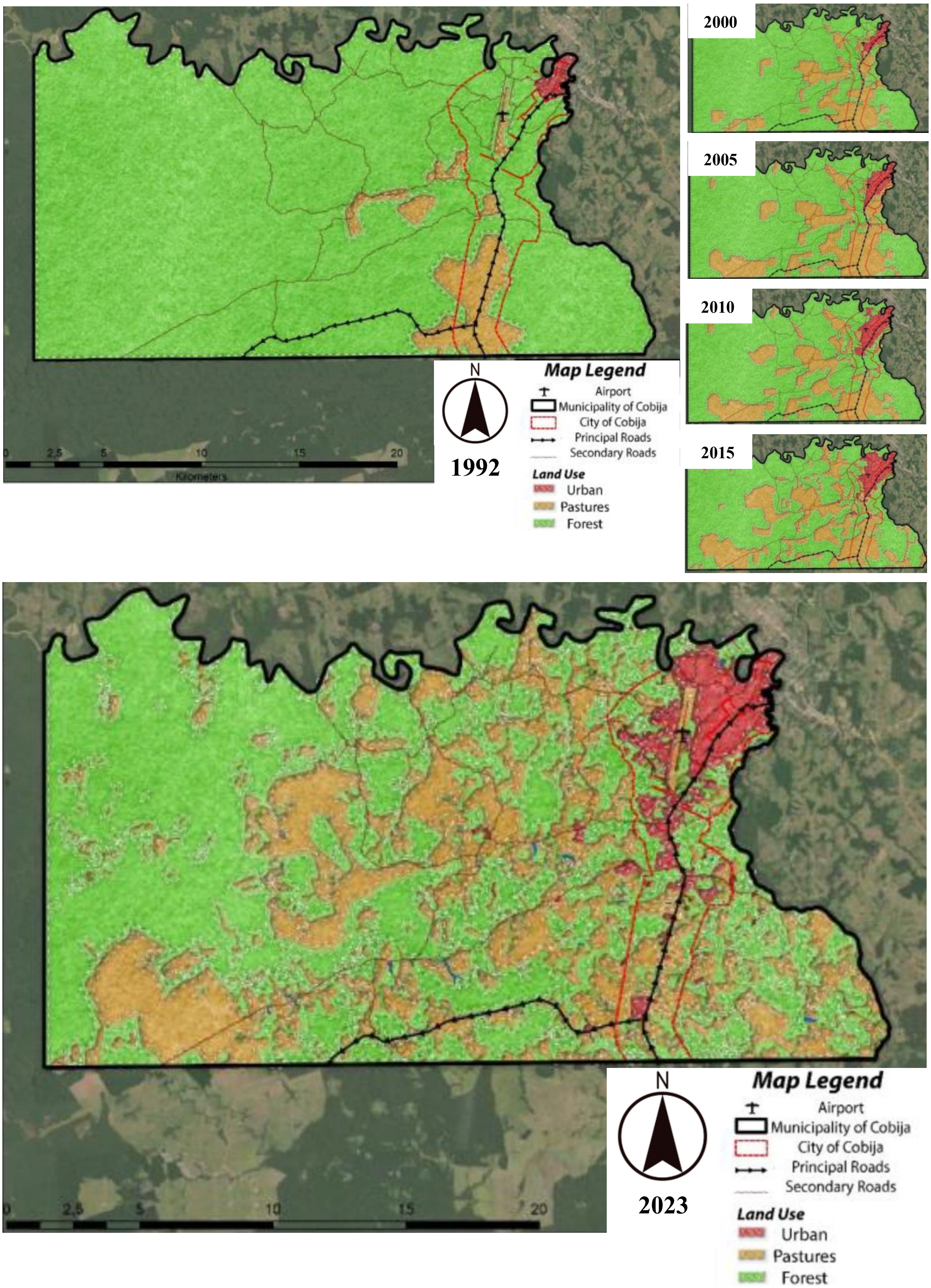

Fig. 2 Land use and land cover changes with Landsat imagery from 1992 to 2023

RESULTS AND DISCUSSION

Temporal Analysis of Land Use Changes

The analysis of Landsat imagery from 1992 to 2023 revealed distinct temporal trends in land use and land cover within the Cobija Municipality (Fig. 2, Tables 1 and 2). Over this three-decade period, noticeable shifts in land cover dynamics were observed, notably in forested areas. Initial assessments indicated a gradual decrease in forest cover, particularly between 2005 and 2015, followed by a potentially accelerated rate of deforestation by 2023. These findings suggest a concerning trend of land transformation.

Table 1 Land use and land cover changes in hectares from 1992 to 2023

	Year					
Land use	1992	2000	2005	2010	2015	2023
Forest	37546.63	31801.28	28354.71	27681.03	26121.14	24043.96
Pasture	1964.90	6544.32	9092.70	9283.15	10201.44	11737.27
Urban area	244.61	609.52	1034.58	1500.74	1924.80	2177.43
Agriculture	344.86	1154.88	1608.1	1636.08	1852.62	2141.34

Table 2 Land use and land cover changes in percentages from 1992 to 2023

	Year					
Land use	1992	2000	2005	2010	2015	2023
Forest	93.63%	79.28%	70.71%	69.03%	65.14%	59.96%
Pasture	4.90%	16.32%	22.70%	23.15%	25.44%	29.27%
Urban area	0.61%	1.52%	2.58%	3.74%	4.80%	5.43%
Agriculture	0.86%	2.88%	4.01%	4.08%	4.62%	5.34%

Analysis of land use and land cover changes between 1992 and 2023 revealed a significant shift in land cover within the study area. Forest cover experienced a substantial decline, decreasing from 93.63% (37,546.63 ha) in 1992 to 59.96% (24,043.96 ha) by 2023, representing a loss of over 13,500 ha. This loss is primarily attributed to the expansion of pastureland, which increased from 4.90% (1,964.90 ha) to 29.27% (11,737.27 ha) over the same period, indicating a strong trend of forest conversion for livestock grazing. While urban and agricultural areas also expanded, growing from 0.61% to 5.43% and 0.86% to 5.34%, respectively, their growth in terms of area was considerably less pronounced than the expansion of pastures. This analysis underscored the dominant role of pasture expansion as the primary driver of deforestation within the study area during the examined time frame.

Spatial Distribution of Deforestation

The spatial analysis of deforestation hotspots across the municipality exhibited spatial clustering primarily along the eastern and southern fringes, coinciding with increased expansion of pasture and urban areas. Notably, these areas exhibited consistent patterns of forest degradation and conversion to other land uses, highlighting specific regions that demanded immediate conservation attention.

Socio-economic Impact on Deforestation

In Bolivia, the department of Pando stands out as one of the most economically challenged regions, grappling with pronounced levels of extreme poverty, as identified by the FAO. Table 3 revealed a population primarily engaged in small-scale, subsistence or socio-communitarian agriculture, focused on agroforestry and Amazonian fruit production, characterized by low incomes, small landholdings (under 1 ha for 88.54% of respondents), and limited formal education. The primary driver of deforestation is economic necessity, with low income (46.87%) and low profitability of agriculture (19.80%).

Also, Fig. 3 illustrated a significant increase in timber price over the past three decades. Prices surged from USD 281 per 1,000 board feet in 1992 to USD 369 in 1996 and USD 430 in 2004. This upward trend intensified after 2015, with prices reaching USD 593 in 2018 and peaking at USD 1,500 in 2021. This trend on rising timber price directly incentivized logging activities, often leading to increased rates of deforestation, particularly in regions where governance and enforcement are weak (FAO and UNEP, 2020; Global Forest Watch, 2021). This escalating profitability has become a key driver of deforestation, particularly in regions with weak governance, such as Cobija, one of Bolivia's poorest cities. Cobija has a remote location, limited state oversight, and proximity to international borders facilitate illegal logging and timber trafficking. As a results, Bolivia's forest cover has declined significantly, from 93.63% in 1992 to 59.96% in 2023. This demonstrates the critical link between rising timber prices and accelerated deforestation in regions with high economic dependence on natural resources and limited regulatory capacity.

Table 3 Socio-economic profiles of farmers in the rural area of municipality of Cobija

Socio-economic characteristics	Frequency	Percentage	Socio-Economic characteristics	Frequency	Percentage
Age			Annual income		
Less than 40	43	44.79	More than 6,000 $	4	4.16
41-50	26	27.08	Between 4,000-6,000 $	8	8.33
54-60	13	13.54	Between 3,900-4,000 $	25	26.04
61-70	8	8.33	Between 740-3,900 $	38	39.58
Above 70	6	6.25	Less than 740$	21	21.88
Gender			Household size		
Male	52	52	1-5	30	31.25
Female	44	44	6-10	40	41.66
Others	4	4	11 persons or more	26	27.08
Farming experience			Agricultural activity		
1-5	8	8.33	Agroforestry	49	51.04
6-10	11	11.45	Rice production	5	5.20
11-15	35	36.45	Tuber production	6	6.25
16-20	26	27.08	Horticulture	8	8.33
More than 21	16	16.66	Fruits production	28	29.16
Education			Type of Farming		
Undergraduate	10	10.41	Extensive	9	9.37
High school	39	40.62	Commercial	20	20.83
Middle school	29	30.20	Subsistence	33	34.37
Basic school	18	18.75	Socio-communitarian	34	35.41
Occupation			Deforestation reason		
Employed	15	15.62	Low income	45	46.87
Self-Employed	75	78.13	Absence of landowner	11	11.45
Pensioner	6	6.25	Low productivity	12	12.50
Land size area			Low profitability	19	19.80
Less than 1 ha	85	88.54	No other income	9	9.37
Between 1 and 2 ha	6	6.25			
More than 2 ha	5	5.20			

Source: Field survey conducted in September 2018

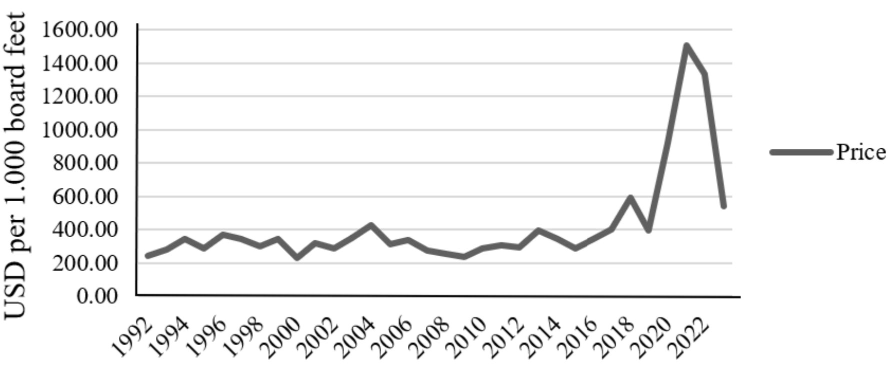

Fig. 3 Changes in timber price in USD for the last 30 years

Identification of Deforestation Drivers

Between 1992 and 2023, forest cover in Bolivia's Pando department declined sharply from 93.63% (37,546.63 ha) to 59.96% (24,043.96 ha), losing over 13,500 ha. Pasture expansion was the primary driver, growing from 4.90% (1,964.90 ha) to 29.27% (11,737.27 ha), fueled by economic necessity in one of Bolivia's poorest regions. In Pando, 88.54% of landholders operate under 1 ha, with low incomes and limited education. Economic pressures, including low income (46.87%) and unprofitable agriculture (19.80%), force land conversion. Rising timber prices, from USD 281 in 1992 to USD 1,500 in 2021, have further incentivized deforestation, particularly in regions like Cobija, where weak governance enables illegal logging. Combined these factors emphasize the urgent need for sustainable agriculture and stricter resource management to mitigate forest loss and support local livelihoods.

CONCLUSION

The land use and land cover analysis spanning from 1992 to 2023 revealed the decline of forest areas and transformation to other land uses. Especially concerning the forest areas, the data indicated a consistent decline over the three-decade period. Although forest area was 93.63% in 1992, it gradually reduced to 59.96% in 2023. This steady decline meant a substantial loss of the region's forested areas over time. Also, this study highlighted a significant land transformation from forest areas into alternative land uses, such as primarily for pastures, urban areas, and agricultural lands as shown in Fig. 2 and Tables 1 and 2. These changes have been progressed consistently over the past three decades in the study area. Among these transformations, the growth of pastures was remarkable. In 1992, pastures covered only 4.90% of the area, but it had risen to 29.27% in 2023. This steady increase suggested a deliberate shift driven by the economic challenges faced by local communities. The conversion to pastureland is particularly significant in regions like Pando, where subsistence agriculture dominates, and limited income opportunities accelerate deforestation.

It was considered that socio-economic conditions were directly related with deforestation. The cohesive analysis underscored the intricate interplay between economic activities, land ownership patterns, and environmental drivers, enriching our understanding of socio-economics influences on land use decisions and the multifaceted causes behind deforestation. Moreover, recognizing the pivotal role of wood prices in shaping land use, policymakers are urged to devise comprehensive strategies intertwining economic incentives with conservation efforts, imperative for fostering sustainable land management practices and mitigating deforestation's adverse impacts on local ecosystems and biodiversity.

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Research article

Long-Term Hydrologic Trend Analysis of the Diamphwe River Basin in Central Malawi

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Abstract Extreme weather events in developing countries can cause economic consequences, livelihood losses, and increased financial and societal costs. Identifying these events is often accomplished through trend analysis of historical climatic and hydrologic data. This study focused on the Diamphwe River basin in central Malawi. The Diamphwe River basin is a vital region supporting wetlands, ecosystems, agriculture, and water supplies, as well as irrigation for winter vegetable cropping for the Dedza and Lilongwe districts. Over 90 percent of local households earn their livelihood through rain-fed reliant farming. Long-term hydrologic trends were analyzed for the region, which is essential for managing and improving its agricultural productivity. Mann-Kendall and Pettit trend tests were conducted using 1975 to 2010 rainfall and river discharge data generated by R software and XLSTAT. The research revealed long-term trends of decreasing rainfall and river discharge, with 1988 as a transition year for the decreasing trends of the parameters in the basin. We also found that there was trend consistency within each month. Both rainy season and dry season months showed decreasing within months trends of the two parameters. Further, the river discharge fluctuation was significant in November and December, when the dry season changes to the rainy season, and in April, when the rainy season changes to the dry season. To sustain rainfed agriculture and introduce irrigated agriculture, it is suggested that water use planning should be based on the assumption that rainfall and river discharge will gradually decrease in/over what time frame? And that river flow fluctuations will become more significant and impactful in November, December, and April.

Keywords climate change, trends, river discharge, rainfall, Mann-Kendall test, Pettitt test

INTRODUCTION

According to the UN Food and Agriculture Organization (FAO), the world's population is expected to be 9.1 billion by 2050 (FAO, 2009). Irrigation development will be necessary to increase and maintain sufficient food production, especially in Africa, due to its combination of projected population gain and relative insufficiency of water. The FAO advocates climate-smart agriculture

(CSA), which requires the promotion of agriculture with enhanced adaptability to climate change (FAO, 2013). Some examples of CSA include vermicompost and mineral water applications to improve plant growth parameters (Saiyakit and Boonthai Iwai, 2022), reduced-tillage cultivation, crop leftovers and cover crops to keep farmland covered and rotating of crops. Additionally, the use of drip irrigation is key to equitable and economical water distribution in areas with water scarcity (Muhammad Zaharaddeen et al., 2023). Analysis of long-term changes in rainfall and river discharge is necessary to develop irrigation plans that adopt CSA and minimize the impact of climate change. A thorough analysis of hydroclimatic parameter trends, for example, by measuring rainfall at the watershed level using Mann-Kendall and Pettitt tests, can help predict potential hazards (Sayemuzzaman and Jha, 2014). Further, Barua et al. (2013), argue that analyzing local hydroclimatic variables is essential to understand and react to climate change's impact on a specific area. Studying river discharge changes and weather patterns is essential to improve ecological sustainability and agricultural production, noted Klavins et al. (2014) and Langat et al. (2017).

Climate change can affect the rain cycle by altering its processes (Pervez and Henebry, 2015). Stream flow is sometimes affected by its nature, either gaining or losing stream (Spellman and Drinan, 2001). If droughts are common in an area, the rivers are directly affected. Over the 20th century, sub-Saharan Africa experienced more El Nino periods with below-normal rainfall, versus La Nina periods of above-normal rainfall. (Gommes, 1996; Ngongondo, 2005).

Hydrologically, Malawi is divided into 17 Water Resource Areas (WRAs) covering 94,000 km². The Diamphwe River in WRA 4 relies on overland flow and can run dry during low rainfall (Kelly et al., 2020). The Diamphwe River basin is an essential watershed for food production in Malawi, where agricultural productivity can also be improved by increasing adaptability to climate change (Malawi Government, 2019). However, long-term hydrological research on rainfall and river discharge trends has not been conducted despite its socio-economic importance to the Lilongwe and Dedza districts. This research, therefore, intends to determine how long-term trends of the two hydrologic parameters (rainfall and river discharge) affect agricultural and water use activities in the river basin.

MATERIALS AND METHODS

Study Site

Figure 1 demonstrates the location of the Diamphwe River basin which spans over 1,390.92 km^2 and originates from the Dzalanyama mountains, joining the Linthipe River at the discharge gauge station (34.0886°E 14.1345°S). The total river length is 82.76 km. In central Malawi, the river borders the Lilongwe and Dedza districts (Banda et al., 2019; Munthali et al., 2022).

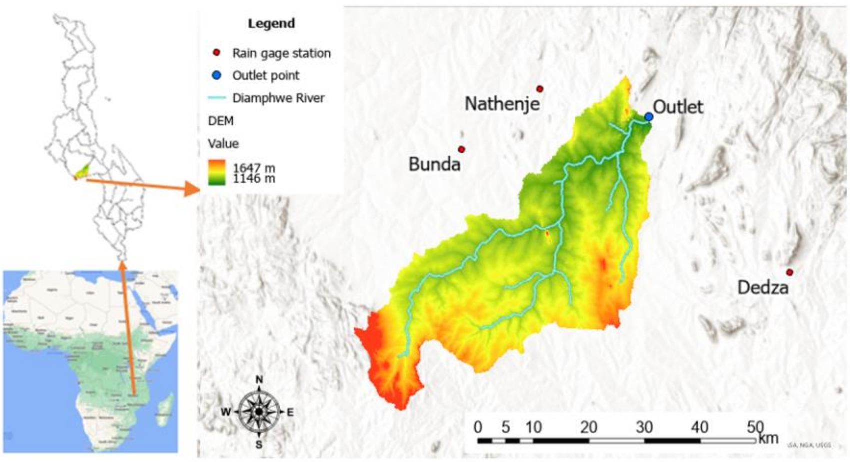


Fig. 1 The Diamphwe River basin in Malawi

Nearly 57.5% of the basin area is utilized for crop cultivation, and only 0.4% is utilized for natural and artificial forests (Malawi Government, 2016). The catchment area comprises flat dambos and plateaus which are rich in clay that retains water and is primarily used for forestry, livestock grazing/ranching, and winter vegetable cropping (Malawi Government, 2016; Mloza-Banda et al., 2001). The Köppen climate classification indicates that Malawi has a temperate climate with cold, dry winters and hot summers. (Belda et al., 2014). The Dedza and Dzalanyama forests, situated at higher elevations, receive more rainfall during the rainy season and, hence, experience a warm tropical climate with annual temperatures ranging from 3.5°C to 39°C. Malawi has three seasons including a warm and rainy season (November to April), a cool and dry season (May to August), and a hot and dry season (September to October). Over 95% of rainfall occurs during the rainy season. The Diamphwe River basin, however, experiences two seasons: the rainy season (November to April) and the dry season (May to October) (Malawi Government, 2016; Munthali et al., 2022). Over 90 percent of the households in the basin are farmers reliant on rain-fed agriculture (Malawi Government, 2019).

Rainfall and River Discharge Data

The daily rainfall data for 36 years, 1975-2010, was obtained from Malawi's Department of Climate Change and Meteorological Services. This Service monitors three weather stations: Dedza, Bunda, and Nathenje. Daily river discharge data for the same period was obtained from the Surface Water Division of the Department of Water Resources.

Statistical Methods and Analysis: Mann-Kendall Trend Test

The Mann-Kendall (MK) trend test is a non-parametric method for analyzing a time series of non-normally distributed data and censored monotonic environmental and climate data trends (Zuzani et al., 2019). The World Meteorological Organisation (WMO) recommends using the MK trend test to identify significant trends (Mann, 1945). MK is preferred due to its robustness against outliers and influential data gaps. MK only considers the sign of the slope, not its magnitude, when calculating the line formed by plotting the variable against time. The MK statistic (*S*) adds up the characters of the slopes to determine the presence of trends.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k) \quad (1)$$

Where *S* is approximately normally distributed, provided the Z-transformation is employed, X_j *and* X_k are the data values at time *j* and *k,* respectively; *n* is the data length.

$$Z = \frac{S-1}{\sigma} \; if \; S > 0; \;\; Z = 0 \; if \; S = 0; \; and \; Z = \frac{S+1}{\sigma} \; if \; S < 0 \quad (2)$$

Where σ is the data variance, *S* is related to Kendall's.

$$\tau = \frac{S}{D} \text{ where } D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j(t_j - 1)\right]^{\frac{1}{2}} \left[\frac{1}{2}n(n-1)\right]^{\frac{1}{2}} \quad (3)$$

Where τ is the correlation coefficient, *D* is the difference in the data points.

The MK trend test identifies trends by comparing each data point to subsequent data points, and the final *S* value determines any trends. A positive value of *S* indicates an increasing trend, and a negative *S* value indicates a decreasing trend (Eq. 1). The *Z* involving *S*, establishes statistical significance (Eq.2). The study's MK analysis was performed using R and XLSTAT.

Pettitt Test as an Abrupt Jump (Change Point) Analysis

In a short-term and extended monotonic trend analysis, hydro-climatic data shows both gradual and abrupt, i.e., step-point, changes (Croitoru and Minea, 2015). Pettitt test detects change points to reveal transitions and abrupt changes in stream flow and rainfall (Pettitt, 1979). The test can identify a significant shift in a time series trend, even when the change's precise timing is uncertain.

RESULTS AND DISCUSSION

Figure 2 shows the average monthly rainfall and river discharge from 1975 to 2010. The monthly river discharge data shown in Figure 2 and Table 1 are the averages of the daily mean river flow data for each month from 1975 to 2010. Monthly rainfall represents the average total rainfall for each month from 1975 to 2010 at the three sites where rainfall was observed (Dedza, Bunda, and Nathenje).

These data show that rainfall and river discharge occur and vary in similar patterns. The rainy season, from November to April, demonstrates overall rainfall, and the highest rainfall month occurs in January (234.44 mm). River discharge was noted to change in tandem with rainfall, with the largest monthly average discharge occurring in February (25 m^3/s). The one-month lag between peak rainfall and peak river discharge is explained by the watershed effect and its temporary storage of water within a watershed.

To determine the variation of rainfall and river discharge for each month, the coefficient of variation (CV) was determined by dividing the standard deviation of each of the two parameters by their respective meaning (Table 1). The CV of rainfall was minimal during the rainy season, ranging from 0.32 to 0.72 (November to April), whereas in the dry season, the CV was extensive, ranging from 1.00 to 2.36. The CV for river discharge was highest in November, December, and April, with values of 2.35, 1.44, and 1.12, respectively. This indicates that monthly rainfall during the rainy season is stable, while rainfall during the dry season is small but highly variable. The river discharge fluctuations are extremely large in November and December at the start of the rainy season. The minimum and maximum river discharge during these months varies significantly from year to year, which should be considered when planning irrigation projects.

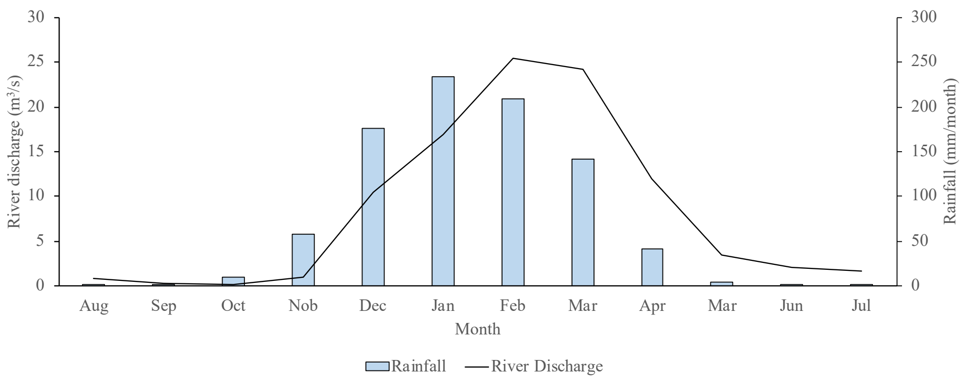


Fig. 2 Monthly averages for rainfall and river discharge for 36 years

Table 1 Rainfall and river discharge - monthly descriptive statistics

	Monthly average		Standard deviation		Coefficient of variation (CV)	
Month	Rainfall (mm/month)	River discharge (m^3/s)	Rainfall (mm/month)	River discharge (m^3/s)	Rainfall (-)	River discharge (-)
August	0.5	0.8	0.9	0.9	1.8	1.1
September	2.1	0.4	4.9	0.3	2.4	0.8
October	10.7	0.2	10.7	0.4	1.0	1.5
November	58.7	1.1	42.0	2.5	0.7	2.4
December	176.3	10.5	75.0	15.1	0.4	1.4
January	234.4	17.0	75.9	11.8	0.3	0.7
February	208.6	25.4	94.0	15.7	0.5	0.6
March	141.7	24.2	68.7	19.0	0.5	0.8
April	41.4	12.0	26.8	13.4	0.6	1.1
May	4.9	3.5	11.3	2.6	2.3	0.8
June	0.7	2.1	1.3	2.6	1.8	1.2
July	0.8	1.6	1.1	2.3	1.3	1.4

To understand the long-term trends over 36 years, average rainfall and river discharge in the rainy and dry seasons were analyzed, with results shown in Figure 3 and Table 2. Long-term trends of rainfall and river discharge were analyzed by the Mann-Kendall (MK) trend test (Table 2), whereby results show that the rainfall Z-value (magnitude of rainfall below or above its mean relative to its standard deviation) for the dry season, -1.799, a significant decreasing trend (indicated by asterisks). River discharge showed -2.073 (rainy season) and -1.889 (annual) significant decreasing trend in the 36-year project period.

The Pettitt test was conducted to detect change points in the trends. The Pettitt test results show that both rainfall and river discharge experienced a drastic trend drop in 2005 and 1988 respectively (Fig. 4). This indicates that river discharge transitioned in 1988, thereby progressing to the 1990s with considerably lower parameter values in the 36-year project period. This is consistent with the worst 1991-2000 El Nino period, which decreased 1992 agricultural production by 50% due to a 50% reduction in rainfall (Ngongondo, 2005). The significant decreasing trend in the two hydrologic parameters in Table 2 (rainfall and river discharge) and also their significant change point trend in 1988, are indicators of climate change in the basin, according to (Kayitesi et al., 2022; Klavins et al., 2014; Langat et al., 2017; Pervez and Henebry, 2015; Queen et al., 2023; Xu et al., 2004).

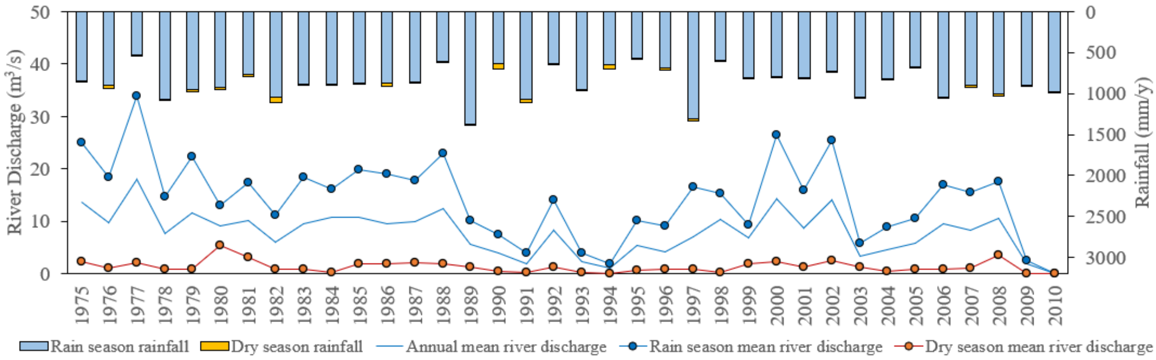
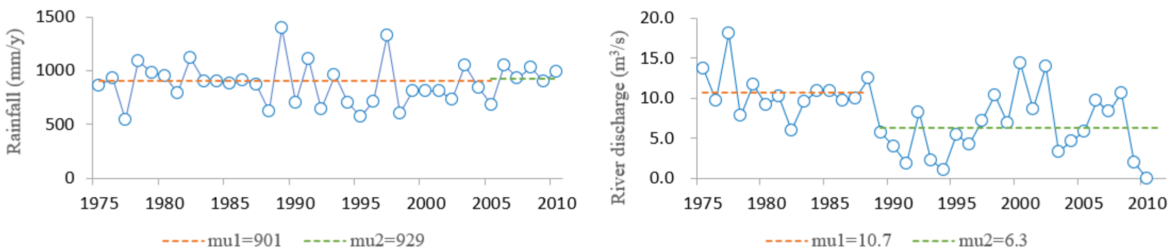


Fig. 3 Rainfall and river discharge descriptions

Table 2 Annual and Seasonal MK Trends

Rainfall	Mann-Kendall test			Pettitt test	
Period	Kendall tau	S-value	Z-value	k-value	t-value
Rainy season	0.003	2	0.01	81	2005
Dry season	-0.212	-133	-1.80*	156*	1991
Annual	-0.003	-2	-0.01	77	2005
River discharge	**Mann-Kendall test**			**Pettitt test**	
Period	Kendall tau	S-value	Z-value	k-value	t-value
Rainy season	-0.247	-147	-2.07**	194***	1988
Dry season	-0.146	-87	-1.22	122	1989
Annual	-0.225	-134	-1.89*	185**	1988

*Note: MK/Pettitt: *trend sig at 0.1 level, **trend sig. at 0.05 level; ***trend sig. at 0.01 level*



Note: mu1 is the mean value before the change and mu2 is the mean value after the change.

a) annual rainfall **b) river discharge**

Fig. 4 Pettitt tests for Diamphwe basin

Figure 5 shows the monthly average river discharge and rainfall for each year of the 36-year project period. To identify the trend within each month's cycle in the 36 years, the MK trend test was conducted for each month`s aggregated monthly average rainfall and river discharge (Table 3). The results indicate that only river discharge decreased significantly (negative Z-values) during the rainy season (November to April). During the dry season, within a month the rainfall trend decreased (negative Z-values) significantly in May and October and River discharge decreased in September. The results indicate that despite the seasonal cycles each year (6 months of rain season and 6 months of dry season), rainfall and river discharge trends also vary differently within each month.

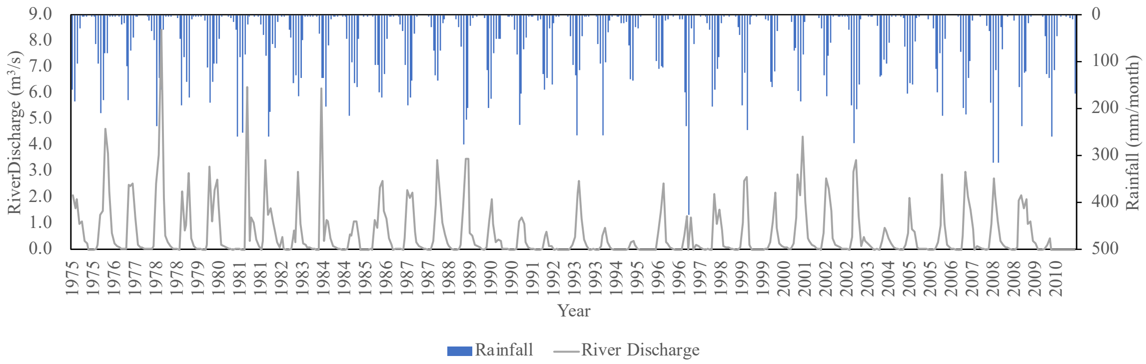


Fig. 5 Monthly averages for year-cycles

Table 3 Monthly MK trend analysis

Month	Period	Monthly Average Rainfall				Monthly Average River Discharge			
		Kendall tau	S	Z	p-value	Kendall tau	S	Z	p-value
November	Rain Season	-0.06	-36	-0.48	0.63	-0.14	-83	-1.17	0.24
December		0.04	26	0.34	0.73	-0.12	-74	-1.04	0.30
January		0.15	93	1.25	0.21	0.10	57	0.80	0.43
February		-0.11	-68	-0.91	0.36	-0.18	-109	-1.53	0.13
March		-0.02	-12	-0.15	0.88	-0.07	-41	-0.57	0.57
April		-0.17	-106	-1.43	0.15	-0.22	-132	-1.86*	0.06
May	Dry Season	-0.32	-195	-2.67***	0.01	-0.09	-54	-0.75	0.45
June		-0.28	-134	-2.12	0.03	0.01	8	0.10	0.92
July		-0.15	-83	-1.17	0.24	-0.03	-18	-0.24	0.81
August		-0.04	-17	-0.28	0.78	-0.12	-73	-1.02	0.31
September		-0.11	-54	-0.81	0.42	-0.22	-132	-1.86*	0.06
October		-0.21	-133	-1.80*	0.07	-0.15	-88	-1.24	0.22

*Note: MK/Pettitt: *trend sig at 0.1 level, **trend sig. at 0.05 level; ***trend sig. at 0.01 level*

CONCLUSION

This study demonstrated the long-term rainfall and river discharge trends in the Diamphwe River basin, Malawi, using data from 1975 to 2010. Rainfall and river discharge were found to be on a long-term declining trend. Within each month, the decreasing trends generally are observed in both rainy and dry seasons. It was also noted that 1988 was a transition year for the decreasing trend of the parameters in the basin. This coincided with the worst El Nino period of the century in the 1990s. "The decreasing trends in both rainfall and river discharge" are worrisome for farmers who rely on rainfed agriculture and for those who implement irrigation projects in the river basin. In addition, this study found that the river flow fluctuation was found to be large in November and December when the dry season changes to the rainy season, and in April when the rainy season changes to the dry season. These results may assist in the establishment of a regional water use plan for future agricultural production including the adoption of irrigation.

Future studies should examine changes in river flow in response to climate change using hydrologic models that simulate changes in river flow response to climate change, providing a more detailed picture of the potential situations and considering appropriate climate change strategies for the region.

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Research article

Comparison of Macroinvertebrate Community Structures between Artificial Environments and Natural Streambeds in Mountain Streams

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Abstract In mountain streams, artificial structures like restoration dams and culverts help maintain forests, roads, and streams. However, while their negative impact on aquatic ecosystem is known in lower river reaches, their effects in mountain streams are less understood. To assess this, we compared benthic macroinvertebrate communities in natural and artificial streambeds in the Ishite River headwaters, Ehime, Japan. We studied benthic macroinvertebrates in pools, riffles, and rapids in natural streambeds and in culverts, dam walls, open ditches, a levee crown and a sedimentary zone associated with a mountain restoration dam. Results demonstrate that benthic macroinvertebrate community densities, taxon richness, and diversity tended to be greater in the natural streambeds than in the artificial environments. In all but the culverts, ordination using non-metric multidimensional scaling revealed that the benthic macroinvertebrate community structure of the natural streambeds and the artificial environments were characterized by their type. For the culverts, the community composition varied among sampling sites. For the dam walls, it was characterized by relatively small taxa such as Chironomidae and Diamesinae. Unlike all other sampling sites, the sedimentary zone tended to show lentic taxa. For the open ditches, the diversity and density were similar to that of natural streambeds. However, the results for the sedimentary zone and open ditches should be interpreted with caution due to the small number of sites examined. The results of this study indicate that the benthic macroinvertebrate communities in artificial environments in mountain streams differ in composition from those in natural streambeds, although the species present are not substantially different.

Keywords benthic macroinvertebrate, erosion control dam, culvert, mountain stream, headwaters

INTRODUCTION

In mountain streams, erosion control dams and mountain restoration dams play a role in storing sediment and preventing stream erosion. In addition, culverts and open ditches intended to manage erosion, are constructed to protect forest roads which cross streams and these artificial structures contribute directly and indirectly to forest maintenance and management. However, it has been demonstrated that such artificial structures are associated with modification of the river environment and that they have an impact on a river's ecosystem. Bylak and Kukuła (2018) reported that concrete slabs altered and degraded downstream benthic macroinvertebrate community. Kanazawa and Miyake (2006) reported that concrete substrate channels altered the community structure in the upper reaches of rivers. Conversely, Nukazawa et al. (2016) found that slit installation on a check dam did not lead to an increase in benthic macroinvertebrates.

Artificial structures contribute to the complexity and diversification of river structure and habitat, and they are thought to have an impact on biodiversity, although the actual impact on increasing species diversity is thought to be small (Palmer et al., 2010). Few studies, however, have assessed the effects of artificial structures on benthic macroinvertebrate communities in river headwaters associated with mountain restoration dams. There is also little knowledge of the structures used to manage forest roads, such as culverts and open ditches. Events in the upper reaches of rivers can have a strong influence on downstream areas, and such knowledge in the headwaters is important.

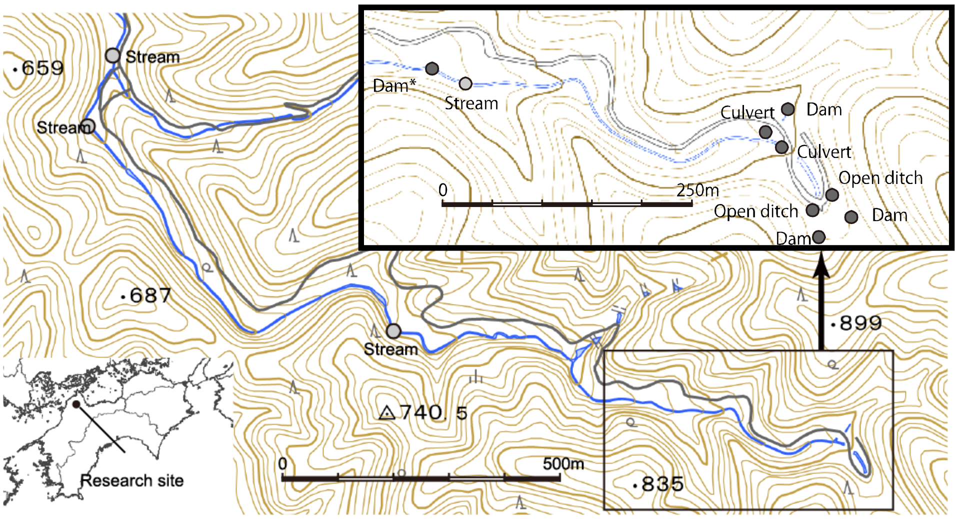
OBJECTIVE

This study aimed to elucidate the effects created by artificial structures on benthic macroinvertebrate communities in a mountain stream in the upper reaches of the Ishite River, Takanawa Peninsula, Ehime Prefecture, Japan. To this end, the benthic macroinvertebrate fauna in natural streams and artificial environments were studied and compared.

METHODOLOGY

Study Area

The study was conducted in two periods, from 28 April to 28 June 2022, the spring period, and from 24 October to 14 November 2022, the autumn period. The study was conducted in a stream flowing through the Experiment Forest attached to the Faculty of Agriculture, Ehime University, which corresponds to the upper reaches of the Ishite River (Fig. 1). Geologically, the upper reaches of the Ishite River are primarily composed of granite. The surrounding forest contains a mixture of Japanese cedar (*Cryptomeria japonica*) and Japanese cypress (*Chamaecyparis obtusa*) plantations and secondary forest dominated by fir (*Abies firma*) and tsuga (*Tsuga sieboldii*).



*Notes: *the dam of which levee crown and sedimentation zone were surveyed. Map modified from GSI map. URL: https://www.gsi.go.jp/tizukutyu.html*

Fig. 1 Map of the study area

Mountain restoration dams were constructed on the stream that runs through this forest. There is sediment on the upstream side of a dam where the river gradient becomes gentler and the river width widens, decreasing water flow. The dams contain culverts, levee crown, and walls. Under and beside the forest road there are culverts and open ditches. All artificial structures were made from concrete (Fig. 2).

Four dams in the river were selected as study sites. At each dam, surveys were carried out at the dam wall where the water was flowing and near the outlet of the culverts installed into each dam wall. For one dam, in addition to the culvert and wall, the survey was carried out at the levee crown of the dam and in the upstream sedimentation zone. Apart from culverts installed in the dam wall, surveys were also carried out in two culverts used to pass water under forest roads. In addition, two open ditches that direct water from dams were surveyed. Then, the number of study areas artificially affected was 14. Study sites were established at four locations in the river to compare the benthic macroinvertebrate communities of natural riverbeds with those of artificial environments. At each site in the natural streambed, three microtopographic locations were selected: a rapid riffle (shallow, fast-moving sections with white caps), a riffle (rippling flow sections), and a pool (deeper and slower-moving sections) (Fig. 1). The number of natural riverbeds studied was 12.

Fig. 2 Images of stream (a), sediment (b), mountain restoration dam (c), open ditch (d) and culvert (e)

During sampling, measurements were taken for both EC (Electrical Conductivity) and pH using an EC meter (AS-EC-33, AS ONE CORPORATION, Osaka, Japan) and a pH meter (AS-pH-11, AS ONE CORPORATION, Osaka, Japan), respectively. In natural streams, the mean values of EC (SSD: Sample Standard Deviation)) were found to be 0.126 (0.011) mS/cm, and in the artificial stream bed, it was 0.128 (0.0085) mS/cm. The mean values of pH (SSD) were 7.8 (0.20) in the natural stream and 7.5 (0.26) in the artificial streambed. Kanazawa and Miyake (2006), who conducted a survey in October 2005 in the watershed immediately downstream of the study site, recorded EC and pH values of 0.102-0.111 mS/cm and 7.3-7.4, respectively, which were lower than the results of the present study. These differences in water quality may be attributed to the higher density of concrete structures in the upper reaches of the study site. The General Linear Model analysis did not identify any significant difference with regard to EC; a significant difference was identified between the artificial and natural riverbeds with regard to pH. However, the pH values were neutral at both sites and do not significantly affect benthic macroinvertebrate communities in this range (Yuan 2004).

Methods

Field survey: At each sampling site, except for dam wall and culvert, a 30 cm square metal frame was placed on the surface of the streambed. A D-frame net (2 mm mesh) was positioned downstream of the frame, and sand, gravel, and debris were disturbed in the frame using the kick and sweep sampling method to flush suspended benthic macroinvertebrates into the D-frame net. This was done by disturbing sand, gravel, and debris to a depth of 5 cm or to the concrete surface from the streambed. In the culvert survey, a metal frame was placed 30 cm from the culvert outlet, benthic macroinvertebrates were swept into the downstream net by hand. For the dam wall survey, a 30 cm square frame was placed on the wall where the water was flowing, a net was positioned under the frame to disturb attached algae and other organisms in the frame, and large benthic macroinvertebrates were washed by hand into the net. The collected benthic macroinvertebrates were preserved in 80% ethanol. Benthic macroinvertebrates in each sample were identified and measured to the lowest possible taxonomic class using a stereomicroscope. After the removal of benthic macroinvertebrates, the sand and organic matter samples were dried at 40°C to a constant mass and weighed to determine the amount of sand and organic matter in the 5 cm surface layer.

Data analyses: To analyze benthic macroinvertebrate community structure, individual density (individuals/m^2), number of taxa, and Shannon-Wiener species diversity were calculated for each of 26 samples. Generalized Linear Model (GLM) analyses were performed to determine the effect of stream bed type on sand, litter, and benthic macroinvertebrate community. The mass of sand and organic matter and the density, number of taxa, and Shannon's diversity index of benthic macroinvertebrates were used as dependent variables. The effect of season and artificial environments (culverts, dam walls, open ditches, bank tops, and sediments) compared to natural streambeds (pools, riffles, and rapids) were used as independent variables. For each analysis conducted, the variance ratio (F value), numerator degrees of freedom, error degrees of freedom, and p value are presented. For the analyses of density and number of taxa, the distribution of the error term is assumed to follow a Poisson distribution, while those of the other dependent variables follow a normal distribution. In each analysis assuming a Poisson distribution and normal distribution, we present the absolute values of the Z-score and F value, respectively along with the p value.

Non-metric dimensional scaling (NMDS) analyses were used to compare benthic macroinvertebrate community structure. Bray-Curtis distances, derived from the abundance of each taxon, were used as a measure of dissimilarity between samples and coordinates were assigned by performing 51 and 108 iterations for spring and autumn, respectively (Kruskal and Wish, 1978). Kendall's rank correlation coefficients (τ) were calculated between the values of each axis and the abundance of each taxon to determine whether the axes obtained by NMDS reflected changes in the absolute abundance of each taxon. All statistical analyses were performed using R 4.3.2 (R Core Team, 2016) and Vegan 2.6-4.

RESULTS

Benthic Macroinvertebrate Fauna

A total of 1,119 benthic macroinvertebrates from 47 taxonomic groups were collected from the samples. Of these, 718 individuals representing 38 taxa were found in the natural streambeds, while 401 macroinvertebrates belonging to 35 taxonomic groups were found in the artificial environments. Of the 47 total taxa, 12 were found only in the natural streambeds and 9 were found only in the artificial environments (Table 1).

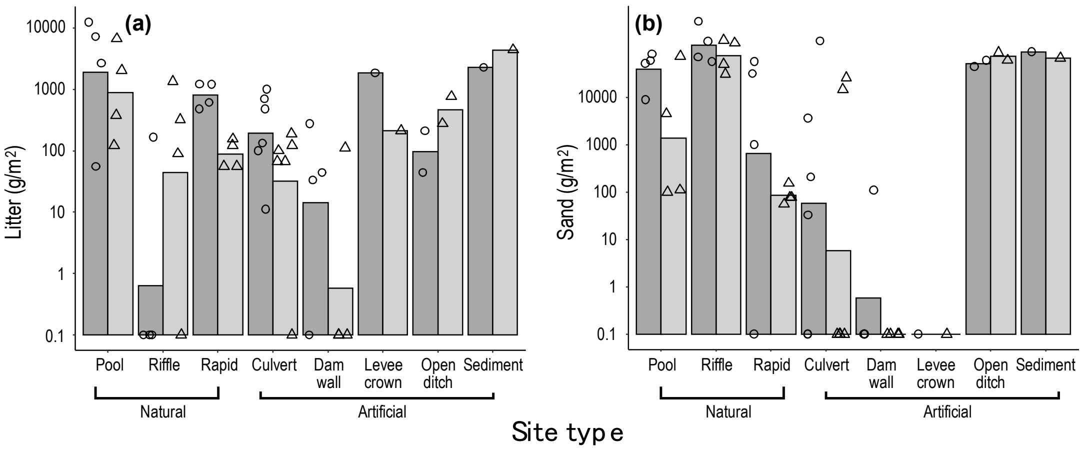
Sand and Litter

Comparing sand and litter mass in artificial and natural streambeds by GLM, a significant difference ($F_{1,48}$=4.3, $p < 0.05$) was found for sand mass, but no significant effect was found for litter mass. No significant effects of season or interaction (artificial influence and season) were found. For litter mass, the variation was greater in rapids, culverts, and on the dam wall. For sand mass, the variation was greater in rapids and culverts. Both litter and sand mass were higher in the open ditches, sedimentation zone and in the pools (Fig. 3).

Table 1 Individual number of dominant macroinvertebrate taxa found in the study sites

Taxon	Natural				Artificial			
	rpd	rfl	pl	clv	dmw	lvc	opd	sdm
Ephemeridae	11	36	93	35		2	37	
Baetidae	27	2	8	44	18	20	22	3
Hydropsychinae	31	1	59	15			6	
Gomphidae	6	4	45	1			3	5
Tipulidae	21	1	23	3			7	1
Chironomidae		1	12		21	6		8
Heptageniidae	18	2	15	1	2		8	
Neoperla sp.	4		31	2			6	
Lepidostomatidae	33		9				1	
Geothelphusa dehaani	10	13	7	3			8	
Psychomyiidae	14	1	1					
Lepidostoma japonicum	12							
Amphipoda	2		4					
Leptophlebiidae	1		3					
Uenoidae	3	1						
Colymbetinae								4
Baetis thermicus				3				
Ephemera japonica				2				
Macrostemum radiatum				2				
Notonectidae								2
Number of taxon observed	20	15	20	14	8	5	15	9

Notes: The top 10 taxa in total and the top 5 taxa found only in artificial environments or natural streams are only shown. Abbreviations are as follows: rpd: rapid riffle, rfl: riffle, pl: pool, clv: culvert, dmw: dam wall, lvc: levee crown, opd; open ditch, and sdm: sedimentation zone.



Notes: Dark grey bars/circles = spring data, light grey bars/triangles = autumn data

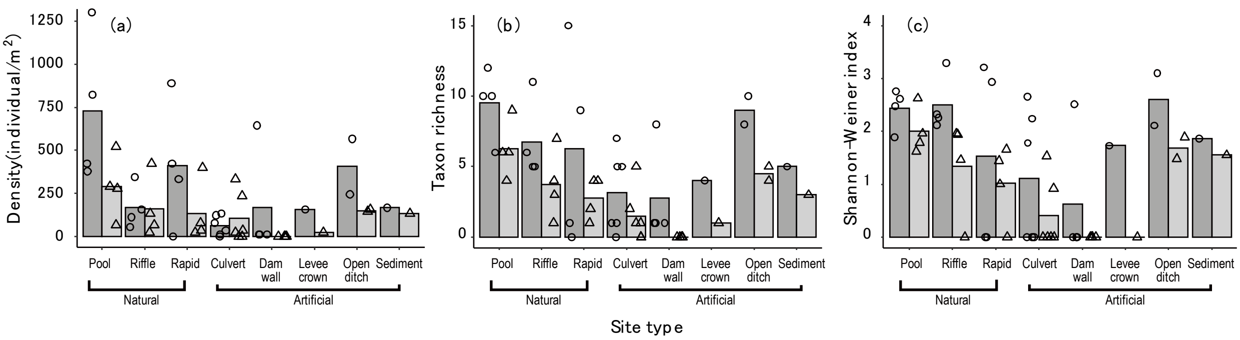
Fig. 3 Mass of litter (a) and sand (b) (g/m²)

Individual and Taxon Number and Diversity

Generalized Linear Model analyses revealed significant differences in density (|Z|=3.9, $p < 0.001$), number of taxa (|Z|=7.5, $p < 0.001$) and diversity ($F_{1,48}$=10.9, $p < 0.001$) of in both cases, no significant effects of the interaction between season and streambed type were found. Density, number of taxes and diversity were all higher in spring. Differences between sampling sites showed that these values tended to be lower at culverts and dam walls and higher at pools, open ditches and sedimentary zones. Taxon numbers and diversity were high in riffles and rapids (Fig. 4).

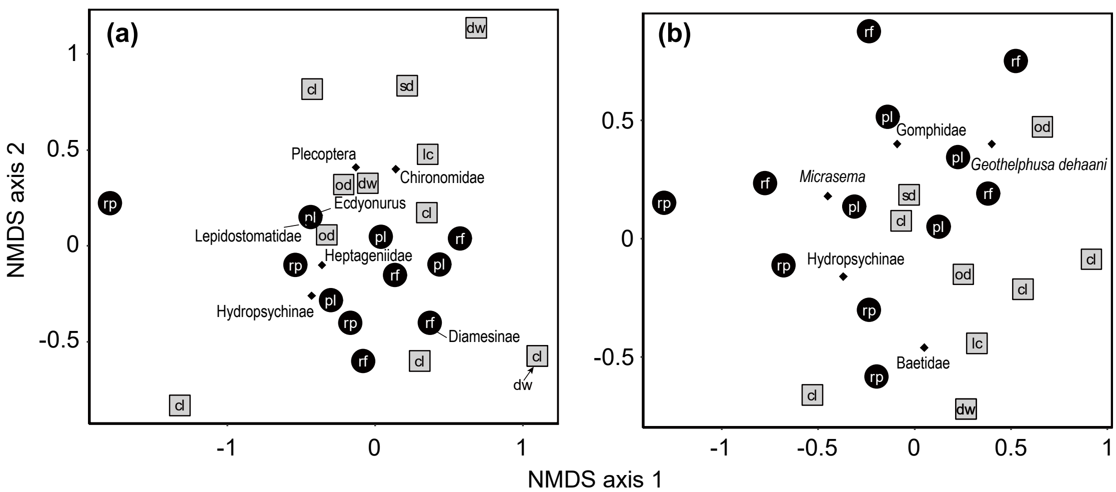
The NMDS Analyses

The NMDS analyses of the two axes based on the abundance of each taxon showed that the areas plotted in spring and autumn tended to be different in the streambeds and the artificial environments, respectively. The NMDS stresses in spring and autumn were 0.14 and 0.19 respectively. Artificial environments in spring tended to be located in areas where one of the two axes were higher than the other. Natural riverbed sites tended to be located in the region of lower values for the second axis. There was a significant correlation ($p < 0.05$) between the first axis and the densities of Diamesinae (τ = 0.37), Heptageniidae (τ = -0.36), Hydropsychinae (τ = -0.43), Ecdyonorus (τ = -0.38), and Lepidostomatidae (τ = -0.45). There was a significant correlation ($p <$ 0.05) with the second axis between Plecoptera (τ = 0.41), Damesinae (τ = 0.44), and Chironomidae (τ = 0.40) (Fig. 5a).



Notes: Dark grey bars/circles= spring data, light grey bars/triangles = autumn data

Fig. 4 Density (/m²) (a), taxon number (b), and diversity index (*H*) (c)



Notes: A black circle represents a natural stream bed, while a grey rectangle represents artificial environments. Abbreviations are as follows: pl: pool, rf: riffle, rp: rapid, cl: culvert, dw: dam wall, lc: levee crown, od; open ditch, and sd: sediment.

Fig. 5 Plots of axis 1 versus axis 2 for the non-metric multidimensional scaling (NMDS) of the density of benthic macroinvertebrates at each study site for (a) spring and (b) autumn, with taxa showing significant correlations.

A tendency was observed for artificially influenced environments in the autumn period to appear in areas with higher values on the first axis and lower values on the second axis. Significant correlations ($p < 0.05$) with the first axis were observed for the number of Hydropsychinae (τ = -0.37), *Geothelphusa dehaani* (τ = 0.40), and *Micrasema* (τ = -0.45). Significant correlations ($p <$ 0.05) with the second axis were found for the number of Baetidae (τ = -0.46), Gomphidae (τ = 0.40), and *Geothelphusa dehaani* (τ = 0.40) (Fig. 5b).

DISCUSSION

In general, many benthic faunal species are known to grow mostly during specific seasons (Hynes, 1970), and such growth periods influence the seasonal variation in distribution. No seasonal variation in litter abundance was observed in the present study (Fig. 3). The density, number of taxa, and diversity of benthic macroinvertebrate taxa were significantly higher in spring than in autumn (Fig. 4). Species that showed significant correlations to the NMDS axes in the Kendall's rank correlation coefficient analyses in spring or autumn were six and five taxa, respectively. The only taxon common to spring and autumn was Hydropsychinae. With the exception of this, the taxa characterizing the NMDS co-ordinates for each season differed. These results indicate that seasonal differences in the dominant taxa led to seasonal differences in the NMDS coordinates. It was suggested that this may not have resulted from seasonal variations in litter mass, but from other factors such as growing seasons.

The results of this study showed that taxa dominated in artificial environments were often found in natural streambeds. Densities were higher in natural streams for most of these common taxa, suggesting that natural streambeds are more productive than artificial environments. With the exception of open ditches and sedimentation zones which showed a similar number of taxa to natural streambeds, these results suggests that artificial environments have a limited contribution to the maintenance of benthic macroinvertebrate community diversity in mountain streams. For some taxa, such as Baetidae and Chironomidae, densities were higher in artificial environments (Table 1). It has been reported that the density of individuals belonging to Baetidae and Chironomidae is higher on concrete substrates with artificial environments. This is attributed to the increased flow velocity on concrete substrates (Kanazawa and Miyake 2006). It has also been reported that the number of taxa that can occur in habitats with high flow velocities is limited (Boyero and Bosch, 2004). The results of the high abundance of Baetidae and Chironomidae identified in this study in artificial environments may also be related to increased flow velocities in concrete environments, as in these previous studies.

Of the artificial environments examined in this study, the culverts, dam walls, levee crowns, and open ditches have concrete as substrates. Of these, the dam walls and levee crown were environments with low amounts of sand and litter. The culverts were a type of environment where the amount of litter and sand varied from point to point. The open ditches and sedimentation zone had high amounts of litter and sand, comparable to the natural streambed. The sedimentation zone not only had a high amount of litter and sand, but also had a lentic environment, which was different from any of the other study sites.

The sedimentary zone, an artificial environment characterized by high litter and sand deposition, was the only environment where taxa such as Colymbetinae and Notonectidae were observed. These taxa are lentic and carnivorous, suggesting that the community composition of this sedimentary zone may be unique. Lentic benthic macroinvertebrates such as *Platambus pictipennis* and *Anotogaster sieboldii* were also observed outside the sampling frame during the survey (M. Hamguchi personal observation). This observation supports the possibility that this habitat may provide environments that are significantly different from others. On the other hand, it has been suggested that the establishment of lentic habitats and changes in biota in such sedimentary zones may merely establish a downstream environment leading to a reduction in diversity (Takemon, 1997). However, it should be noted that only one site was surveyed in this study. The autumn NMDS coordinates are not far from other sites, suggesting that further research is needed to elucidate the role of these depositional zones.

The benthic macroinvertebrate community in the open ditches showed a higher density, number of taxa, and diversity than in other artificial environments, and the positions of the NMDS coordinates were close to those of the natural streambeds, indicating that the community structure was similar to that of the natural streambed. The substrate of the open ditch in the study was concrete, but it was located on a gentle slope and its substrate was not well exposed due to litter and sand deposition (Fig. 2d, Fig. 3). As a result, the open ditches may have had an environment similar to a natural riverbed, which may have led to the observed community structure in these open ditches.

Regarding the dam wall, the water flowed vertically, and algae and other organisms were attached to the wall surface, and although almost no benthic macroinvertebrates were observed during the autumn season, some organisms were observed during the spring season. According to Ota et al. (2023), small body size taxa such as Chironomidae are reported to be present amongst the algae growing on the concrete riverbed, and indeed small body size Chironomidae and Diamesinae were observed on this wall, and these taxa have also been identified in NMDS analyses of spring data as taxa with a preference for artificial environments. As for culverts, not only do litter/sand levels vary widely between sites, but the extensive plotting of culverts in the MNDS analysis indicates that community structure here varies from site to site. The reasons for this are not clear but may be influenced by the environment around the culverts and the upstream structure.

CONCLUSION

The results of NMDS analyses indicate that community composition differs between artificial environments and natural riverbeds. Many of the taxa identified in the artificial environments were also found in the natural streambeds. These results suggest that the benthic macroinvertebrate communities in artificial environments in mountain streams differ in composition from those in natural streambeds, although the species present are not substantially different. In the sedimentary zone, however, unique species were identified that differed from those in natural riverbeds and other artificial environments. These results indicate that artificial environments in mountain streams do not significantly increase the diversity of benthic communities throughout the watershed. It should be noted that our results suggest that unique communities possibly exist in the sedimentary zone, but previous studies have indicated that such communities may be more similar to those in the lower reaches of the watershed.

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Research article

Relationships between Soil Characteristics and Brewing Grape Quality in Katsunuma, Yamanashi Prefecture, Japan

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Abstract In this study, the qualities of Chardonnay grapes from Katsunuma, Yamanashi Prefecture used for making wine, in, and the physical and chemical properties of the soils around the target fruit trees were analyzed to define the relationships between the grapes and soil properties. The survey covered three garden sites from one winery in Katsunuma Town. Undisturbed soil and disturbed soils were sampled from a depth of 20 cm, 30 cm below the trunk of the vines, and were used to measure physical and chemical properties, respectively. The physical properties measured were three-phase distribution, soil particle size composition, and hydraulic conductivity. Chemical properties measured were pH, EC, K_2O, Na_2O, CaO, and NO_3-N. Grapes were collected at harvest time, de-stemmed and pressed, and then analyzed for sugar content, glucose, fructose, acidity, malic acid, and tartaric acid. Software R was used for statistical analysis. The experimental results indicate that differences in soil particle size composition and soil properties may affect the sugar and acid levels of the grapes. In addition, soil pH, permeability, and CaO were found to be important factors to be considered in wine making. Soil pH has a strong correlation with glucose, grape pH, and sugar content, and may serve as an indicator when evaluating soil pH in the future. In summary, it was clear that soil physical and chemical properties affect fruit quality.

Keywords vineyard, wine, terroir, vinification grapes, soil pH, Yamanashi

INTRODUCTION

Wine production in Japan began in 1870, when the Meiji government added measures to promote grape cultivation and winemaking as part of its industrial development policy. However, wine making failed and ended in 1890s, because the wine’s acidity did not suit the Japanese taste. In 1918, various brewing companies succeeded in marketing sweet wines that suited Japanese tastes. The number of wines consumed in Japan has changed dramatically since then, with the first wine boom in 1972, followed by a seventh boom in 2020. In the process, consumers have become more knowledgeable about wine and have a better understanding of its taste and culture.

The number of domestically produced wines continued to increase and to a 2018 policy regarding, strict labeling standards for Japanese wines was established, requiring that at least 85% of the grapes used in a wine must be from that region and vinified in that region to be labeled with the wine's origin name, raising expectations that quality grapes are fully available in each wine-growing region. On the producer's side, it is also necessary to produce high quality wine in Japan for surviving at the international market.

There is a recognition that to produce quality wine, quality grapes must be grown. In other words, terroir is important as it directly affects the properties of wine.

What is required for vinification grapes is a fruit with a higher concentration of sugar and aroma components than grapes eaten for fresh consumption, and although various theories are known about the physicochemical properties of the garden soil that produces such excellent fruit (Miura et al., 2020), there is insufficient scientific verification. In addition, there have been very few studies on vineyard soils in Japan compared to those in Europe and the United States, and the soil environmental conditions suitable for cultivation of grapes for vinification in the Japanese climate have not been clarified.

OBJECTIVE

Given the above background, understanding the influence of soil's physical and chemical properties on oenological grape quality is essential for improving wine quality. Accordingly, the objectives of this study were to evaluate the physical and chemical properties of Chardonnay, a white wine grape variety grown in Katsunuma, Yamanashi Prefecture, and to clarify its relationship with soil physical and chemical properties and fruit quality.

METHODOLOGY

In this experiment, 3 vineyard sites which grow Chardonnay grape varieties were surveyed: In Site 1, grapes were grown as a hedge cultivar and the soil group was lowland soil, in Site 2, grapes were shelf grown and the soil group was also lowland soil, and in Site 3, grapes were hedge grown and the soil group was brown forest soil (Figs. 1 to 3).

Fig. 1 Vineyard site 1 **Fig. 2 Vineyard site 2** **Fig. 3 Vineyard**

Soil Sampling

Approximately 300 g of undisturbed and disturbed soil was collected at 27 locations in each garden in July, using a 100 ml core sampler can from a depth of 20 cm, 30 cm or less below the tree trunk.

Soil Measurements

Physical properties of undisturbed soil were measured by three-phase distribution, particle size composition (hydrometer method), and permeability (hydraulic conductivity test). Chemical properties were measured using disturbed soil after passing the soil through a 2 mm sieve. Chemical properties were measured using a HORIBA compact ion meter.

Juice Components

The grapes were de-stemmed, crushed, and pressed before being made into juice as a pretreatment for juice component analysis. Items measured were sugar content, glucose, fructose, acidity, tartaric acid, and malic acid (Humitsuki, 2006; Nakayama, 1993).

Statistical Analysis

Statistical software R was used for statistical analysis between soils, and multiple comparison analysis was performed. T-tests were performed in Excel for soil and grape components.

RESULTS AND DISCUSSION

Soil pH showed a strong positive correlation with glucose, a grape component, and grape pH and sugar content. This indicates that soil pH is closely related to the major grape juice components. The soil pH in this study was lower than the gardener's target value, so it is necessary to consider how to improve soil pH in the future.

The hydraulic conductivity was strongly correlated with sugar content. Previous studies have generally agreed that grapes produced under moderate moisture stress produce wines with superior sugar and aroma (Van Leeuwen et al., 2009; Feiring and Lepeltier, 2017). Because of Japan's humid climate with high rainfall, well-drained soils are considered important for the production of quality vinification grapes (Saito et al., 2017). In this study, the permeability in the soil was good in the range of 10-3~10-4 and did not differ significantly among the orchard sites, which is attributed to the high sugar content of the grapes due to the excellent permeability of the soil in the target sites. This suggests that the sugar content is highest when the soil is subjected to moderate moisture stress.

The concentration of CaO was strongly correlated with malic acid. Malic acid is found in many organisms, not only grapes. Malic acid and tartaric acid are the major organic acids in wine and, depending on the degree of ripeness, have a significant impact on the acidity quality of wine. Concentrations range from 100 to 200 (mg/L) in warmer areas, but are relatively low at 15 to 30 (mg/L) in target areas. We believe that lime application is also effective for soil pH in order to improve CaO in the soil.

Table 1 Correlation coefficient and confident interval

	Permeability	EC	Soil pH	K_2O	CaO	Na_2O	NO_3-N
Brix (%)	0.88**	-0.70	0.98*	-0.22	0.82	0.06	-0.30
Glucose (%)	0.55	-0.93	0.98*	-0.59	0.52	-0.34	0.11
Fructose (%)	-0.92	-0.92	-0.77	0.24	-0.08	0.73	-0.54
Grape pH	0.96	-0.84	0.99*	-0.43	0.68	-0.16	-0.08
Acidity (%)	0.97	-0.61	0.99	-0.11	0.65	-0.19	-0.04
Malic acid	0.38	0.34	0.62	0.78	0.98**	0.72	-0.87
Tartaric acid	0.97	-0.61	0.99	-0.11	0.65	-0.19	-0.04

*Notes: n=27, *: 95% confidence interval, **: 99% confidence interval*

■: site1 ▲: site2 ◆: site3

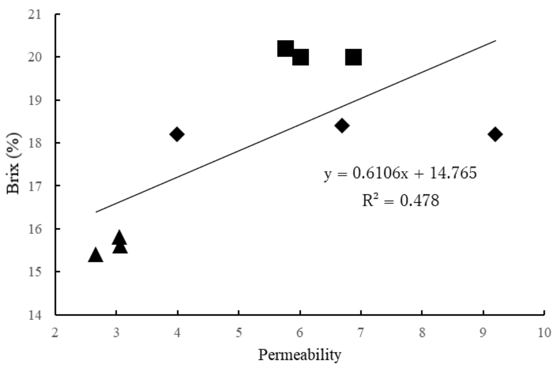

Fig. 4 Correlation between hydraulic conductivity and sugar content

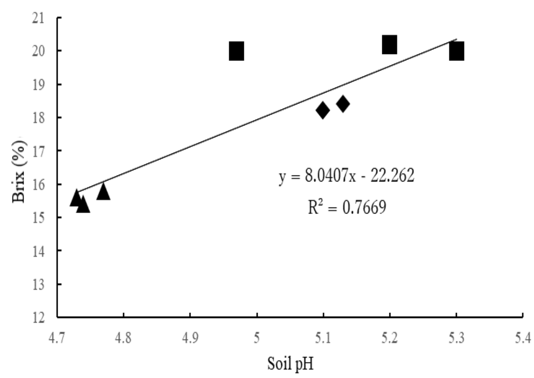

Fig. 5 Correlation between soil pH and sugar content

■: site1 ▲: site2 ◆: site3

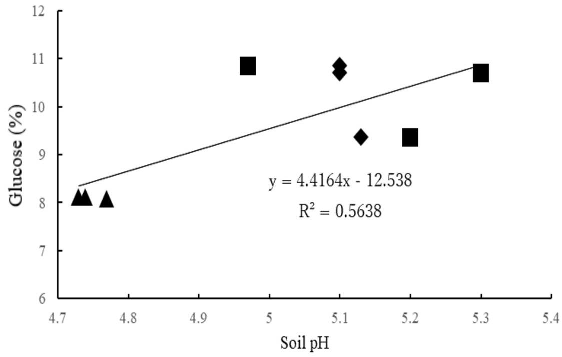

Fig. 6 Correlation between soil pH and glucose

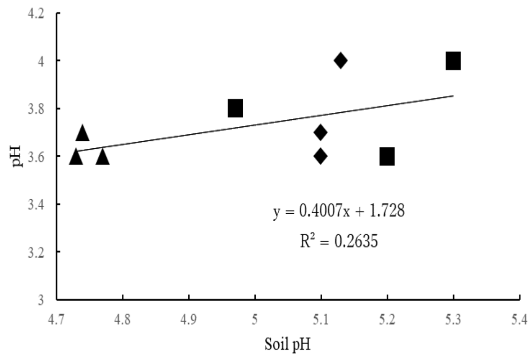

Fig. 7 Correlation between soil pH and grape pH

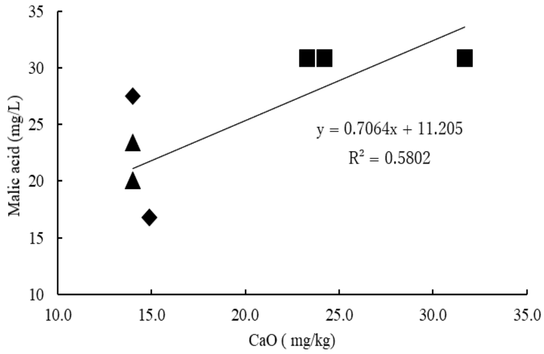

Fig. 8 Correlation between calcium oxide and malic acid

CONCLUSION

Soil pH, permeability, and CaO were found to be important factors to watch in winemaking. Especially, soil pH has a strong correlation with glucose, grape pH, and sugar content, and may serve as an indicator when evaluating soil pH in the future. The measurements that did not correlate were not considered to have an impact on the production of grapes for vinification. In addition, it is important for wineries to produce grapes with high sugar content to produce desirable grapes, and for this purpose, soil pH and hydraulic conductivity should be closely monitored and used as a guide when making improvements through soil amendments.

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Research article

Technical Efficiency of Rice Yield: Insights from IADA North-West Selangor, Malaysia

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Abstract Despite Malaysia's concerted efforts to increase rice production, the self-sufficiency ratio significantly declined from 70.0% in 2018 to 62.6% in 2022. The country's rice production primarily relies on ten granary areas in Peninsular Malaysia, with the Integrated Agricultural Development Area (IADA) North-West Selangor known for its high productivity. In the 2015 - 2016 main season, the region achieved a rice production rate of 6.0 tons per hectare, higher than the national average of 4.6 tons per hectare and 5.0 tons per hectare for other granary areas. However, by the 2020 - 2021 main season, productivity in IADA North-West Selangor had fallen to 4.8 tons per hectare, mirroring a worrying trend observed across other granary areas. Concurrently, the average national yield fell to 3.8 tons per hectare, while the average in granary areas dropped to 4.4 tons per hectare, indicating an overall downward trend. This study aims to identify factors influencing rice productivity in IADA North-West Selangor, a region struggling to maintain its historically high productivity levels. We conducted interviews with 74 Malay and Chinese farmers using a structured questionnaire to assess technical efficiency, which is a key determinant of yield. Stochastic frontier analysis (SFA) revealed significant variations in technical efficiency among farmers, suggesting potential for improvement across the region. Although farmers in IADA North-West Selangor currently exhibit lower yields and technical efficiency compared to their historically high values, there are promising signs of improved productivity with the right interventions which are applicable in other rice granaries.

Keywords paddy farmer, yield, technical efficiency, trust, agricultural information

INTRODUCTION

Given the critical role of rice in Malaysian diets, achieving self-sufficiency in rice production is a top priority for the agricultural sector. Malaysia is not self-sufficient and importing rice to meet their need is well established. In 2023 however, the country grappled with economic strain due to the soaring prices of imported white rice, resulting in widespread confusion among consumers over costs and retailer stock levels (Goh, 2023; The Asahi Shinbun, 2023). This situation intensified public anxiety about food security, prompting the government to encourage the purchase of locally grown rice, which led to a surge in consumer stockpiling. With the price control for local white rice at 2.6 ringgit per kg (Khoo, 2023), it suggests a potential revitalization of domestic rice production and a renewed appreciation for its significance.

According to the national report by the Ministry of Agriculture and Agro-Based Industry (2008), the self-sufficiency level recorded relative stability at 70.0 percent and even grew to 72.2 percent from 2004 to 2007. However, by 2022, the level plummeted to an unprecedented low of 62.6 percent. In response, the Malaysian government set an ambitious target to achieve 75 percent self-sufficiency by 2025. In this context, optimizing rice farming areas and technology are critical for economic and national security. A secure domestic rice supply insulates the nation against potential disruptions in the global food chain and ensures that Malaysians have access to this critical dietary staple.

The main granary areas in Malaysia are responsible for producing and meeting the country's rice demand. Ten of these areas are located along the peninsula's coastlines. In 2022 - 2023, these regions produced a modest yield of 4.0 tons per hectare. This underwhelming national production reflects a concerning trend as the shrinking number of paddy farmers and contracting cultivated areas contribute to lower yields, further impacting overall rice production. IADA North-West Selangor historically outperforms other granary areas, though its output decreased from 6.3 tons per hectare in 2015 to 4.4 tons per hectare in 2023. This area traditionally excels, and the farmers were able to sell their harvested rice as seeds for the following year rather than only for consumption purposes. As a comparison, the national average yield was 4.0 tons per hectare in 2015, which further declined to about 3.7 tons per hectare in 2020 (Table 1). Therefore, investigating yield patterns and determining key factors to boost production are critical for the future of Malaysian rice farming (IADA North-West Selangor, unpublished).

Table 1 Rice production indicators in Peninsular Malaysia's granaries

	2015	2016	2017	2018	2019	2020
Number of paddy farmers (people)	197,189	194,931	193,679	193,378	192,663	189,500
Paddy planted area (hectare)	681,559	688,770	685,548	699,980	672,084	644,908
Rice production ('000 tons)	1,767	1,766	1,656	1,700	1,516	1,624
Average yield (kg)	4,022	3,978	3,750	3,770	3,501	3,654

Source: Ministry of Agriculture and Food Industries, 2020

OBJECTIVE

This study seeks to identify key input factors that can enhance yield in Malaysia's main granary areas by examining what influences farmers' technical efficiency (TE). By measuring the TE levels in IADA North-West Selangor, Malaysia, using Stochastic Frontier Analysis (SFA), the research reveals the distribution of TE among paddy farmers. The analysis will also provide insights into crucial determinants of yield and the distribution patterns of TE among paddy farmers in IADA North-West Selangor.

METHODOLOGY

Respondents of the Study

Table 2 presents the profile of the 74 paddy farmers surveyed from Sungai Burung and Sekinchan, comprising 44 Malay and 30 Chinese farmers (Fig. 1). Most of these farmers are male owner-tenant cultivators specializing in producing rice seeds through a transplanting method. The average age of the farmers is 51.8 years old, which is younger than the national average of 55 years old (Engku Ariff et al., 2023). These farmers operate on an average farm size of 3.65 hectares and achieve yields exceeding the average of IADA North-West Selangor.

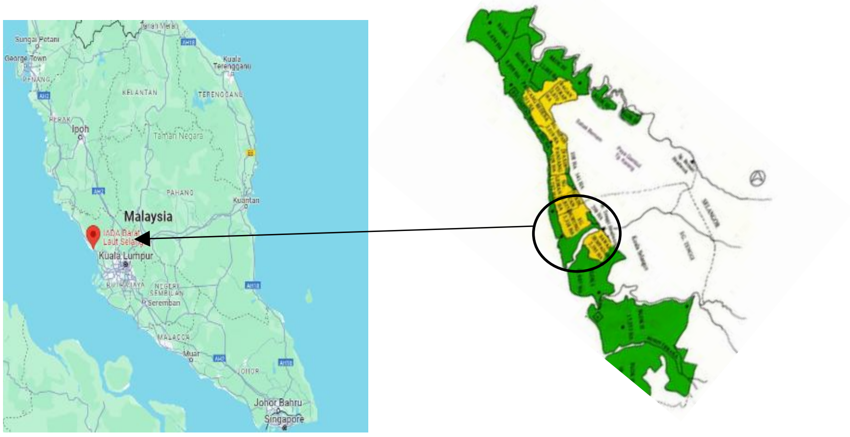
Study Area

We conducted the study in the IADA North-West Selangor, Malaysia, a prominent granary area known for its high productivity and advanced rice farming technology. Since its establishment in 1978, the area spanning 20,000 hectares has benefited from river improvement works and irrigation facilities that enable large-scale rice farming. IADA North-West Selangor supports 10,200 farmers across eight blocks who utilize advanced transplanting farming practices that transform the area into a leading producer of rice, not just for consumption but also for seed production. The widespread adoption of these technologies and a solid knowledge base among the farmers make IADA an ideal location for this study. The survey focused on two key areas, namely Sungai Burung and Sekinchan.

Table 2 Profile of the respondents (*n*=74)

Items	Number of farmers and size	
Gender (people)	Male (70)	Female (4)
Ethnicity (people)	Malay (44)	Chinese (30)
Average age (years old)	51.8	
Family size (Number of people)	3.9	
Average farming experience (years)	21.4	
Yield (tons per hectare)	6.6	
Average farm size (hectares)	3.6	

Source: Own survey



Source: IADA North-West Selangor (unpublished)

Fig. 1 Map of IADA north-west Selangor

Data Collection

We conducted a field study in September 2023 with 74 farmers in Kampung Burung and Sekinchan (Fig.1), the two villages in IADA North-West Selangor, Malaysia. The farmers were selected randomly by their heads of villages. These areas operate under the extension system of IADA, where extension and administrative officers actively monitor, support, and guide farmers toward improved farming practices. There is also an experiment field used to conduct trials and errors to help farmers overcome potential issues with rice farming techniques. The survey specifically focused on the amount of rice production input and output. A structured questionnaire was designed that included questions on demographic profiles, farming inputs and outputs, and farming methods. To ensure accuracy and reliability, we chose face-to-face interviews to allow clarification and minimize the risk of misinterpretations that can arise from written responses on a questionnaire.

Analysis of the Study

Technical efficiency is commonly used to find potential to improve yield among crops (Elias et al., 2023). We utilized the Stochastic Frontier Analysis 4.1 (University of Queensland, 2018) to calculate the technical efficiency of rice yield. The software program was developed by Professor Tim Coeli at the University of Queensland (Coelli et al., 2005). The inputs used in this analysis include seed (kilograms per hectare), fertilizer (kilograms per hectare) from the first to the fourth application, and labor (persons per season). The Maximum Likelihood technique was used to analyze the explanatory variables among the inputs for rice production.

RESULTS AND DISCUSSION

The study collected data from 74 Malay and Chinese farmers. Rice yield from the two villages (i.e., Kampung Burung and Sekinchan) averaged 6.67 kg per hectare, with a distribution ranging from 1.6 to 8.23 tons per hectare. This variability in yield is influenced by several factors, with the amount of fertilizer application emerging as a significant factor contributing to the differences in yield and technical efficiency (TE). While the mean rice production is 5.75 tons per hectare, the typical yield tends to be closer to the average of 6.67 tons per hectare. This indicates that the overall yield is generally higher than the mean production figure. The farmers in the area are involved in seed production. In terms of inputs, the farmers used an average of 93.3 kg of seed per hectare for transplanting (Table 3). Fertilizer applications typically occur four times per season, with some instances of only three applications. Fertilizers are primarily subsidized by the government, with the supply of Sebatian (nitrogen, phosphorus, potassium (NPK) mixed at 240 kg per hectare), urea (80 kg per hectare) and NPK (150 kg per hectare). Labor input comprised 3.3 workers per season.

Table 3 Input details for paddy farming in Kampung Besar and Sekinchan

Input	Quantity
Seed (kg/hectare)	93.3
Fertilizer application	
First application after transplanting	134.1
Second application	204.6
Third application	186.6
Fourth application	107.7
Labor (workers per season)	3.3

Source: Own survey

The Stochastic Frontier Analysis was applied to analyze yield data from 74 farmers. The Maximum Likelihood Estimate (MLE) results, as shown in Table 4, revealed varying impacts on the frequency of fertilizer applications for the farming season from 2021 to 2022. The application frequency varies depending on individual management decisions. The SFA indicated that the first, third, and fourth applications significantly influenced yield, whereas seed and labor input did not significantly affect the model. Although all farmers applied fertilizer the first three times, only 50 out of 74 applied it a fourth time. This suggests that the frequency and the amount of fertilizer applications could be critical factors influencing yield. Moreover, the results indicate that seed and labor, previously considered crucial for yield, may be less important. Instead, the model highlights the potential importance of optimizing fertilizer applications, particularly during the first four applications.

Table 4 Maximum Likelihood Estimates (MLE) of Technical Efficiency (TE)

Input	Coefficient	SE	t-ratio	Sig.
Seed	-0.0893	0.1280	-0.6974	
Fertilizer				
First application after transplanting	0.2561	0.1032	2.4821	**
Second application	0.1910	0.1341	1.4257	
Third application	0.3924	0.1618	2.4246	**
Fourth application	0.0427	0.0177	2.4122	**
Labor	0.1381	0.0917	1.5062	

*Source: Own survey, Note: ** indicates 5% significance*

The SFA calculated the technical efficiency (TE) for rice production in the study area. TE scores range from 0 to 100, with higher scores indicating more efficient use of inputs like seed, fertilizer, and labor. Table 5 shows that the TE scores in the study area varied considerably, ranging from 30.65 to 87.56.

Over half the farmers (47) achieved TE scores in the 70-100 range, suggesting relatively efficient practices, while 27 achieved scores in 0-69. The analysis suggests potential improvements, particularly in fertilizer application. Farmers might benefit from reevaluating fertilizer application practices, particularly the amount used in the first and third applications. Based on these findings, investigating the impact of introducing a fourth fertilizer application on rice productivity could provide valuable insights into enhancing overall efficiency.

Table 5 Distribution of technical efficiency, TE (*n*=74)

TE distribution	Average TE in the category	No. of farmers
80-100	85.1	23
70-79	75.0	24
60-69	65.1	18
00-59	48.1	9
Overall average	72.6	74

Source: Own survey 2023

CONCLUSION

IADA North-West Selangor is one of Malaysia's most productive rice farming areas. This study surveyed local farmers to assess their technical efficiency (TE) levels and analyze the distribution of these levels. Although many farmers achieve high yields, there remains significant room for improvement among those with lower yields. A key finding of this study is the critical role of fertilizer in achieving higher yields. Specifically, the frequency and timing of fertilizer applications significantly impact TE, with the first, third, and fourth applications being influential. Although some farmers apply fertilizer only three times per season, the addition of a fourth application can further enhance both TE and yield. This implies that farmers with lower TE can improve significantly by optimizing their fertilizer practices, particularly by adjusting the frequency and quantity of application throughout the season. To further this understanding, future research should investigate the factors influencing farmers' fertilizer practices to develop strategies that promote higher technical efficiency.

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Research article

Factors Affecting the Use of Trichoderma by Rural Rice Farmers in Thailand

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Abstract Trichoderma is a genus of fungi that can help plants grow, resist disease, and improve nutrient uptake. It's often used as a biocontrol agent in agriculture and horticulture. The use of Trichoderma fungi to reduce the use of chemicals and maintain environmental balance is an alternative to control plant diseases in agriculture. For rice farmers, the use of Trichoderma is a viable alternative as they can save on the cost of chemical fertilizers, which preserve the environment. However, many farmers are aware of how effectively to use Trichoderma and as such may be resistant to its use. The objective of this research was to evaluate the socio-economic factors affecting the adoption and use of Trichoderma by rice farmers in North Thailand regions and the role of agricultural extension in influencing their decision. 172 farmers were interviewed for this research, Structured interviews were used for data collection. The statistics employed included frequency, percentage, mean, and standard deviation. The study's findings include: 1) most farmers were male, with an average age of 53.92 years, and with completion of primary school. Farmers received training regarding the use of Trichoderma from the District Agriculture Office, with an average of 2.67 training sessions per farmer. The average rice farming experience was 17.99 years, the average cultivated rice area was 11.94 rai, the average rice production cost was 31,453.33 baht per year, and the average income was 40,334.33 baht per year and 2) the factors that influenced farmers' adoption of Trichoderma in rice fields were statistically significant at the 0.05 confidence level and included the farmers' experience in growing rice, attendance at Trichoderma training, and their knowledge of Trichoderma.

Keywords Trichoderma, rice production, Thailand, organic

INTRODUCTION

Rice is an economically important food crop, and it is integral to national food security in Thailand. In 2022 - 2023, Thailand was self-sufficient in rice production, and it exported 7.69 million tons of rice, an increase of 22.1 percent over the previous year (21-22) valued at 138 billion baht. Rice exports were to key trading partners including China, the United States, the European Union, South Africa, and Oceania (Department of Foreign Trade, 2022). The Thai government encourages farmers to produce and export high-quality rice. To compete in the world market, domestic rice farmers face many challenges including high production costs due to the outbreak of diseases and more severe pests. Recent challenges related to climate change resulted in decreased rice production. Farmers bear the burden of debt from these increasing operational costs and agricultural inputs.

Rice cultivation in the lower northern region of Thailand covers 5 provinces: Phitsanulok, Sukhothai, Uttaradit, Phichit, and Tak. The total area of rice cultivation is 5.25 million rai (Office of Agricultural Economics 2, Phitsanulok, 2022). In 2022, rice production in the region was 3.09 million tons, with an average yield of 556 kilograms per rai (OAE, 2022). Production conditions in the northern lower region are facilitated and enhanced by irrigation from water sources. This allows farmers to cultivate rice in both the annual and second rice seasons. Farmers often focus on producing quantity rather than quality and farmers are essentially continuously cultivating rice without resting the soil which has resulted in an outbreak of rice weed disease and pest outbreaks. This is due in part to plant diseases, associated with the accumulation of pathogens in the soil that can cause root, vascular, and seedling rot. The health of the soil can affect how likely it is for plants to become infected. Plant disease outbreaks caused by fungi are now common including blight disease, sheath drying disease, and spotted seed disease (Rice Department, 2023). To combat this, farmers were using more agricultural chemicals resulting in chemical residues in the produce and with negative effects on the environment. The introduction of Trichoderma as an alternative to using chemicals to reduce disease outbreaks in plants was introduced in rice fields (Khempol, 2016). Trichoderma helps to inhibit growth, or it destroys the hyphae of plant pathogens (Jamsawang, 2013). It also stimulates plants to develop effective resistance to many common diseases. Therefore, the use of Trichoderma is another way to reduce the use of agricultural chemicals such as Bensulfuron-methyl (BSM), Chylapof-butyl, and Glyphosate-based herbicides (Daotak, 2014).

OBJECTIVE

The objective of this research was therefore to evaluate the social and economic factors influencing farmers' decision to use Trichoderma and the impact on agriculture extension on their decision-making process.

METHODOLOGY

This research utilized a survey to investigate the factors affecting the use of Trichoderma by rice farmers in the five provinces in the lower northern region of Thailand. Sampling was done by a population of 300 members who registered with the Department of Agricultural Extension in 2022 were the target group (DOAE, 2023). Of this population, 172 interviews use structured questionnaires. The selection of the sample size was based on the Taro Yamane formula with an error value of 0.05. The questionnaires used for the structured face-to-face interviews comprised questions focused on: demographics (age, household composition, gender, farming experience), economics conditions (income, earnings, production cost, land ownership status), usage of fertilizers and practices, and level of training received in the use of Trichoderma (type and frequency). The questionnaire was first piloted amongst 30 farmers who provided feedback on how the final questionnaire could be modified including the removal of terms (Chemical names, pest names, disease names) that were not understandable to farmers and specific details about what was covered during 'extension' training. As highlighted above, the final interviews were done face-to-face with farmers in the 5 provinces with a concerted effort to do this proportionately (approximately 36 in each province). Statistics used were frequency, percentage, mean, standard deviation, and multiple regression. w) Descriptive Inferential statistics were done to test the research hypothesis by multiple regression analysis to analyze the factors affecting the use of Trichoderma by rice farmers by farmers in the lower northern region. The forecast equation is as follows.

$$Y_i = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 \quad (1)$$

Where Y_i refers to farmers' acceptance of Trichoderma fungus use, a means constant, b means the coefficient of the relationship between the independent variable and the dependent variable, X means independent variables, including age (X_1), the experience of rice cultivation (X_2).

Period of being a member of the Community Pest Management Center (X_3) Receiving training on Trichoderma (X_4) Using Trichoderma in farming (X_5) Level of engagement with training (as a proxy for 'knowledge of the use of Trichoderma'e About farmers' Trichoderma fungus (X_6) and the promotion of Trichoderma use (X_7).

RESULTS AND DISCUSSION

Social and Economic Conditions of Farmers

The basic information about the social and economic conditions of farmers (n=172) reveals that there was almost an equal amount of male and female farmers with an average age of 53.96 years and who had completed primary school. The average number of agricultural workers in the household was 2.39 people, the average rice cultivation experience was 17.99 years, the average duration of membership in the community plant management center was 3.53 years, and the average number of training sessions on Trichoderma was 2.67 times. Most farmers received training about Trichoderma from the District Agriculture Office.

From the study results, it was found that 51% of the farmers were male and 49% female, which reflects the general approach in rural communities of rice farming involving family units (wife and husband teams). As highlighted above, most farmers were over 50 years of age, with only 17.4% below 30 years of age. This reflects the national trend, where farmers are starting to enter an aging society, and the younger generation is less involved in farming. The aging population in farming means knowledge of good practices has been lost and continuing need for training is required in Trichoderma use is needed (Seerasarn et al., 2020). This finding is similar to (Seerasarn et al., 2020)and (Samritnok, 2017), who studied the factors influencing the adoption of Trichoderma for pest control in rice fields among farmers in the San Sai District, Chiang Mai Province. They found that farmers had an average age of 58.66 years and an average rice cultivation experience of 27.59 years. Farmers received training on Trichoderma in the community an average of once times. Farming was often done as a husband-wife household activity, with both working together. This is also similar to Sudprasert (2010), who studied the use of biological agents to prevent and eliminate crop pests among farmers in Phitsanulok Province, where it was found that farmers had an average of 2.24 workers in their households for farming.

When farmer's land ownership, production, and earnings were explored it was found that 89.70% of farmers owned land. The average rice cultivation area was 11.94 rai, with an average rice production cost of 31,453.33 baht per year and an average rice production income of 40,334.33 baht per year. The average rice yield per rai was 753.50 kilograms. Farming has been passed down from ancestors, and the land has been divided among children and grandchildren to make a living. This is similar to the results of a study by Daotak (2014) on the adoption of Trichoderma for plant disease prevention among rice farmers in Mae Hong Son Province, which found that farmers had an average rice cultivation area of 7.14 rai. Similarly, Samritnok's study (2017) found that farmers had an average rice production income of 24,427.51 baht from rice cultivation, as most farmers grow rice for household consumption. Any surplus is sold, which results in limited income from rice sales. First of all the growing of rice for personal consumption meant farmers were more keen to produce rice with fewer chemicals, so were more willing to engage in training in the use of Trichoderma "General statements from farmers such as "the chemical affected by breathing and health when applying to the field" and "I don't want my kids to eating too much food with some chemical, it is not good". Secondly, the small amount that farmers make from their rice production means they would rather not spend on chemicals, which are expensive and can put them in debt. Any alternative, particularly where it saves money and is good for the environment and their health, they are more willing to try.

Data Analysis Using Inferential Statistics to Test Research Hypotheses

The results of testing the linear relationship of the independent variables (Table 1) found that the correlation coefficient for each pair of independent variables was not greater than 0.80. This indicates that variables $X_1 – X_7$ can be used as independent variables in multiple regression analysis without creating issues of multicollinearity among the independent variables.

Table 1 Correlation matrix

Variable	X1	X2	X3	X4	X5	X6	X7
X1	1	.541**	.122	.082	.193*	.122	-.100
X2		1	.179	.202*	.350**	-.027	-.106
X3			1	.565**	.302**	.306**	-.246**
X4				1	.528**	.311**	.020
X5					1	.138	-.055
X6						1	-.079
X7							1

An analysis of the factors affecting the use of Trichoderma by rice farmers in the lower northern region was conducted using a multiple regression model with variable reduction (Table 2).

Table 2 Factors affecting adoption of Trichoderma in rice fields of farmers

Variable	Coefficient	t-statistics	Prob.
a	1.650	2.192	0.030*
X_2	- 0.017	- 2.430	0.017*
X_4	0.105	2.400	0.018*
X_6	0.046	2.015	0.046*

*Note: * Significant at P < 0.05*

The results of the multiple regression analysis in Table 2 found that the factors affecting the use of Trichoderma among rice farmers in the lower northern region were as follows.
1) The coefficient of the variable rice growing experience (X_2) was equal to -0.017, meaning that with 1 year more experience growing rice, it will not result in acceptance of the use of Trichoderma fungus in rice fields. Farmers increased by 1.7 percent, with statistical significance at the 0.05 level.
2) The coefficient of the variable receiving training about Trichoderma (X_4) was equal to 0.105, meaning that when farmers received training about Trichoderma one more time, as a result, farmers' acceptance of the use of Trichoderma in rice fields increased by 10.5 percent, with statistical significance at the 0.05 level. Most of the training is delivered through agricultural extension, which is developed to be accessible to farmers with a basic primary school education, The training is very practical and participatory, giving farmers hands-on experience, rather than based on too much theory.
3) The coefficient of the variable knowledge about Trichoderma among farmers (X_6) was equal to 0.046, meaning that when farmers' knowledge about Trichoderma increases by 1 point, it will affect acceptance of the use Trichoderma fungus in rice fields by farmers increased by 4.6 percent, with statistical significance at the 0.05 level.

The results of the research analyzed in Table 2 found that training on Trichoderma and farmers' knowledge about Trichoderma showed no significant difference in experience in growing rice. Therefore, if farmers receive more information about Trichoderma fungus, and continuously. It will also increase farmers' knowledge about Trichoderma. Affects farmers' adoption of the use of Trichoderma in rice fields. Consistent with the study of (Seerasarn et al., 2020) and (DOAE, 2023), it was found that experience in growing rice labor within the household participating in activities related to Trichoderma awareness of news about Trichoderma within the community and attitudes towards the use of Trichoderma. It was the main factor affecting farmers' adoption of the use of Trichoderma for pest control in rice fields. Therefore, agricultural extension officers or relevant agencies should organize training to transfer knowledge about Trichoderma to farmers on a basis, to increase the use of Trichoderma fungi in rice fields.

CONCLUSION

Most farmers are male, have an average age was 53.92 years and completed primary school. Because in the past it was basic education. Most household members consist of husband and wife, their rice cultivation area of less than 10 rai, and the average income from selling rice products was 40,334.33 baht/year. Since most of the rice production was consumed within the household, there was not much income. Most farmers received training on Trichoderma from the District Agriculture Office but still lack skills and knowledge on some issues resulting in farmers a moderate level of knowledge about Trichoderma in rice fields. Factors affecting farmers' acceptance of the use of Trichoderma in rice fields.

Including experience in growing rice training on Trichoderma and farmers' knowledge about Trichoderma and factors that did not affect farmers' adoption of using Trichoderma in rice fields including gender, age, and time period as a member of the community pest management center. Number uses of Trichoderma in farming and a source for receiving information about Trichoderma. Therefore, agricultural extension officers should regularly train and transfer knowledge on the properties and benefits of Trichoderma to farmers. Including gathering groups of farmers to produce and grow Trichoderma. To increase farmers' knowledge about Trichoderma fungi. There was increasing expertise in producing Trichoderma fungus for use in controlling plant diseases in rice fields. The farmers were more knowledgeable about Trichoderma fungus. This will result in a higher use of Trichoderma fungus in farmers' rice fields.

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Research article

Changes in the Evaluation of Rural Landscape Before and After Farmland Improvement

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Abstract Rural landscapes especially in hilly and mountainous areas have been attracting attention of urban people and some farmlands have become busy tourist destinations. Other rural farmlands suffer from low workability, aging farmers, and declining demand for rice which often results in abandoned farmland. To address this, farmland improvement is being carried out to encourage continued sustainable agricultural production activities. This causes the change of shape and layout of plots, which are the components of the rural landscape. There have been many studies on the economic evaluation of landscapes, the recognition and impression of cultural landscapes, and the ecology of farmland improvement projects, but there have been few studies on the changes in the impressions of farmland landscape before and after farmland improvement. Therefore, in order to clarify the differences in the impression of the landscape before and after farmland development, we conducted a survey in the farmland development area of Hyogo Prefecture. Specifically, we asked district residents which of 16 rice field landscape photos they liked the best, and we then used a semantic differential method to ask them about their impressions of the selected landscape photos. In a related question, we asked how the local landscape had changed as a result of the farmland improvement project, and whether the changes were viewed as positive or negative. This questionnaire survey asked all local residents, but farmers in particular were asked how much time they spent working on the farm had been reduced and how much their labor productivity had improved as a result of field maintenance. After analyzing the survey results, it was found that the farmland improvement project had improved labor productivity and created a beautiful landscape. On the other hand, there were also a few responses that assessed that the landscape had deteriorated, which requires deeper consideration.

Keywords farmland improvement, landscape impression, SD method

INTRODUCTION

The size of each agricultural land is small, and labor productivity is low, resulting in high rates of non-cultivation and abandonment of farms in Japan. In order to minimize this trend, it is necessary to improve farmland to increase labor productivity. Due to the implementation of the farmland improvement project, the area of one cultivation unit was expanded and the landscape changed significantly. Research on the changes in landscape impressions before and after farmland improvement project has been limited to only a few regions (Ito et al., 2003), There are a few studies that have focused on landscape changes before and after farmland improvement projects that take landscape aspects into account, and the authors' research was the only one (Fujimi and Yamaji, 2020).

Regarding the maintenance and improvement of the environment and the landscape of rural spaces, eight areas were incorporated in Articles 3 and 34 of the Food, Agriculture, and Rural Areas Basic Act (1999). The revised Land Improvement Act (2001) established “consideration for harmony with the environment" as a principle when implementing farmland improvement projects. Against this background, considering the impact of field maintenance projects on the rural landscape, it is recommended that farmland maintenance be done in harmony with the environment and consideration of the landscape. In 2007, the Ministry of Agriculture, Forestry and Fisheries issued the "Guide to Landscape Consideration in Agricultural and Rural Development Projects" as concrete guidelines. And in order to disseminate the idea of landscape consideration, "Technical Guidelines for Landscape Consideration in Agricultural and Rural Development Projects" were published in 2018.

Previous Research

Fujimi et al. (2006) pointed to an abandonment of cultivation and farmland improvement, which changes the shape and arrangement of farmland, as possible causes of landscape deterioration. Previous plots that matched the conventional topography were changed to rectangular plots or contour plots; stone walls and soil slopes were replaced with concrete blocks. Looking at the landscape, local people estimate the landscape value of each. Yamaji (1992) states that the long sides of a plot should be curved rather than straight, as long as they are parallel. Hagihara et al. (2013) considered the impact of farmland maintenance on residents' awareness of the landscape and compared the effects of farmland improvement with village areas. However, it has been stated that the preservation of biological diversity is a factor that influences awareness of landscape conservation, but this was not applied to fields such as rice paddies and fields. After the field is improved, farmers will begin to accumulate farmland and form large-scale agricultural management entities. Hosokawa et al. (2005) conducted a case study on agglomerations in hilly and mountainous areas and identified low labor productivity in the area. Matsuoka et al. (2017) focused on and summarized the situation of farmland agglomeration and found the constraints on agglomeration for individual management entities. Such agglomeration may also develop into the selective use of improved field drainage facilities or the further expansion of farmland plots. Naturally, when the farmland area is expanded, the landscape of the farmland also becomes different.

OBJECTIVE

Therefore, in this study, we aimed to ask local residents to evaluate how the farmland landscape changed before and after the implementation of the farmland improvement project, and to clarify quantitively, using adjective pairs, how they felt about the farmland landscape before and after the project.

METHODOLOGY

Selection of Experimental Site

The preferred study site was to select an area where field development was carried out after the creation of the "Guidebook for Landscape Consideration in Agriculture and Rural Development Projects." We listed the areas and considered the contents of the project and the possibility of cooperation with local leadership.

As a result, we chose the Yakata district farmland improvement project in Ichikawa Town, Kanzaki Region, Hyogo Prefecture. This district-level farmland improvement project has been underway since 2018. As of the month of 2024, surface construction has been completed, and cultivation is being carried out on temporary allocated land. Land replacement is currently underway, and the final project completion is expected in the month of 2025. This 36.7-hectare (ha) farmland improvement area is relatively flat with an average slope of 1/61, and it is along a river. The number of each cultivation plot was 640 and the size of it was 0.05 ha before the project and it became 70 plots with the size of around 0.5 ha after the project.

Evaluation Method

The semantic differential method (SD method) was adopted for landscape evaluation. The SD method is a method of measuring a subject's impression of an object by converting their impression into a numerical value. We placed adjectives with opposite meanings at both ends, such as comfortable - uncomfortable, favorite - hate, sophisticated - rustic. Respondents are asked to choose one of five choices. For example, it is very fun, fun, intermediate, boring, and very boring. Adjective pairs were collected from those used in past research completed by the same authors. We examined them and decided to use 24 pairs of adjectives.

Preparation of Photos

To evaluate the impression of the landscape, we obtained 36 photos from the Ichikawa Town Construction Division. Photos were taken before the farmland improvement project. We attempted to identify the location for each photo by reviewing the topography, the orientation to roads, and the background landscape. We identified five of the 36 photos, and after additional review, we selected four photos for our study.

The results are shown in Figure 1. Place of arrows A, B, C, and D are the locations and directions of photos taken before the project implementation, and A, B, C, and D are the photos taken at the same locations before and after the project implementation. We also prepared four photos after the project, i.e. E, F, G, and H, the locations of these photos are shown in Fig. 1. We selected typical four photos before the project, which were not identified the taken place, are shown at the bottom of Fig. 1.

For the landscape evaluation, we showed 16 landscape photos, which were randomly arranged, to be scored on a scale of 1-10. Then, the participants were asked to choose the photo with the highest score (if there were more than one photo with the highest score, they were asked to choose one). Then we asked them to choose the impression of the selected landscape photo by 24 adjective pairs.

The evaluation was conducted from January to February 2024, targeting all residents and their families in the Yakata area.

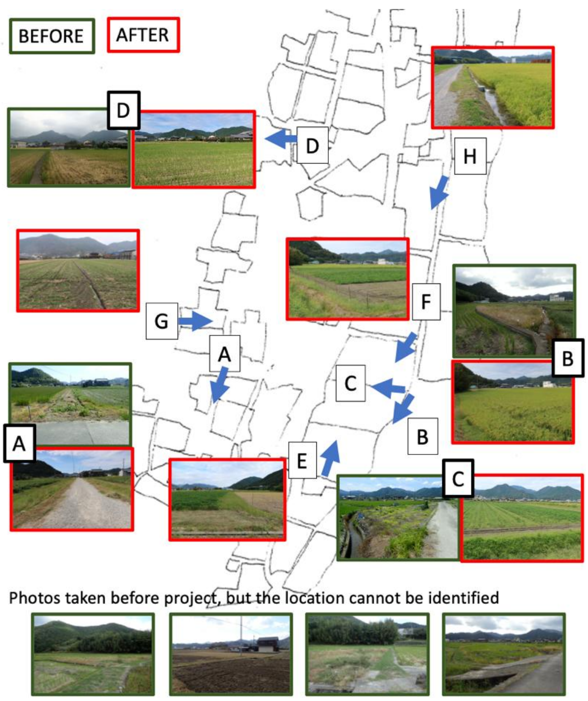

Fig. 1 Four sets and other eight photographs

RESULTS AND DISCUSSION

Execution of Questionnaire Survey

Four pages questionnaire sheet and three copies of the answer sheet were distributed by post mail to each of the 251 households in the Yakata district, and responses were solicited from residents of junior high school age and above. We asked each household to respond from at least one person, but we also informed them that, if possible, we would like to receive responses from family members living together. This is because if only one person answered, there was a risk that most of the answers would be by men. If two or more people respond, we can expect responses from women and young people as well.

Responses were collected by post mail. We received 75 answers; 52 were by one person, 20 were two persons from one family, and 3 were 3 people from one family. So, the total number of respondents was 101. The attributes of respondents are shown in Table 1. In terms of gender, there was almost an equal number of men and women, so it can be said that this is a good group of respondents. By age group, most of the responses were from elderly people, but since the original population distribution was also dominated by elderly people, we judged this to be unavoidable.

Table 1 Sex and age of respondents

Sex	Ratio
Female	47 %
Male	46
NA	8

Age	Ratio
10-19y	2 %
20-29y	3
30-39y	2
40-49y	5
50-59y	21
60-69y	18
70-79y	30
80y-	15
NA	5

Evaluation of 16 Photos

Respondents were asked to rate all 16 rice field landscape photos on their preference with a scale of 1 to 10. The fourth line of Table 2 shows the average evaluation scores. After scoring all the photos, they were then asked to choose the one they liked best among the 16 rice field landscape photos. The fifth line of Table 2 shows the number of people chosen as the top. 12 photos are selected as top by 1 to 21 respondents. 4 photos are not selected as the top by any respondent.

Seven of the eight photos taken after farmland improvement were selected as top. Five out of eight photos of the landscape before farmland improvement were selected as top. From this, it was found that there are many people who choose pictures of the landscape after farmland improvement, however, some people choose pictures of the landscape before the project.

Table 2 Average score and number of chosen as the best landscape

Photo Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Place	D	E	D	A	-	-	G	-	B	A	C	F	B	C	H	-
Before / After	B	A	A	B	B	B	A	B	A	A	B	A	B	A	A	B
Average Score	6.1	6.1	7.5	5.6	5.4	6.0	6.6	5.0	7.0	6.6	5.2	7.2	4.9	7.4	7.4	5.5
Choosed TOP	2	0	21	4	2	0	2	0	11	3	4	6	1	21	15	0

We prepared four sets of corresponding photos before and after farmland improvement. Figure 2 shows the evaluation result of four sets. At all points, the scores were higher after farmland improvement, especially at points C and B.

Evaluation by Using 24 Adjective Pairs

The landscape photos that received the most first-place votes were evaluated using adjective pairs to see how they were perceived. No. 14 and No. 15 are landscape photos taken after the project, and the average adjective evaluations are shown with orange dots and lines. No. 4 and No. 11 are landscape photos taken before the project, and the average adjective evaluations are shown with blue dots and lines.

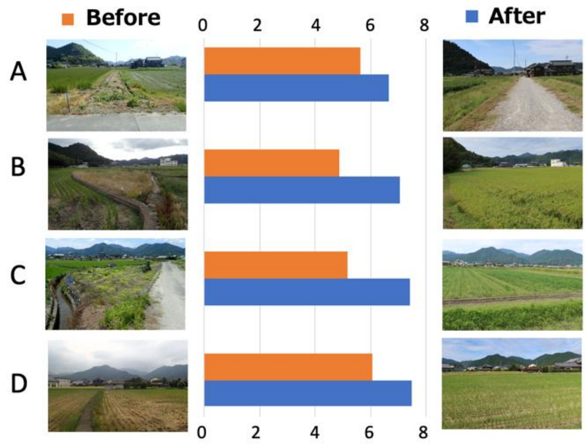

Fig. 2 Landscape evaluation of before / after project

These two sets of evaluation results are somewhat similar, but there are also differences. The landscape photos taken before the project were evaluated as rustic, rich in variety, cluttered, natural, rich in living things, and dynamic. The landscape photos taken after the project were evaluated as sophisticated, monotonous, artificial, and static.

Many people praised the landscapes taken after the project for being well-organized, but at the same time, they were also evaluated as monotonous and boring. This makes it clear that there is a certain number of people who think that the landscapes taken before the project were better.

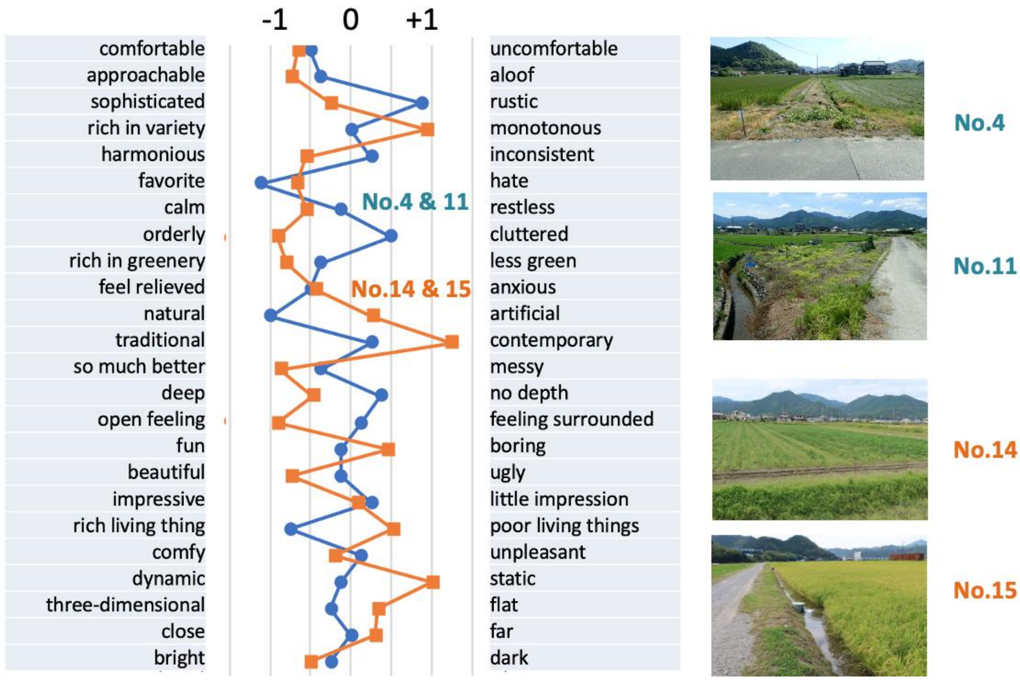

Fig. 3 Comparison of SD between two landscape groups

DISCUSSIONS

As mentioned in the previous section, it was found that the elements that show changes in landscape evaluation before and after farmland improvement projects can be described by specific adjectives. Although the landscape after improvement is generally considered to be a good landscape, it is also important to point out that some good landscape elements before improvement have been lost. It was shown that in future improvement, it would be beneficial to add vegetation or establish a biotope to avoid evaluations such as monotony or poor living things.

In this field development, the previous 640 plots (average 0.05 ha) will be rezoned and changed to 70 plots (average 0.43 ha). In addition, irrigation canals that were previously open canals will be converted into pipelines. Of these things, the local government office estimated the agricultural work time per 0.1 ha will decrease from 39 hours to 15 hours.

This questionnaire survey asked all residents, but farmers, in particular, were additionally asked how much time they spent working on the farm had been reduced and how much their labor productivity had improved as a result of field maintenance. They answered much decrease in each farming work except for weeding. The first target of the project to increase labor productivity was achieved. On the other hand, the survey results regarding the scenery showed that the scenery is generally good. However, some respondents assessed that the landscape had deteriorated, so deeper consideration is required.

All photos used in the questionnaire survey had a known date and time. When taking photos after field preparation, I tried to take photos under similar lighting conditions as much as possible. However, the effects of seasonal differences on vegetation remained. At first, we considered processing the photo to make it look as if all the rice fields were being cultivated, but this was not done due to technical difficulties and the issue of what to do with elements other than the rice fields. In the future, we should deepen our consideration of the evaluation bias caused by these influences.

CONCLUSION

An attempt was made to ask not only the farmers who would benefit from the farmland improvement project but also all local residents, about the changes in the landscape caused by the improvement of rice fields. Although the response rate was only 30% in the household base, due to the method of requesting and responding by post mail, the ratio of male and female respondents was almost even, and some responses were from the younger generation. Regarding changes in the landscape due to the farmland improvement project, many respondents said that it had improved, which is an achievement, but it is necessary to examine the validity of the photos used in the survey and conduct a deeper analysis.

ACKNOWLEDGEMENTS

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Research article

Impact of Street Tree Base Management on the Plants Colonizing Street Tree Bases in Western Japanese City

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Abstract The space at the base of street trees (hereafter referred to as "street tree bases") is invaded and colonized by a diverse plant population, primarily consisting of native species. As such, it is implied that street tree bases contribute to urban biodiversity. Various types of street tree bases exist (hereafter referred to as "street tree base types"). These include trees with garden beds at their bases, and trees with bases covered by artificial structures. However, there is a lack of information regarding the plants that invade and colonize street tree bases and comprehensive research is required in this direction. Therefore, we conducted a study involving street tree bases (n=104) and we examined the effects of street tree base types on the plant species that colonize the bases of street trees, in Fukuoka City, one of Japan's five largest cities. In addition, the street tree base's contribution to urban biodiversity was examined and was based on the presence of buried seed populations. Our results show that many plants that were not found in other types invaded and colonized in each street tree base type, forming a plant community that differed from other types. We believe that street tree bases can further increase urban biodiversity by establishing various street tree base types and management of their street tree bases. In addition, it was found that buried seed communities were present in many street tree bases indicating that they also serve as urban soil seed banks.

Keywords street tree base type, urban biodiversity, nature positive, buried seed

INTRODUCTION

The development of natural spaces (Ishii et al., 2010; Xiu et al., 2020), overfishing (Wolanski et al., 2020; Zhang et al., 2022), alien species (Mohammad et al., 2013; Lucero et al., 2022), climate change (Kapuka et al., 2022; Zhang et al., 2022), and other factors have contributed to the destruction of natural habitats and seriously affected ecosystems. As a result, the concept of 'nature positive', which is an ecological concept based on the prevention and restoration of biodiversity loss, has received increased worldwide attention in recent years (Ermgassen et al., 2022). In order to realize 'nature positive', it is necessary to not only protect spaces with healthy ecosystems, but also to create biodiversity within urban areas (Birkeland, 2022).

Studies on the creation and maintenance of urban biodiversity have been conducted in woodlands (Ishii et al., 2010; Muluneh and Worku, 2022), temples and shrines (Imanishi et al., 2005), rivers (Cheang et al., 2020; Hwang et al., 2021), gardens (Oishi, 2019; Prendergast et al., 2022), green roofs (Furuno et al., 2021a; Durà et al., 2023), road gaps (Uchida et al., 2014), street trees (Hotta et al., 2015; Jian et al., 2021), and other urban environments.

Additionally, several studies have examined the creation of urban biodiversity in the space around the roots of street trees (hereafter referred to as “street tree bases”). The findings of these studies show that herbaceous and woody plants invade and colonize street tree bases from other environments (Furuno et al., 2014a; Furuno et al., 2014b; Furuno et al., 2022; Omar et al., 2018). Since many of these colonizers are native species, street tree bases can play a role in increasing urban biodiversity (Furuno et al., 2014a; Furuno et al., 2014b; Furuno et al., 2022; Omar et al., 2018). Although the spatial scale of each of these spaces is very small and does not contain many plant species, the cumulative impact of these street tree bases on urban biodiversity is considered to be comparable to that of large urban green spaces (Furuno et al., 2022). This is consistent with the findings of the Single Large or Several Small patches controversy in which a single large area of space is considered effective in creating biodiversity, while there are some findings that multiple small areas of space are effective (Bolgovies et al., 2019; Deane et al., 2020; Murakami et al., 2005). However, there is still much that is unknown about the plants that invade and colonize street tree bases and more knowledge is required.

There are various types of street tree base (hereafter, “street tree base types”), some have garden beds at their bases, and some have their bases covered by man-made structures such as iron grating, at the base (Furuno et al., 2021b). However, no studies have explored the relationship between “street tree base types” and “invasive plants.”

OBJECTIVES

The purpose of this study was to gain new insights into how street tree bases affect urban biodiversity. We explored the effects of the aforementioned street tree base types on the plant species that invade and colonize these bases. In addition, we report the results of an investigation into the contribution to urban biodiversity of seeds buried in the soil at the street tree bases.

MATERIALS AND METHODS

Invading and Colonizing Plants

The study was conducted in Fukuoka City, Fukuoka Prefecture in western Japan (Fig. 1). Fukuoka City (33°36’N, 130°25’E), which is one of Japan’s five largest cities, had a population of approximately 1.51 million people as of October 2013 (Fukuoka city, 2025).

We randomly selected 33 intersections in Chuo Ward, which is predominantly urbanized and has the lowest green coverage in Fukuoka City at 22.2% (Fukuoka city, 2009). All intersections were located in similar environments, with no large green spaces and were along arterial, prefectural or city roads. The survey targeted four street tree base types (Types A, B, C, and D) maintained within 50 m of each intersection (n=104) (Fig 1). Type A trees had bases that were not maintained (n=23), Type B trees had garden beds at their bases (n=18), Type C trees had bases that were covered by artificial structures, such as iron grating (n=31), and Type D has a narrower base of the tree due to trees being trimmed low to form hedges (n=32). Tall trees and subcanopy trees such as *Ginkgo biloba* L., *Ilex rotunda* Thunb., *Zelkova serrata* (Thunb.) Makino. were planted in Types A, B, and C, and species resistant to trimming such as *Rhaphiolepis indica* (L.) Lindl., *Abelia x grandiflora* (Rovelli ex André) Rehder, *Camellia japonica* L. were planted in Type D (Table 1). There were 24 unique tree species (including Ericaceae sp. and Rosaceae sp.) which were assigned to one to three street tree base types (Table 1). We placed quadrats over each street tree base and recorded the invading/colonizing plant species in the quadrats. The size of the quadrats was adjusted to the conditions at each street tree base (Type A: 1.4 m^2 on average, Type B: 1.8 m^2 on average, Type C: 2.2 m^2 on average, Type D: 2.2 m^2 on average). The survey was conducted from early September to mid-October 2013.

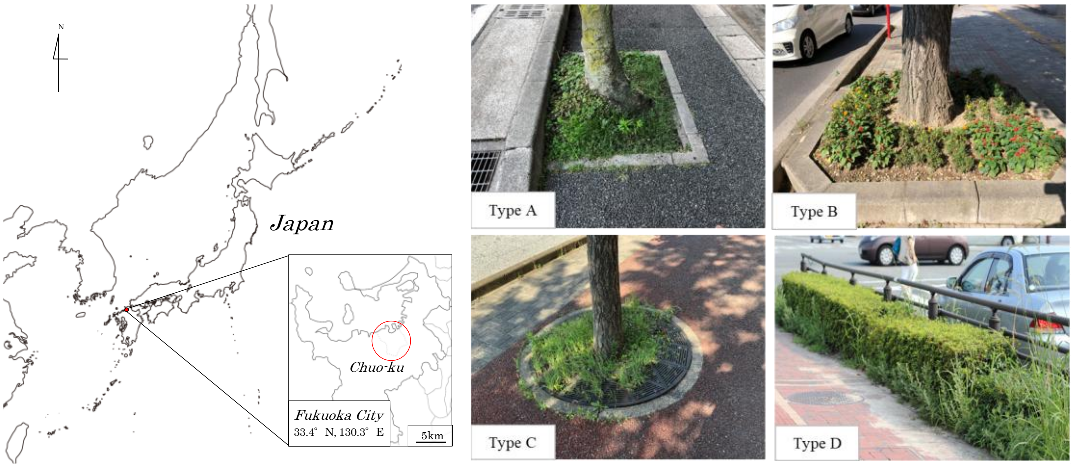

Fig. 1 Location of the study site in Fukuoka city, Fukuoka prefecture, Japan and targeted street tree base types

Table 1 Street tree species in each street tree base types

Species	Family	Street tree base types †			
		A (n=23)	B (n=18)	C (n=31)	D (n=32)
Abelia x *grandiflora* (Rovelli ex André) Rehder *	Caprifoliaceae				11
Acer buergerianum Miq.	Sapindaceae	5	2		
Aesculus hippocastanum L.	Sapindaceae			1	
Aesculus turbinata Blume	Sapindaceae			1	
Aesculus x *carnea* J.Zeyh.	Sapindaceae			2	
Camellia japonica L. *	Theaceae				3
Diospyros kaki Thunb.	Ebenaceae		1		
Elaeocarpus zollingeri K.Koch	Elaeocarpaceae	1	2	2	
Eurya emarginata (Thunb.) Makino *	Theaceae				1
Fraxinus griffithii C.B.Clarke	Oleaceae		2	3	
Ginkgo biloba L.	Ginkgoaceae	6	3	8	
Ilex rotunda Thunb.	Aquifoliaceae	5	4	7	
Liquidambar styraciflua L.	Altinglaceae			2	
Lithocarpus edulis (Makino) Nakai	Fagaceae	1	1		
Magnolia kobus DC.	Magnoliaceae			1	
Machilus thunbergii Siebold	Lauraceae	1			
Pieris japonica (Thunb.) D.Don *	Ericaceae				1
Pinus thunbergii Parl.	Pinaceae		1		
Pittosporum tobira (Thunb.) W.T.Aiton *	Pittosporaceae				3
Rhaphiolepis indica (L.) Lindl. *	Rosaceae				11
Toona sinensis (A.Juss.) M.Roem.	Meliaceae	1			
Zelkova serrata (Thunb.) Makino	Ulmaceae	1	1	3	
Ericaceae sp. *	Ericaceae				2
Rosaceae sp.	Rosaceae	2	1	1	
Total number of species		9	10	11	7

Notes: † Values are planting locations by street tree base type

Buried Seed

To assess buried seed, topsoil samples were collected from any of the selected street tree bases (n=86). Furthermore, the pH and Electrical conductivity (EC) of the topsoil were 7.7±0.5 and 0.05±0.04

mS/cm, respectively, the values were approximately similar. A seeding-out test was conducted to identify seeds buried within the collected topsoil. In the seeding-out test, 500 ml of vermiculite was placed in a vinyl pot (top diameter: 105 mm, bottom diameter: 75 mm, height: 90 mm) and covered with 200 ml of the collected topsoil. The pots were maintained under a photoperiod of 12h dark:12h light at a room temperature of 25 degrees Celsius. For lighting, 9 fluorescent lamps with a color temperature of 4,000 K and a total luminous flux of 2,850 lm were used. The soil was sprinkled with water.

Analysis

To evaluate the impact of street tree base types on the species diversity of the plant community of street tree bases, the Shannon-Wiener diversity index, H', was calculated. The Bray-Curtis index was calculated to evaluate the similarity among the plant communities at each street tree base. In addition, to further clarify the similarity between plant communities at the base of each street tree, the non-metric multidimensional scaling (nMDS) was performed using the Bray-Curtis index. This index was calculated based on the cover scores of plant species at the base of each street tree, determined using the Braun–Blanquet total estimation method. In addition, percentage differences, such as the percentage of native species, were calculated using the $\chi 2$ test. The R software package (Ver. 4.2.1) was used to calculate Shannon-Wiener's diversity index, Bray-Curtis index, and nMDS, and SPSS Statistics Ver. 27 (IBM) was used to calculate for the $\chi 2$ test.

RESULTS

Plants that Invade and Colonize Different Types of Street Tree Bases

Invasion and Colonization Status of Plants

A total of 123 plant species (excluding Rosaceae sp.) in 46 families were observed at the bases of street trees (n=104) (Table 2). Of these species, 81 (65.8%) were native species. Also, ephemeral species (annuals, biennials and winter annuals) accounted for 50 species (40.7%), perennials for 49 species (39.8%), and woody plants for 24 species (19.5%).

By street tree base types, in Type A (n=23), 56 species in 26 families (excluding cherry species) were found, of which 16 species such as *Eragrostis minor* Host, *Eragrostis multicaulis* Steud., *Ginkgo biloba* L., *Hydrocotyle ramiflora* Maxim., *Ipomoea nil* (L.) Roth. were found only in this type and not in other types (Table 2). In Type B (n=18), 40 species (excluding cherries) in 21 families were found, 38 species in 14 families were found in Type C (n=31), and 76 species in 35 families were found in Type D (n=32), respectively (Table 2). Some of these plants, as in Type A, were not found in the other types: 12 species such as *Acer palmatum* Thunb., *Acer buergerianum* Miq., *Ambrosia artemisiifolia* L., *Calystegia japonica* Choisy in Type B, 10 species such as *Aster microcephalus* (Miq.) Franch., *Centipeda minima* (L.) A.Braun, *Cerastium glomeratum* Thuill., *Dactyloctenium aegyptium* (L.) P.Beauv. in Type C, and 39 species such as *Achyranthes bidentata* Blume, *Agrostis gigantea* Roth, *Aphananthe aspera* (Thunb.) Planch., *Boehmeria nivea* (L.) Gaudich. in Type D (Table 2). The percentage of plants not found in other types ranged from 26.3% to 51.3%.

Bray-Curtis index values ranged from 0.59 to 0.75 among the types, and the species composition of each type differed greatly, with diversity indices (H') of 3.81 obtained for Type A, 3.57 for Type B, 3.22 for Type C, and 4.5 for Type D (Tables 2 and 3, Fig. 2). Furthermore, A total of 17 species, including *Acalypha australis* L., *Artemisia indica* Willd., *Cyperus amuricus* Maxim., *Digitaria ciliaris* (Retz.) Koeler. were common to all types (Table 2).

Table 2 Plants found by street tree base type

Species	Family	Native	Herbaceous		Woody	Plant life types ‡				Street tree base types *			
			Ephemeral †	Perennials		Dormant	Underground organ	Seed dispersal	Growth	A (n=23)	B (n=18)	C (n=31)	D (n=32)
Acalypha australis L.	Euphorbiaceae	●	●			Th	R5	D3	e	0.991	0.005	0.006	0.166
Artemisia indica Willd.	Asteraceae	●		●		Ch	R2	D4	e	0.026	1.984	0.181	0.881
Cyperus amuricus Maxim.	Cyperaceae	●	●			Th	R5	D4	t	5.870	2.895	1.210	2.344
Digitaria ciliaris (Retz.) Koeler	Poaceae	●	●			Th	R4	D4	t	1.957	0.274	3.145	1.875
Digitaria radicosa (J.Presl) Miq.	Poaceae	●	●			Th	R4	D4	t	2.948	1.979	0.171	0.794
Eleusine indica (L.) Gaertn.	Poaceae	●	●			Th	R5	D4	t	2.391	0.005	0.329	0.003
Erigeron annuus (L.) Pers.	Asteraceae		●			Th(w)	R5	D1	pr	0.004	0.005	0.006	0.009
Euphorbia maculata L.	Euphorbiaceae		●			Th	R5	D3	b	2.835	1.189	2.023	0.184
Oxalis corniculata L.	Oxalidaceae	●		●		Ch	R4	D3	p	0.817	0.553	0.355	0.656
Oxalis dillenii Jacq.	Oxalidaceae			●		Ch	R4	D3	p	0.009	0.268	0.003	0.025
Paederia foetida L.	Rubiaceae	●		●		Ch	R3	D4	l	0.004	0.005	0.003	1.416
Plantago asiatica L.	Plantaginaceae	●		●		H	R3	D2	r	0.009	0.005	0.019	0.009
Setaria viridis (L.) P.Beauv.	Poaceae	●	●			Th	R5	D4	t	7.304	1.716	2.994	0.806
Solanum nigrum L.	Solanaceae	●	●			Th	R5	D2	b	0.009	0.016	0.010	0.159
Taraxacum officinale Weber	Asteraceae			●		H	R3	D1	r	2.426	0.295	0.510	0.044
Youngia japonica (L.) DC.	Asteraceae	●	●			Th(w)	R5	D1	ps	0.004	0.005	0.010	0.003
Zoysia japonica Steud.	Poaceae			●		H	R1	D4	t	0.009	0.789	6.619	1.347
Eragrostis minor Host	Poaceae		●			Th	R5	D4	t	0.004			
Eragrostis multicaulis Steud.	Poaceae	●	●			Th	R5	D4	t	0.761			
Ginkgo biloba L.	Ginkgoaceae	●			●	MM	R5	D4	e	0.217			
Hydrocotyle ramiflora Maxim.	Araliaceae	●		●		Ch	R4	D4	p	1.848			
Ipomoea nil (L.) Roth	Convolvulaceae		●			Th	R5	D4	l	0.009			
Lepidium virginicum L.	Brassicaceae		●			Th(w)	R5	D4	pr	0.004			
Lolium multiflorum Lam.	Poaceae		●			Th(w)	R5	D4	t	0.004			
Mirabilis jalapa L.	Nyctaginaceae		●			Th	R5	D4	e	0.217			
Persicaria capitata (Buch.-Ham. ex D.Don) H.Gross	Polygonaceae			●		H	R5	D4	b	0.004			
Rumex crispus L.	Polygonaceae		●			H	R5	D4	ps	0.004			
Sedum mexicanum Britton	Crassulaceae			●		Ch	R4	D4	p	0.217			
Setaria pumila (Poir.) Roem.	Poaceae	●	●			Th	R5	D4	t	0.004			
Talinum paniculatum (Jacq.) Gaertn.	Talinaceae		●			Th	R5	D4	b	0.987			
Toona sinensis (A.Juss.) M.Roem.	Meliaceae				●	MM	R5	D4	e	0.217			
Vicia hirsuta (L.) Gray	Fabaceae	●	●			Th(w)	R5	D3	l	0.004			
Wahlenbergia marginata (Thunb.) A.DC.	Campanulaceae	●		●		H	R2	D4	ps	0.004			
Acer palmatum Thunb.	Sapindaceae	●			●	MM	R5	D1	e		0.005		
Acer buergerianum Miq.	Sapindaceae				●	MM	R5	D1	e		0.005		
Ambrosia artemisiifolia L.	Asteraceae		●			Th	R5	D4	e		0.005		
Calystegia japonica Choisy	Convolvulaceae	●		●		G	R2	D5	l		0.263		

Table 2 Continued

Species	Family	Native	Herbaceous		Woody	Plant life types ‡				Street tree base types *			
			Ephemeral †	Perennials		Dormant	Underground organ	Seed dispersal	Growth	A (n=23)	B (n=18)	C (n=31)	D (n=32)
Cyperus iria L.	Cyperaceae	●	●			Th	R5	D4	t		0.005		
Diospyros kaki Thunb.	Ebenaceae	●			●	MM	R5	D2	e		0.005		
Lygodium japonicum (Thunb.) Sw.	Lygodiaceae			●		H	R2	D1	l		0.005		
Oenothera speciosa Nutt.	Onagraceae			●		Th(w)	R5	D1	ps		0.005		
Persicaria lapathifolia (L.) Delarbre	Polygonaceae	●	●			Th	R5	D4	e		0.005		
Plantago virginica L.	Plantaginaceae			●		H	R3	D2	r		0.005		
Trigastrotheca stricta (L.) Thulin	Molluginaceae	●	●			Th	R5	D4	b		0.005		
Viola mandshurica W.Becker	Violaceae	●		●		H	R3	D3	r		0.005		
Aster microcephalus (Miq.) Franch.	Asteraceae	●		●		Ch	R3	D1	pr			0.003	
Centipeda minima (L.) A.Braun	Asteraceae	●	●			Th	R3	D4	p			0.003	
Cerastium glomeratum Thuill.	Caryophyllaceae		●			Th(w)	R5	D4	b			0.003	
Dactyloctenium aegyptium (L.) P.Beauv.	Poaceae		●			Th	R4	D4	p			0.003	
Draba nemorosa L.	Brassicaceae	●	●			Th(w)	R5	D4	ps			0.003	
Elymus tsukushiensis Honda	Poaceae	●		●		H	R5	D4	t			0.161	
Geranium carolinianum L.	Geraniaceae		●			M	R5	D4	e			0.161	
Kummerowia striata (Thunb.) Schindl.	Fabaceae	●	●			Th	R5	D4	e			0.003	
Rumex japonicus Houtt.	Polygonaceae	●		●		H	R5	D4	ps			0.003	
Spergula arvensis L.	Caryophyllaceae		●			Th(w)	R5	D4	b			0.006	
Achyranthes bidentata Blume	Amaranthaceae	●		●		H	R3	D2	e				0.003
Agrostis gigantea Roth	Poaceae	●		●		H	R3	D4	t				0.003
Aphananthe aspera (Thunb.) Planch.	Cannabaceae	●			●	MM	R5	D2	e				0.156
Boehmeria nivea (L.) Gaudich.	Urticaceae	●		●		Ch	R3	D4	e				1.175
Briza minor L.	Poaceae		●			Th	R5	D4	t				0.003
Celtis sinensis Pers.	Cannabaceae	●			●	MM	R5	D2	e				0.706
Chenopodium album L.	Amaranthaceae	●	●			Th	R5	D4	e				0.003
Cinnamomum camphora (L.) J.Presl	Lauraceae	●			●	MM	R5	D4	e				1.097
Commelina communis L.	Commelinaceae	●	●			Th	R5	D4	b				0.013
Cyperus pygmaeus Rottb.	Cyperaceae	●	●			Th	R5	D4	e				0.003
Dioscorea japonica Thunb.	Dioscoreaceae	●		●		G	R5	D1	l				0.156
Dioscorea tenuipes Franch.	Dioscoreaceae	●		●		G	R5	D1	e				0.003
Elymus racemifer (Steud.) Tzvelev	Poaceae	●		●		H	R5	D4	t				0.003
Equisetum arvense L.	Equisetaceae	●		●		G	R1	D1	e				0.003
Erigeron bonariensis L.	Asteraceae		●			Th(w)	R5	D1	pr				0.003
Farfugium japonicum (L.) Kitam.	Asteraceae	●		●		H	R2	D1	ps				0.003
Ficus erecta Thunb.	Moraceae	●			●	M	R5	D2	e				0.006
Gnaphalium japonicum Thunb.	Asteraceae	●		●		H	R5	D1	b				0.003
Ipomoea triloba L.	Convolvulaceae		●			Th	R5	D4	l				0.547

Table 2 Continued

Species	Family	Native	Herbaceous		Woody	Plant life types ‡				Street tree base types *			
			Ephemeral †	Perennials		Dormant	Underground organ	Seed dispersal	Growth	A (n=23)	B (n=18)	C (n=31)	D (n=32)
Ixeris japonica (Burm.f.) Nakai	Asteraceae	●		●		H	R3	D1	ps				0.003
Ixeris stolonifera A.Gray	Asteraceae	●		●		H	R4	D1	p				0.003
Ligustrum japonicum Thunb.	Oleaceae	●			●	M	R5	D2	e				0.003
Lolium arundinaceum (Schreb.) Darbysh.	Poaceae			●		H	R3	D4	t				0.547
Machilus thunbergii Siebold	Lauraceae	●			●	MM	R5	D4	e				0.156
Magnolia kobus DC.	Magnoliaceae	●			●	MM	R5	D4	e				0.006
Paspalum dilatatum Poir.	Poaceae			●		H	R3	D4	t				0.003
Paspalum urvillei Steud.	Poaceae			●		H	R3	D4	t				0.003
Pleioblastus argenteostriatus (Regel) Nakai	Poaceae	●			●	M	R1	D4	e				0.156
Pterostyrax hispida Siebold	Styracaceae	●			●	MM	R5	D4	e				0.003
Quercus glauca Thunb.	Fagaceae	●			●	MM	R5	D4	e				0.156
Rhaphiolepis indica (L.) Lindl.	Rosaceae	●			●	N	R5	D4	b				0.003
Rorippa indica (L.) Hiern	Brassicaceae	●	●			Th(w)	R5	D4	pr				0.003
Rumex conglomeratus Murray	Polygonaceae			●		H	R5	D4	ps				0.003
Solidago altissima L.	Asteraceae			●		Ch	R2	D1	pr				0.006
Sorghum halepense (L.) Pers.	Poaceae			●		G	R1	D1	e				0.003
Toxicodendron succedaneum (L.) Kuntze	Anacardiaceae	●			●	MM	R5	D2	e				0.003
Trichosanthes cucumeroides (Ser.) Maxim.	Cucurbitaceae	●		●		G	R5	D4	l				0.547
Ulmus parvifolia Jacq.	Ulmaceae	●			●	MM	R5	D1	e				0.859
Zelkova serrata (Thunb.) Makino	Ulmaceae	●			●	MM	R5	D4	e				0.156
Bromus catharticus Vahl	Poaceae			●		H	R3	D4	t		0.005		0.003
Calystegia hederacea Wall.	Convolvulaceae	●		●		G	R2	D5	l				0.156
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	●	●			Th(w)	R5	D4	ps			0.003	0.003
Carex leucochlora Bunge	Cyperaceae	●		●		M	R3	D4	t	0.761		0.568	
Causonis japonica (Thunb.) Raf.	Vitaceae	●		●		G	R2	D5	l		0.268	0.003	0.547
Cynodon dactylon (L.) Pers.	Poaceae	●		●		H	R4	D4	t	0.004			
Cyperus compressus L.	Cyperaceae	●	●			Th	R5	D4	t	0.222			0.156
Echinochloa crus-galli (L.) P.Beauv.	Poaceae	●	●			Th	R5	D4	t	1.635	0.005		
Eragrostis ferruginea (Thunb.) P.Beauv.	Poaceae	●		●		H	R3	D4	t	0.004	0.005	0.003	
Erigeron canadensis L.	Asteraceae		●			Th(w)	R5	D1	pr	0.013		0.168	0.006
Erigeron sumatrensis Retz.	Asteraceae		●			Th(w)	R5	D1	pr	0.013			0.003
Fraxinus griffithii C.B.Clarke	Oleaceae	●			●	N	R5	D2	e	0.004	0.005		0.009
Gamochaeta coarctata (Willd.) Kerguélen	Asteraceae			●		H	R5	D1	b	0.217		0.810	0.166
Gamochaeta pensylvanica (Willd.) Cabrera	Asteraceae		●			Th	R5	D1	b	0.004			
Ilex rotunda Thunb.	Aquifoliaceae	●			●	MM	R5	D2	e				0.003
Imperata cylindrica (L.) Raeusch.	Poaceae	●		●		G	R1	D1	e	0.004		1.210	0.159
Lactuca indica L.	Asteraceae	●	●			Th	R5	D1	pr	0.765		0.161	0.013

Table 2 Continued

Species	Family	Native	Herbaceous		Woody	Plant life types ‡				Street tree base types *			
			Ephemeral †	Perennials		Dormant	Underground organ	Seed dispersal	Growth	A (n=23)	B (n=18)	C (n=31)	D (n=32)
Lithocarpus edulis (Makino) Nakai	Fagaceae	●			●	MM	R5	D4	e	0.761	0.263		
Mallotus japonicus (L.f.) Müll.Arg.	Euphorbiaceae	●			●	MM	R5	D4	e	0.004	0.263		0.003
Melia azedarach L.	Meliaceae	●			●	MM	R5	D2	e				0.003
Miscanthus sinensis Andersson	Poaceae	●		●		H	R3	D1	t	0.004		0.003	2.188
Oenothera laciniata Hill	Onagraceae		●			Th(w)	R5	D4	ps	0.004			0.003
Phyllanthus lepidocarpus Siebold	Phyllanthaceae	●	●			Th	R5	D3	e	0.217	0.005		0.009
Plantago lanceolata L.	Plantaginaceae			●		H	R3	D2	r	0.004	0.006		
Portulaca oleracea L.	Portulacaceae	●	●			Th	R5	D4	b	0.009	0.921		0.163
Sagina japonica (Sw.) Ohwi	Caryophyllaceae	●	●			Th	R5	D4	b	0.004		0.010	
Setaria faberi R.A.W.Herrm.	Poaceae	●	●			Th	R5	D4	t	0.004	0.005		
Trifolium repens L.	Fabaceae			●		Ch	R4	D4	p	0.217		0.161	0.003
Zephyranthes candida (Lindl.) Herb.	Amaryllidaceae			●		G	R5	D5	r	0.004			0.003
Rosaceae sp.	Rosaceae	–	–	–	–	–	–	–	–	0.004	0.263		
Diversity indices（H'）										3.81	3.57	3.22	4.50

† Annuals, biennials and winter annuals, ‡ Plant life types were confirmed using the illustrated books by Numata, (1990) and Numata and Yoshizawa, (2002)

** Values are average cover by street tree type*

Table 3 Relationships estimated by the Bray-Curtis index for different street tree base types

	Type A	Type B	Type C
Type B	0.64	–	–
Type C	0.63	0.65	–
Type D	0.75	0.59	0.69

Notes: Calculated by average coverage of each species

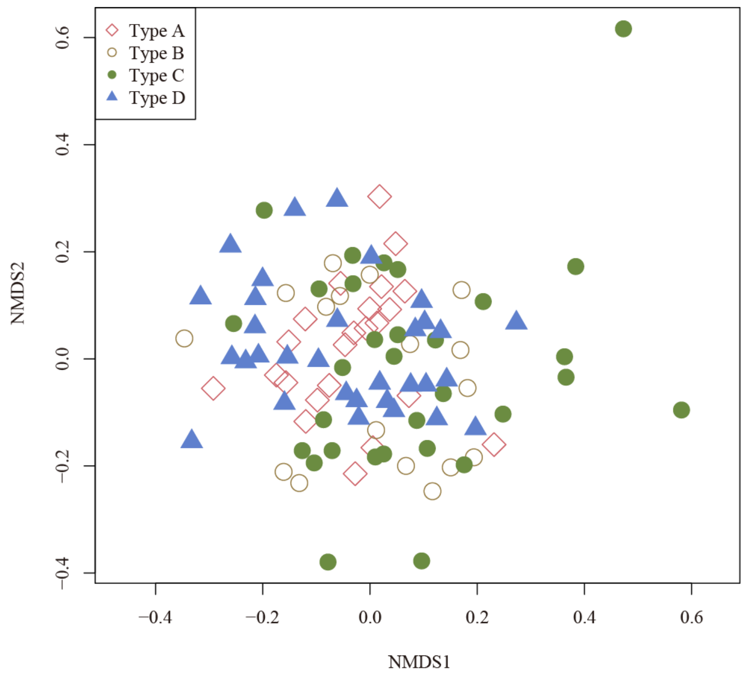

Fig. 2 Survey plot shown on the non-metric multidimensional scaling (nMDS)

Plant Characteristics

No woody species were identified exclusively in Type C, indicating a significant difference in the proportion of woody species among the street tree base types ($P < 0.01$) (Table 2 and Fig. 3). In contrast, the percentage of native species exceeded 50% for all street tree base types, and the proportion of native species did not vary between types ($P > 0.05$) (Table 2 and Fig 4). The percentage of dormant types was generally highest for Th (not overwinter), followed by H (dormant buds located just above the ground), a trend consistent across all types (Fig. 5). Similarly, R3 (rhizomes short and branched, forming the narrowest contacts) and R5 (those standing alone without underground or above-ground contacts) were prominent for the underground organ type, D1 (wind or water) and D4 (gravity) for the seed dispersal type, and e (erect with a distinct above-ground main axis), b (the lower part of the stem with many branches and an unclear main axis), and t (stems growing in clusters from a plant) for the growth type (Figs. 6, 7, and 8). There were no significant differences ($P > 0.05$) among the different modes of plant life types (dormant type, underground organ type, seed dispersal type, and growth type).

Buried Seeds

Plant germination was confirmed at 84 of the 86 (97.7%) sites where topsoil was collected. Of the seeds sampled, a total of 31 plant species in 14 families were identified (Table 4). Twelve of these species, including *Cardamine occulta* Hornem., *Cotula australis* (Sieber ex Spreng.) Hook.f., *Galium gracilens* (A.Gray) Makino., *Galium spurium* L. were not observed during the field survey.

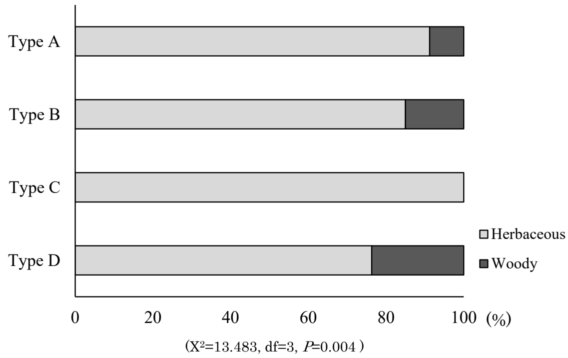

Fig. 3 Percentage of herbaceous and woody species by each street tree base type

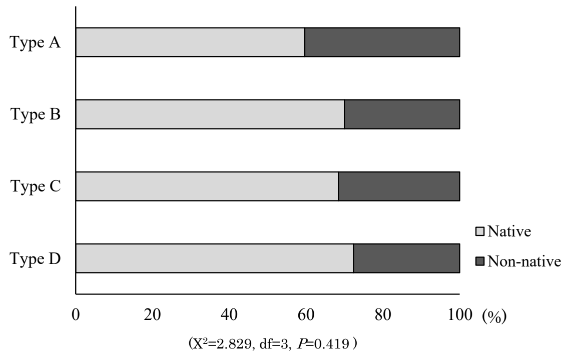

Fig. 4 Percentage of native species by each street tree base type

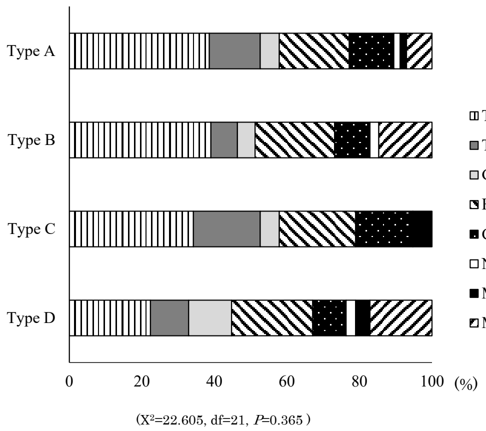

Fig. 5 Percentage of dormant type by each street tree base types

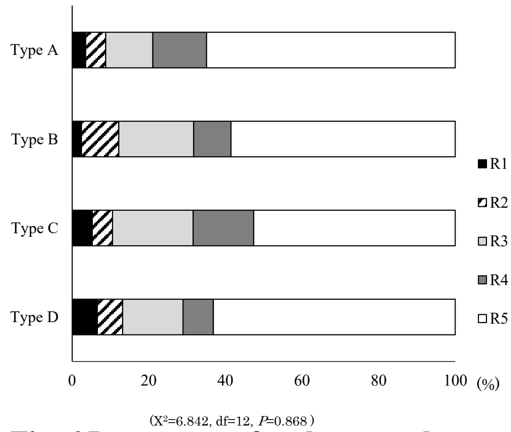

Fig. 6 Percentage of underground organ type by each street tree base type

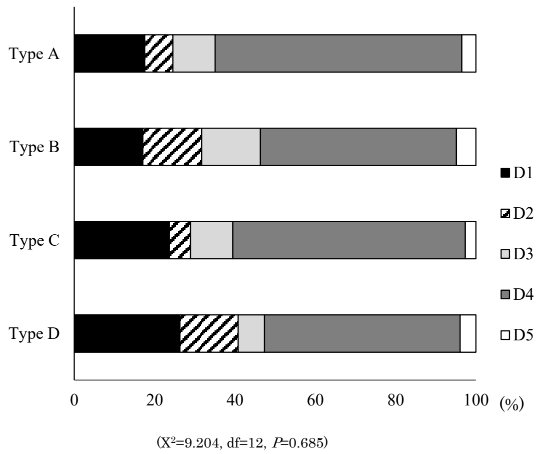

Fig. 7 Percentage of seed dispersal type by each street tree base type

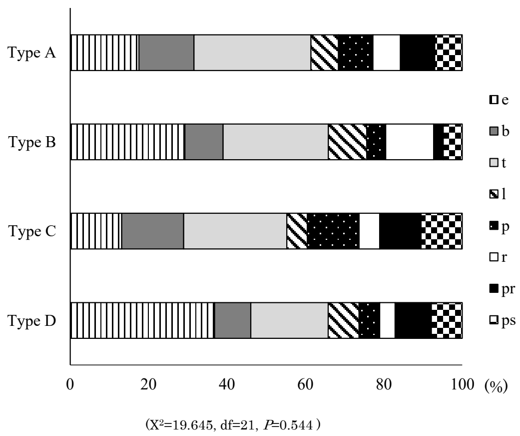

Fig. 8 Percentage of growth type by each street tree base type

DISCUSSION

A variety of street tree species planting were identified in this study (Table 1). In addition, plant communities consisting of herbaceous as well as woody species, most of which were native species, were observed at the street tree bases (Table 2). We consider that, in addition to the trees planted at the planting sites examined in this study, the street tree bases also contribute significantly to urban biodiversity. This is consistent with the findings of Hotta et al. (2015), Jian et al. (2021), Uchida et al. (2014), Furuno et al. (2014), Furuno et al. (2022), and Omar et al. (2018). On the other hand, like woodlands (Brown and Oosterhuist, 1981; Godefroid et al., 2006), grasslands (Kinugasa and Oda, 2014; Ghasempour et al., 2022), waterside (Alderton et al., 2017; Keddy and Reznicek, 1986), sand dunes (Fujiki et al., 2000), and road gaps (Sudo et al., 2009), this study also found well-developed seed banks in the soil at the street tree bases (Table 4). We believe that these street tree bases also function as seed banks in urban areas. Furthermore, since these seed banks contained the seeds of many species that were not identified in the field survey, we consider that street tree bases have the potential to further increase urban biodiversity.

Table 4 Plants confirmed to seeding-out test

Species †	Family	Species †	Family
Sagina japonica (Sw.) Ohwi	Caryophyllaceae	*Briza minor* L.	Poaceae
Acalypha australis L.	Euphorbiaceae	*Youngia japonica* (L.) DC.	Asteraceae
Stellaria neglecta Weihe *	Caryophyllaceae	*Cynodon dactylon* (L.) Pers.	Poaceae
Cardamine occulta Hornem. *	Brassicaceae	*Atocion armeria* (L.) Raf. *	Caryophyllaceae
Gamochaeta pensylvanica (Willd.) Cabrera	Asteraceae	*Trifolium repens* L.	Fabaceae
Eragrostis minor Host	Poaceae	*Veronica arvensis* L. *	Plantaginaceae
Cerastium glomeratum Thuill.	Caryophyllaceae	*Galium gracilens* (A.Gray) Makino *	Rubiaceae
Oxalis corniculata L.	Oxalidaceae	*Galium spurium* L. *	Rubiaceae
Lamium amplexicaule L. *	Labiatae	*Lygodium japonicum* (Thunb.) Sw.	Lygodiaceae
Cotula australis (Sieber ex Spreng.) Hook.f. *	Asteraceae	*Miscanthus sinensis* Anderss.	Poaceae
Oxalis dillenii Jacq.	Oxalidaceae	*Nephrolepis cordifolia* (L.) C.Presl *	Davalliaceae
Gamochaeta coarctata (Willd.) Kerguélen	Asteraceae	*Solanum nigrum* L.	Solanaceae
Erigeron sumatrensis Retz.	Asteraceae	*Thelypteris acuminata* (Houtt.) C.V.Morton *	Asplaniaceae
Capsella bursa-pastoris (L.) Medik.	Brassicaceae	*Trifolium dubium* Sibth. *	Fabaceae
Digitaria radicosa (J.Presl) Miq.	Poaceae	*Veronica peregrina* L. *	Plantaginaceae
Eragrostis ferruginea (Thunb.) P.Beauv.	Poaceae		

*Notes: n=86 (Confirmation of plant germination: n=84), † Ferns were included, * Unconfirmed in the field survey*

On the other hand, there are various street tree base types: some have garden beds at their bases, and some have their bases covered by man-made structures such as iron grating, at the base (Fig. 1). In this study, we surveyed street tree bases in similar environments and found no differences in the proportions of native species and life types in the plant communities identified in the street tree bases of each type (Table 2 and Figs. 4, 5, 6, 7 and 8). However, each type of plant community consisted of species, many of which were not found in the other types, and thus formed a plant community that differed from the others (Tables 2 and 3, Figs. 2 and 3). In other words, we consider that the maintenance of various street tree base types can further enhance urban biodiversity.

In Type D, the trees are trimmed to form a hedge, which means that plants that invade and colonize this type are less likely to be weeded out. Further, compared to Type A, the beds of Type B are maintained, which implies that there is more soil disturbance due to weeding and digging of the soil to plant flowers. In Type A, nothing is maintained at the street tree bases, but in Type C, the street tree bases are covered with artificial structures such as iron grating, which is thought to suppress the growth of invading and colonizing plants. In other words, the environment of the street tree bases differs greatly depending on the street tree base types, and this is considered to be a factor in the establishment of diverse plant communities.

On the other hand, 17 species, such as *Acalypha australis* L., *Artemisia indica* Willd., *Cyperus amuricus* Maxim., *Digitaria ciliaris* (Retz.) Koeler. are found in all street tree base types, (Table 2), and thus are representative of the street tree bases in Fukuoka city.

CONCLUSION

This study highlights three key findings. First, both planted street trees and their bases play a significant role in enhancing urban biodiversity. Second, street tree bases function as seed banks within urban areas and have the potential to further boost urban biodiversity. Third, the management of street tree bases differs significantly among various base types, and these differences can lead to environmental changes that may influence the establishment of diverse plant communities.

In rapidly urbanizing areas where space for new habitats or green spaces is limited, street trees which require far less land than traditional green spaces may emerge as a promising solution for enhancing urban biodiversity. This study underscores the importance of incorporating a variety of street tree base types in urban planning to maximize their potential benefits on biodiversity. Finally, while this survey did not pinpoint the definitive characteristics of plant species that invade and colonize different street tree base types, future research will focus on characterizing these plant communities. This will help in designing street tree planting strategies that further support urban biodiversity.

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Research article

Recycling of Nitrogen and Phosphorus from Urban Wastewater Using Calcium-Silicate-Hydrate: A Case Study in Cambodia

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Abstract The main goal of this research study was to evaluate the calcium-silicate-hydrate (CSH) synthesized from calcium hydroxide ($Ca(OH)_2$) and rice husk charcoal and to determine if the CSH is economically and environmentally friendly and can be used as a promising strategy for nitrogen and phosphorus recovery. The CSH material was prepared by combining $Ca(OH)_2$ and rice husk charcoal in a 1:4 ratio and mixing the sample with 75% deionized water. Following mixing, a vibrator was used for 1 minute for case 1, 2minute for case 2 and 3minute for case 3. The CSH was then put into molds which were maintained at room temperature for 3 weeks before starting the experiments. The adsorption experiment considers parameters such as pH, EC, Ca, K, NH_4^+, and PO_4^{3-} in 2 weeks. The 1st and 2nd elusion experiments were carried out on used CSH to test the dissolution rate of NH_4^+ and PO_4^{3-}. To confirm the used CSH effectiveness as a fertilizer, a plant growth experiment was also carried out to measure the growth rate of spinach and the improvement of soil fertility. The results of the adsorption experiment indicated that CSH can effectively remove nutrients from wastewater, achieving removal rates of 97% for NH_4^+ and 98% for PO_4^{3-}. The adsorption capacity of CSH is 0.065 mg-NH_4^+/g-CSH and 0.11 mg-PO_4^{3-}/ g-CSH. Additionally, the used CSH can release 3-5 mg/kg for NH_4^+ and 6.6-7.7 mg/kg of PO_4^{3-} in the elusion experiments. Moreover, the plant growth experiment also indicates that the soil fertility increased 3 times with the 5% addition of used CSH treatment, compared to the control treatment. These results suggest that CSH, made from $Ca(OH)_2$ and rice husk charcoal, could serve as a cost-effective solution to wastewater treatment and production of fertilizer for agricultural production.

Keywords CSH, dissolution fertilizer, Phosphate, Ammonium, plant growth

INTRODUCTION

Cambodian urbanization has led to environmental problems, especially water pollution. Water degradation has been reported near the discharge point of the Phnom Penh city into the Mekong River (Chea et al., 2016**.** Research has been done to assess the water quality in Cheung Ek Lake which found excess nutrient content (Samuel et al., 2019). As recently as ten years ago, this lake was known for its natural wastewater treatment capacity to remove the nutrients from the lake's water, including a 22% and 67% reduction for total nitrogen (TN) and total phosphorus (TP), respectively (Visoth et al., 2010), Most natural lakes typically possess the capability for self-purification; however, this process requires time, with nitrification typically requiring 2-6 weeks. However, as Cheung EK lake's area decreases by half (Kawamura et al., 2015; Ro et al., 2020), the hydraulic retention time in the lake also diminishes, resulting in a reduction or loss of the lake's wastewater treatment capacity. Hence, there is a necessity to find additional new methods to improve the water quality. Low-cost and high-performance materials or techniques that could synergistically remove pollutants in a simple manner are highly desired.

Manmade wastewater treatment methods are summarized into 5 main categories: adsorption, membrane, chemical, electric, and photocatalytic. (Qasem et al., 2021). Given that Cambodia is a developing country, the adsorption method was adopted in this study because of its cost-effectiveness and being environmentally friendly. The adsorption-based method has been widely studied and its benefits and costs discussed (Vievard et al., 2023; Araujo et al., 2018) but only calcium silicate hydrate (CSH) can remove the pollution from water and be used as fertilizer (Lee et al., 2018). Although previous studies evaluated the use of CSH for pollutant removal and as a fertilizer, the initial material and process of manufacturing CSH were different from one to another, leading to differences in capacity and effectiveness. Therefore, this paper will highlight the CSH production method that is applicable to Cambodia.

This research endeavors to identify the simplest, and most suitable method to produce CSH, such as with a material like rice husk and calcium hydroxide. Rice husk is the principal agricultural waste product generated during rice processing and it is known for its effectiveness in the removal of pollution in water (Okoro et al., 2022). In Cambodia, the Food and Agriculture Organization (FAO) reported in 2022 that the country produces approximately 11.6 million tons of rice annually, generating 2.3 million tons of rice husk each year (FAO, 2023). Simultaneously, calcium is readily accessible in Cambodia due to calcium mining, rendering calcium hydroxide affordable for farmers at a price of USD 300 per ton. This new use of rice husks will directly contribute to decreasing agricultural waste and allowing farmers to produce their own fertilizer for application to their farmland soil.

OBJECTIVE

The objectives of this research study were to propose a new method for simplifying the synthesis of CSH, assessing its performance, and determining if it should be presented as an economically and environmentally friendly strategy for wastewater treatment.

METHODOLOGY

Preparation for CSH

CSH material was synthesized from $Ca(OH)_2$ and rice husk charcoal (RHC). This experiment utilized commercially available products with a purity of ≥ 99%. First RHC was crushed to powder form, then mixed with $Ca(OH)_2$. The resultant mixture of CSH was the mass-based ratio of $Ca(OH)_2$:1 and RHC:4 and 75% deionized water was added for the hydration reaction. After mixing, it was processed with a concrete vibrator for 1 minute for case 1, 2 minutes for case 2 and 3 minutes for case 3 (Fig. 1). Scanning electron microscope (SEM) images of the CSH are shown in Fig. 2, revealing an agglomeration of crystalline particles with rough surfaces. Pores become smaller with an increase in the vibration time from 1 to 3 minutes.

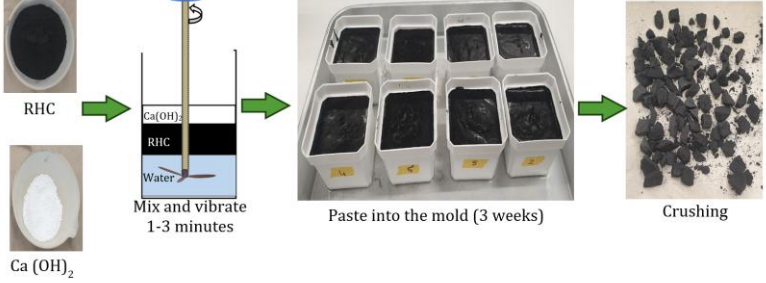

Fig. 1 Process of preparation of CSH

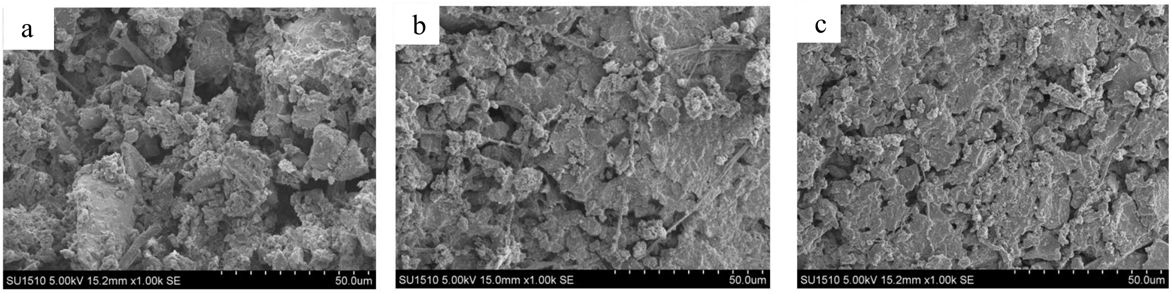

Fig. 2 SEM images of the CSH sample
(a) 1 minute (b) 2 minutes and (c) 3 minutes of vibration 1,000x magnification

Preparation for Adsorption Experiment

A total of nine samples were used in the examination in the adsorption experiment, with three samples from each of Case 1, Case 2 and Case 3. The 4 g of CSH materials (1 minute, 2 minute, and 3 minutes vibration) were immersed in 40 ml of deionized water (maintained at 21ºC) for 3 hours to test for the dissolution components from CSH shown in Table 1. Upon immersing the CSH in deionized water, a consistent increase in pH levels from 7 to 12 was observed across all cases in 3 hours. When water is added to cement, the calcium silicate phases, primarily tricalcium silicate (C3S) and dicalcium silicate (C2S) begin to dissolve, releasing calcium ions and silicate ions into the solution (Blanc et al., 2010). This dissolution explains the high concentration of calcium ions released into the water, resulting in elevated pH levels. This explains the high concentration of calcium ions released into water and leads to high pH as well. The low concentration of silicate ions observed could be because, upon release during hydration, the silicate ions reacted immediately and were swiftly incorporated into the forming C-S-H structure.

Table 1 Dissolution components from produced CSH

Case	pH	EC (mS/m)	Ca (mg/L)	K (mg/L)	Si (mg/L)
Case 1	12.03	121.7	300	3	5.8
Case 2	12.09	79	270	1	6.9
Case 3	12.28	103	390	2	3.4

After the dissolution test, the CSH was air-dried for 1 week to eliminate the access water and then soaked again in 20 mL of wastewater for 14 days to test nutrient removal capacity. The initial condition of wastewater is indicated in Table 2.

Table 2 Initial condition of wastewater

Solution	pH	EC (mS/m)	Ca (mg/L)	K (mg/L)	NH_4^+ (mg/L)	PO_4^{3-} (mg/L)
Wastewater	6.60	55.0.5	31.5	160	13.4	23.4

Evaluation of Ammonium and Phosphate Recovery Performance

The amount of adsorbed ammonium and phosphate at time t (Q_t: $mgNH_4^+/g$) and (Q_t: $mgPO_4^{3-}/g$) was calculated as the difference between concentrations in solution initially (C_i: mgL^{-1}) and at time t (C_t: mgL^{-1}) using the following Eqs. (1)

$$Q_t = (C_i - C_t)\ V / W \qquad (1)$$

Where V is the volume of solution L and W is the dry mass of adsorbents (g). The nutrient removal rate (RE) was calculated using Eq. (2).

$$\%\ RE = [(C_i - C_e)/Ci] \times 100 \qquad (2)$$

Preparation for an Elusion Experiment

The elusion experiment was conducted to assess the potential of used (nutrient-adsorbed) CSH as fertilizer. The used CSH that was obtained from the adsorption experiment was air dried for 1 week and placed in the deionized water for 24 hours to measure the release of the NH_4^+, and PO_4^{3-}. Using the same process utilized for the first elusion test, the 2nd elusion test was conducted the second time release of the NH_4^+, and PO_4^{3-} from the used CSH material.

Preparation of Plant Growth Experiment

Pot experiments are controlled studies used to investigate plant growth and soil processes, complementing field measurements (Kawaletz et al., 2014). In this study the pots experiment was conducted in the summer of 2022 in the land and water use engineering laboratory of Tokyo University of Agriculture at the temperature 20^0c-25^0c with 2 treatments: control treatment (without CSH) and CSH treatment (5% of used CSH).

To enhance germination, spinach seeds underwent pretreatment by soaking in warm water at 55-60 ℃ for 15 minutes (Yuan et al., 2022). After pretreatment, the seeds were directly planted in pots, with each pot containing six seeds. Two weeks after planting, water was evenly irrigated at a rate of 20 mL every three days. Artificial light was consistently supplied 24 hours a day throughout the entire duration of the plant growth experiment. The height of the spinach was observed and measured in three-day intervals from the one week until one month old. After one month, the spinach was harvested and measured for plant weight, leaf area and stem height. The plant growth was measured using Image J.

RESULTS AND DISCUSSION

Ammonium and Phosphate Removal by of CSH

Figure 3 illustrates the average results of 1 to 3-minute vibration for CSH. On Day 1, the removal rate for NH_4^+ was 27%, gradually increased to 97% by Day 7 and remained stable until the end of the experiment (Day 14). Similarly, for PO_4^{3-}, the removal rate starts at 45% on day 1, gradually increased to 98% on Day 7, and was stable until Day 14. The phosphate and ammonium adsorption capacity of CSH was 0.11 PO_4^{3-}-mg/g-CSH, and 0.065 NH_4^+-mg/g-CSH. However, the capacity observed in this experiment should not be taken as the definitive maximum capacity of the CSH. Additional experiments are necessary to ascertain its upper capacity limits, as the current findings are based on a single experimental result. The adsorption of NH_4^+ and PO_4^{3-} was lower than that of activated carbon (29 mg-N/g, 14.1 mg-P/g) and bio-adsorbent (45 mg-N/g, 12 mg-P/g) (Vassileva et al., 2009; Wang et al., 2012; Yadav et al., 2015; Kizito et al., 2015).

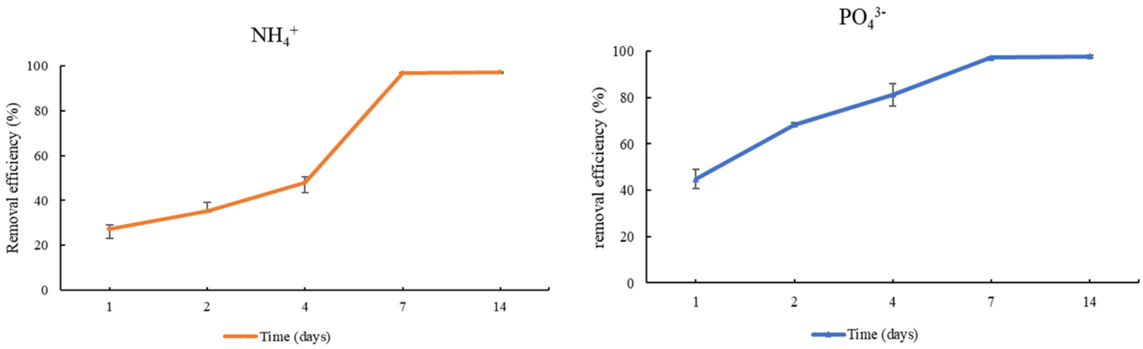

Fig. 3 Average removal efficiency of ammonium and phosphate with CSH

The variation in absorbent rates can be primarily attributed to the physical properties of CSH, characterized by its macroporous structure, in contrast to activated carbon and biochar, which exhibit a micro-mesoporous type configuration. From SEM image in Fig. 2 confirmed that CSH derived from rice husk charcoal and calcium dioxide had macropores with an average of 50-100 µm and high porosity, which led to a lower specific surface area. The micro-mesoporous type possesses a larger specific surface area, enabling it to effectively absorb ions to a greater extent compared to structures with larger pores. Furthermore, according to Kizito et al. (2015), the optimal pH range for adsorption is 4-8. In this experiment, the CSH was eluted at a high pH (11-12) in the solution during the adsorption process, which affected its removal capacity.

Release of Ammonium and Phosphate from Used CSH

This CSH exhibits a unique characteristic in its ability to elute back nutrients without additional activators, a feature that is not present in other absorbent materials.

The elution test was carried out to assess the amount of ammonium and phosphate that could be released from used CSH in deionized water without any additional pre-treatment, such as pH adjustment. In Figure 4 (a) and (b), CSH exhibited the release of ammonium ranging from 3-5 mg-NH_4^+/kg-CSH and 6.6-7.7 mg-PO_4^{3-}/kg-CSH during 3 hours of elution. The reduction of phosphorus concentration at 24 hours (Fig. 4b) due to the presence of Ca^{2+} ion in the solution, which led to the formation of calcium phosphate ($Ca_3(PO_4)_2$). Under neutral or alkaline conditions, direct precipitation $Ca_3(PO_4)_2$ and $Ca_5(PO_4)_3OH$ are readily achieved most likely follow as Eqs.

$$5Ca^{2+} + 3HPO_4^{2-} + 4OH^- = Ca_5(PO_4)_3OH + 3H_2O \quad (3)$$

$$3Ca^{2+} + 2HPO_4^{2-} + 2OH^- = Ca_3(PO_4)_2OH + 2H_2O \quad (4)$$

Where increases in OH^- allow the chemical precipitations to occur more readily, resulting in higher removals. However, a large excess of OH^- would appear to impair $Ca_5(PO_4)_3OH$ precipitation allowing a dissolution back into solution with increased reaction times (Kim et al., 2020). The results of the second elution test demonstrate a sustained release of ammonium and phosphate into the deionized water over a period of 3 hours, followed by a subsequent decrease within 24 hours.

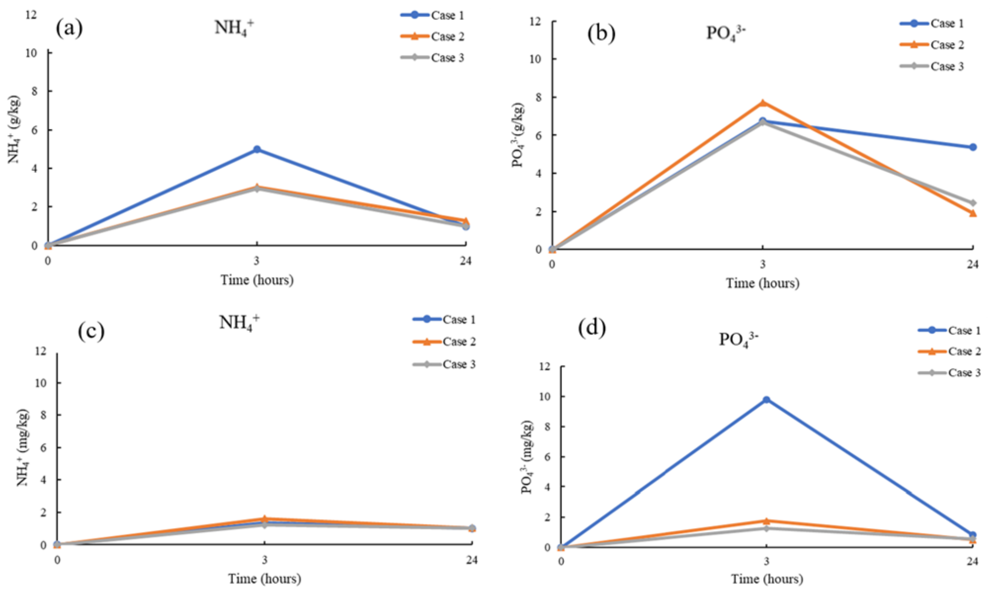

Fig. 4 Release of NH_4^+ and PO_4^{3-} from used CSH
First elution test (a), (b) and Second elusion (c), (d)

This pattern aligns with the observations from the first elution test. Nevertheless, in the second elution test, Case 1 exhibited the highest rate compared to the other cases, suggesting that CSH with 1 minute of vibration is optimal for release capacity, likely attributed to its high porosity. In contrast to commercial chemical fertilizers, this CSH exhibits a gradual release of nutrients, making it highly suitable for application in farmland soil as a fertilizer.

Plant growth Changes with Adding used CSH

Figure 5 illustrates the comparison between the control and CSH treatment in terms of spinach plant growth. The results indicate a significant impact of the CSH treatment on height, root development, leaf length, and leaf width. Similarly, in Table 3, the soil fertility with a 5% addition of used CSH shows a threefold increase in nitrogen (N), phosphorus (P), and potassium (K) compared to the control. The findings from these results suggest that used CSH can serve as a viable alternative fertilizer to chemical fertilizers in agricultural production.

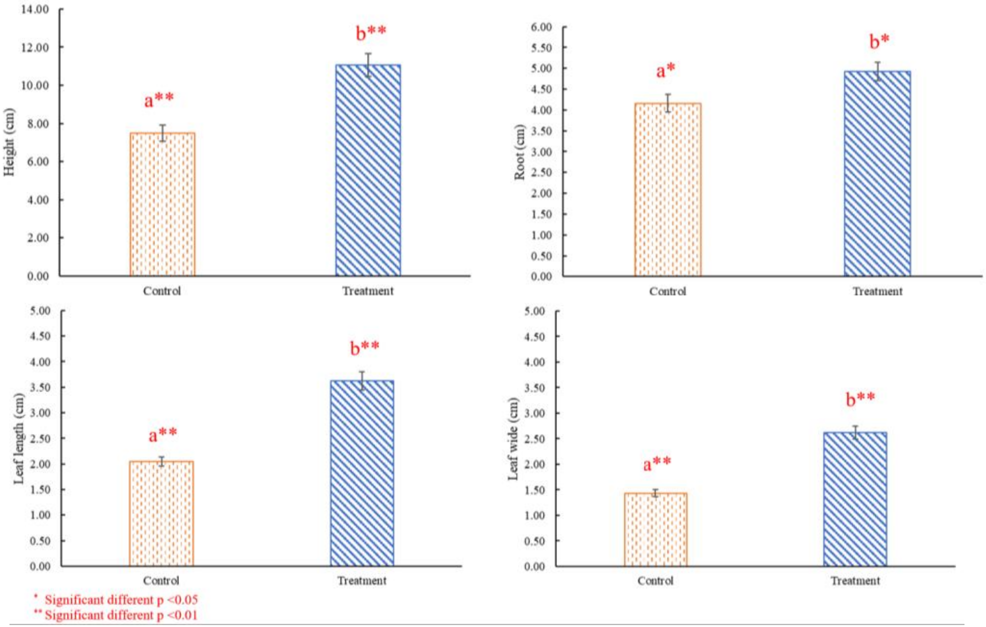

Fig. 5 Effect of used CSH on spinach plant growth

Table 3 Effect of CSH on soil fertility

Treatment	pH	EC (µS/cm)	N (mg/kg)	P (mg/kg)	K (mg/kg)
Control	5.58	120.88	9.33	13.17	26.83
CSH treatment	7.78	411.17	29.00	40.33	81.50

CONCLUSION

This study aimed to deal with the development of CSH and evaluate its capacity for nutrient removal from wastewater and its ability to be used as fertilizer. The findings demonstrated that CSH synthesized from calcium hydroxide ($Ca(OH)_2$) and rice husk charcoal can efficiently absorb 98% of PO_4^{3-} and 97% of NH_4^+.The adsorption quality was 0.11 mg-PO_4^{3-} /g-CSH and 0.065 mg-NH_4^+ /g-CSH. In the 1st elution experiments, the used CSH can release 3.23 mg/kg for NH_4^+ and 7.05 mg/kg for PO_4^{3-}. NH_4^+ and PO_4^{3-} were also observed to continue to be released in the second experiment. The outcomes of the spinach plant growth experiment, where used CSH was applied as a treatment, demonstrated enhanced growth rate of the height, root, leaf length and leaf width, accompanied by a threefold improvement in soil fertility (N, P and K). The distinctive feature of this CSH lies in its requirement for only two components, namely calcium hydroxide ($Ca(OH)_2$) and rice husk charcoal. The manufacturing process is straightforward, devoid of the need for any additional treatment or activator, making it easily adaptable for farmers. In conclusion, it can be inferred that CSH is effective in the removal of nutrients, particularly NH_4^+ and PO_4^{3-}. Additionally, according to the results of this study, CSH has the potential to be a viable substitute for commercial chemical fertilizers in agricultural production. However, additional economic analysis research needs to be conducted to verify the potential and assess the real market value of the CSH.

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Research article

Assessment of Soil Quality in Paddy Fields at Dakawa Irrigation Scheme, Morogoro, Tanzania

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Abstract Soil quality, a measure of a soil's capacity to function, can be assessed using indicators based on physical, chemical, and biological properties. A soil quality assessment for soils used for rice production was conducted at the Dakawa Irrigation Scheme, located in Mvomero District, Morogoro, Tanzania. Eight disturbed soil samples, together with twenty-four undisturbed core soil samples, were obtained from two pitches (blocks 18 and 23) for laboratory analysis. The soil texture was identified as sandy clay loam for both pitches, and the pH levels in all layers of all pitches were rated as medium (5.7-7.0) to very high (7.0-8.6). The levels of organic carbon (OC) and organic matter (OM) were found to be very low, especially in the first layer for pitch one, where the average OM was 1.49% and OC was 0.83% and pitch two demonstrated OM of 1.34% and the OC was 1.08%. Average bulk density for all pitches was very high which cause soil compaction, all layers in each pitch has B.D> 2g/cm^3, for the case of permeability was very low ranges from 1.922 x 10^{-5} to 3.712 x 10^{-7} cm/s for pitch one and 1.2436 x 10^{-5} to1.89 x 10^{-7} cm/s. The cation capacity exchange (CEC) and exchangeable bases were rated as low to medium in all blocks. According to soil taxonomy and the world reference base for soil resources, the soil at the Dakawa Irrigation Scheme is classified as Vertic Calciusteps, fluvisols and Haplic Vertic combisols, respectively. It is recommended to increase the organic matter in the soil by applying organic matter. Additionally, the use of rice husk as a soil amendment should also be taken into consideration to control permeability and compaction.

Keywords soil quality, assessment, soil properties, paddy fields, Tanzania

INTRODUCTION

Rice is among the most important crops in the world, serving as a staple food to more than half of the world's population (Gnanamanickam et al., 2009). In Tanzania, rice is one of the most widely grown crops, and it is the second most important crop (Kolleh et al., 2017). Rice is both a cash and a food crop for the majority of people, and it is estimated that 60 percent of the population consumes rice each day (Achandi and Mujawamariya, 2016). The production of rice in Tanzania is an average of 1.8 tons/hectare (t/ha) (Mosha et al., 2022). The demand for this crop is growing rapidly daily as a food source in several countries of the world, following wheat (Gale et al., 2015). It was reported that there is a projected increase in rice demand from 680 million tons in 2015 to 771 million tons in 2030 (Bruinsma, 2017)

According to data from the Ministry of Agriculture (2022), the irrigation area in the country is 727,000 ha out of 29.4 million ha suitable for irrigation. Soil properties have also been reported as a contributing factor to rice growth. Usually, nutrient content and availability in soils determine the chemical and physical properties of that soil. Soils with high OM content are known to hold more nutrients necessary for paddy growth (Isdory et al., 2021). As soil OM content increases from 0.5

to 3.0%, the available water-holding capacity in the soil also increases. Therefore, low OM or losses of OM in the soils can significantly reduce paddy rice yields. Tanzania, like other developing countries in sub-Saharan Africa, is struggling to improve its rice yields. For instance, in the present study area, rice yields have ranged from 0.4 to 3.8 t/ha (average 1.87 t/ha). These yields were low compared to those in countries such as Egypt and the USA, where the average rice yields are close to 10 t/ha (Aagaard et al., 2019). Smallholder paddy rice growers in the present study sites have been complaining about uneven and low production, leading to low family income. Therefore, this study aimed to assess the impacts of soil quality on paddy rice productivity at the Dakawa Irrigation Scheme in Morogoro, Tanzania. The major factors contributing to the low yield include low soil fertility due to excessive nutrient mining coupled with low use of fertilizers, monocropping, poor agronomic practices, use of unimproved seeds, and poor access to output markets (Ngailo et al., 2016).

OBJECTIVE

The objective of the research is to assess the quality of soil at the Dakawa Irrigation Scheme in Morogoro, Tanzania.

METHODOLOGY

Description of the Study Area

The research was conducted at the Dakawa Irrigation Scheme in Mvomero District, Morogoro, Tanzania. The scheme has an area of 2000 ha and lies at Latitude 6°24'S and Longitude 37°33'E with a mean altitude of 361m a.m.s.l. It is located 45 km from Morogoro town, 7 km northeast of Wami-Dakawa village, and northwest of Wami River on an extensive flat plain. The Dakawa Irrigation Scheme has 29 Blocks (each block has 20 plots of 4.86 ha each).

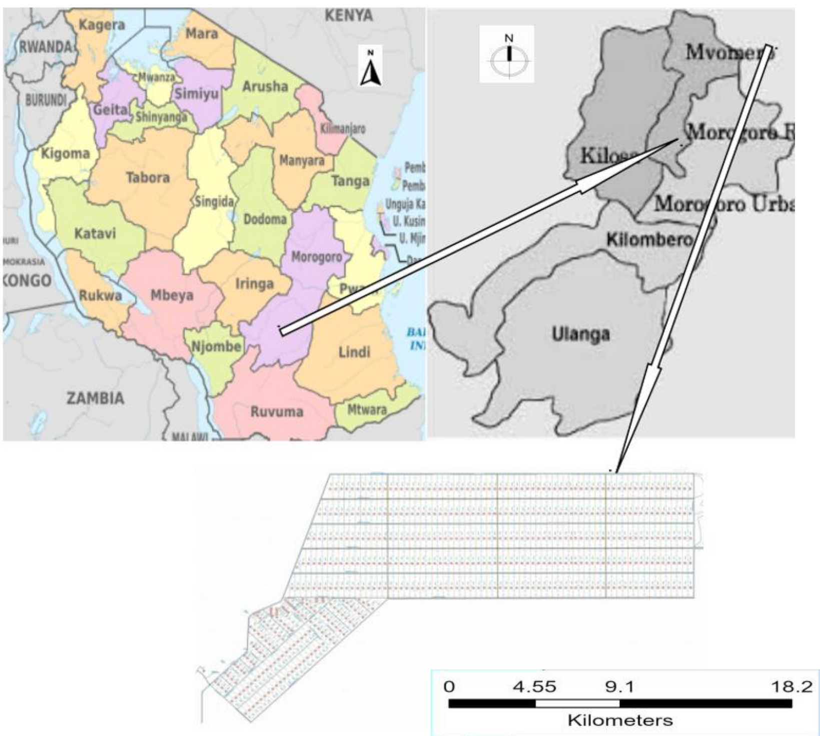


Fig. 1 Study area location

Soil Sampling

Soil samples were collected across the two blocks, block 18 (Pitch 1) and block 23 (Pitch 2) as shown in Fig. 3. In these blocks, farmers use a lot of fertilizer, and the soil appears to be compacted and the yield in this specific block is very low (0.5 ton/ha). Proper sampling equipment (soil auger and other related devices), representative sampling, timing of sample collection, multiple samples for variability, proper handling and transport, quality control in the laboratory analysis and data interpretation were the methods used to ensure the accuracy of soil sample collection and analysis. Both disturbed and undisturbed soil samples were collected, and the soil pitch where the soil samples were collected were excavated to 2 m deep with a surface area of 1 m x 1 m each pitch. At each pitch, four depths of 0.5 m were established, and at every depth 2 samples of undisturbed soil were taken, and one sample of disturbed soil was taken at each depth as well. After the sample, the soil was taken to the laboratory for the experiments and analysis for assessing soil quality.

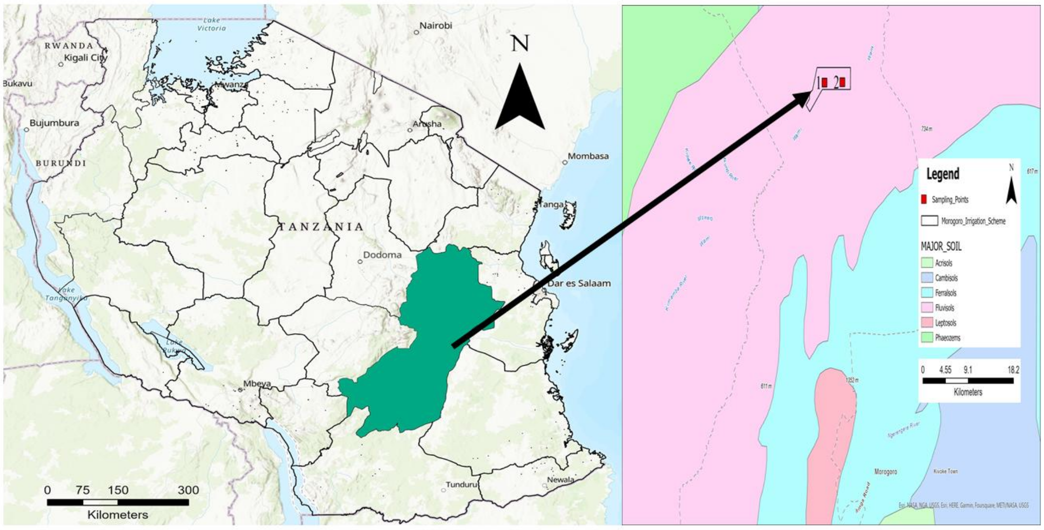


Fig. 2 Soil map with sampling points both having fluvisols soil

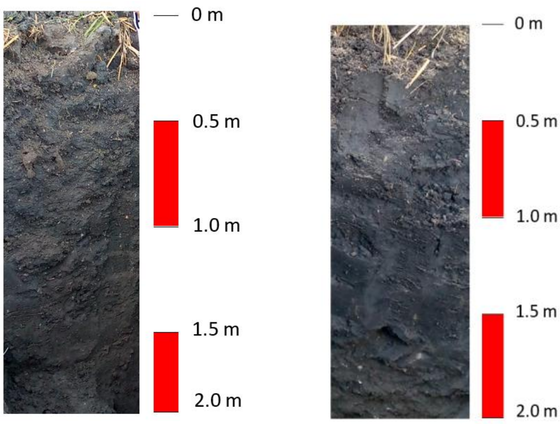


Fig. 3 Soil profile for pitches 1 and 2 at Dakawa Irrigation Scheme

Laboratory Experiments of Soil Quality

Both physical and chemical soil quality from Pitch one and Pitch two were measured and analyzed in the laboratory, For the case of permeability (k) was measured by using the falling head method and computed by using the following formula (1).

$k = 2.3al / (At) \{log_{10} (h_1/h_2)\}$ (1)

Bulk density (BD) was measured by using the oven method and then computed by using the following formula (2).

BD = mass of oven dry soil / volume of soil (2)

Also, organic matter (OM) and organic carbon (OC) contents were measured in the laboratory by using the ignition loss method at temperature 800°C and then following formula (3) was used to compute the variables.

OM = (M1-M2) / M2 x 100% and *O.M = OC (%) x 1.72* (3)

For chemical properties assessments in the laboratory, at first the soil was treated with an excess of 1M neutral ammonium acetate to saturate the colloidal complex with ammonium, and the excess ammonium ions are removed by washing with alcohol. The ammonium in the soil is then determined by distillation in an alkaline medium, absorbed in boric acid, and titrated with sulfuric acid. Then, after filter paper, filtering funnel, filtration pump, weighing balance, flame photometer, atomic absorption spectrometer, volumetric flask, pH meter, and EC meter were all used to determine the chemical properties of soil in the laboratory.

RESULTS AND DISCUSSION

After laboratory experiments for both pitches, the results came as following tables below.

Table 1 Physical property assessed for Pitch 1

Layer	Depth (m)	Organic matter (%)	Orrganic carbon (%)	Moisture content (%)	Bulk density (g/cm^3)	Permeability (cm s^{-1})
1	0.0-0.5	1.49	0.83	1.51	1.5	1.922 x 10^{-5}
2	0.5-1.0	3.41	1.99	2.78	1.45	2.050 x 10^{-7}
3	1.0-1.5	3.84	2.23	3.58	1.49	3.71 x 10^{-7}
4	1.5-2.0	3.74	2.17	2.42	1.53	2.23 x 10^{-6}

Table 2 Physical properties assessed for Pitch 2

Layer	Depth (m)	Organic matter (%)	Orrganic carbon (%)	Moisture content (%)	Bulk density (g/cm^3)	Permeability (cm s^{-1})
1	0.0-0.5	1.34	1.08	1.8	1.63	1.24 x 10^{-5}
2	0.5-1.0	2.64	1.50	2.37	1.67	1.98 x 10^{-7}
3	1.0-1.5	3.31	1.92	2.79	1.52	1.89 x 10^{-7}
4	1.5-2.0	4.11	2.39	3.39	1.47	2.13 x 10^{-6}

Based on the physical soil assessments shown in Tables 1 and 2, the results of permeability for both pitches had low permeability less than 10^{-5} cm s^{-1}, which may cause the difficulty in nutrient from applied fertilizer, poor growth of plants, poor internal soil drainage and roots restriction which leads to poor productivity (Esringü et al., 2017).

Although the range of bulk density (BD) for paddy fields should range between range between 1.2 and 1.3 g/cm^3 (Liu et al., 2021), observed soil bulk density of the samples from both pitches was more than 1.4 g/cm^3, then the soil seems to have high compaction which may impose many stresses such as mechanical resistance, poor aeration and changes in hydrological system in soil, such as poor infiltration of water. According to the results, the bulk density obtained was higher at 0.15 to 0.47 g/cm^3 for both pitches than the recommended range of bulk density for paddy fields.

Organic matter (OM) contents ranged from 1.49 to 3.84% for Pitch 1, and 1.34 to 4.11% for Pitch 2. Although organic matter (OM) contents in paddy field are requested to be higher than 2%, OM in the first layer (topsoil) till 0.5 m were low as shown in Tables 1 and 2. Also, the lowest organic carbon (OC) contents were observed on the topsoil, as 0.8% for Pitch 1 and 1.08% for

Pitch 2 as shown in Tables 1 and 2. According to Landon (1991) and Bandyopadhyay et al. (2010), these values are rated as very low since they are < 2 %. Also, there was tendency that organic carbon (OC) contents increased with depth. The trend of OC being lower in the topsoil than other layers, it may be caused during the levelling process with the removal of topsoil which has higher organic carbon (OC) contents. For rehabilitating topsoil, some measures should be done for improving organic matter (OM) and organic carbon (OC) contents for higher rice productivity.

Table 3 Chemical properties assessed for Pitch 1

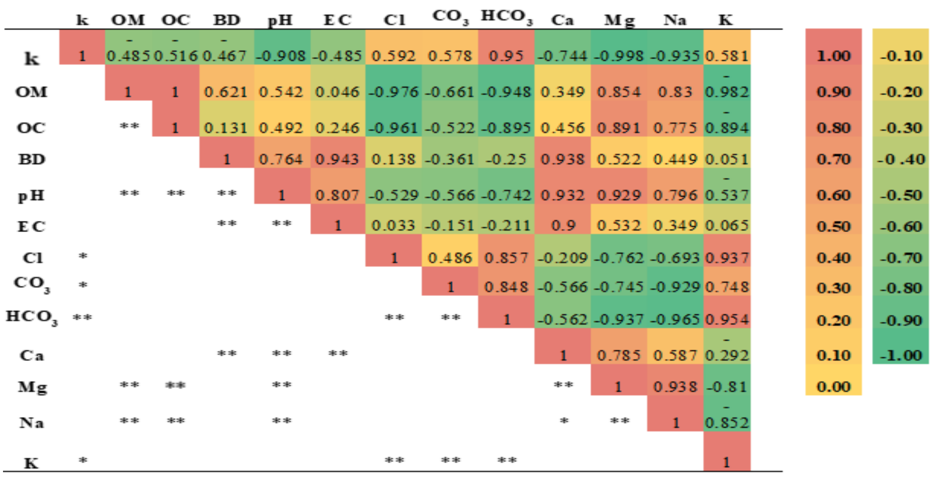
Layer	Depth (m)	pH in H_2O	EC (mS/cm)	Cl (mg/kg)	CO_3 (mg/kg)	HCO_3 (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)
1	0.0-0.5	7.54	266	77.97	335	976	110	1711.2	29.9	478
2	0.5-1.0	8.00	278	63.79	330	795	116	1905.6	271.4	429
3	1.0-1.5	8.56	446	99.23	210	976	120	1813.2	460.0	468
4	1.5-2.0	8.48	576	120.5	210	793	136	1918.8	558.9	468

Table 4 Chemical properties assessed for Pitch 2

Layer	Depth (m)	pH in H_2O	EC (mS/cm)	Cl (mg/kg)	CO_3 (mg/kg)	HCO_3 (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	K (mg/kg)
1	0.0-0.5	7.92	291	78.77	340	998	118	1790.4	110.4	472
2	0.5-1.0	8.10	288	72.54	320	893	122	2078.7	347.3	586
3	1.0-1.5	8.60	489	100.00	230	992	130	1921.2	457.7	507
4	1.5-2.0	8.51	591	128.12	225	801	140	1920.0	577.3	585

Chemical Properties

Some chemical properties of both of soil profile are summarized in Tables 3 and 4. The highest soil pH in Pitch 1 was 8.56, and 8.51 in Pitch 2. These highest pH values were observed at the depths from 1.0 to 1.5 m. For both pitches, there was a tendency for soil pH to increase with depth from the topsoil. Landon (1991) rated these pH values as very high (7.0-8.5). High soil pH of this soil could be attributed to relatively high concentrations of Na, Ca, and Mg, which were also increasing with soil depth. The Na might be originating from surface evaporation of water in the Wami River, containing a substantial amount of Na due to alluvial deposition (Kisetu et al., 2013). Some measures should be taken to reduce soil pH, as those ranges indicate the soils are alkalinity (Tokpah et al., 2017).



*Notes: **k**: Permeability; **OM**: Organic matter; **OC**: Organic carbon; **BD**: Bulk density; **pH**: Soil pH; **EC**: Electric conductivity; **Cl**: Chloride; **CO3**: Carbonate; **HCO3**: Hydro carbonate; **Ca**: Calcium, **Mg**: Magnesium; **Na**: Sodium; **K**: Potassium, **p < 0.01, * p <0.05*

Fig. 4 Correlation matrix among soil properties analyzed at Dakawa Irrigation Scheme

Electrical Conductivity (EC) values ranged between 266 and 576 mS/cm at Pitch 1, and the average EC value was 391.5 mS/cm. Also, EC values ranged between 291 and 591 mS/cm at Pitch 2 with the average of 414.8 mS/cm for all soil layers of Pitch 2. As shown in Tables 1 and 2, other chemical properties, such as Cl, CO_3, HCO_3, Ca, Mg, Na, and K are assessed in both pitches are as standard and they matched up with the FAO guidelines of soil for paddy production (FAO, 2021).

Correlation Among Soil Properties

The correlation matrix among soil physical and chemical properties analyzed at Dakawa Irrigation Scheme was summarized in Fig. There were significant correlations between organic matter (organic carbon) contents and soil pH, magnesium and sodium concentrations, respectively. Also, soil pH values were related with electric conductivity, calcium, magnesium and sodium concentrations, respectively.

CONCLUSION

Since this assessment has identified problems of low permeability, high bulk density, which led to soil compaction, very low OM and OC, and also the emergence of alkalinity of the soil which all of which at the end lead to poor productivity in particular areas. In this case, it is recommended to increase the OM and OC and control soil pH by using organic matter of cow dung compost, this is due to the fact that it’s available in the area and it’s very easy to make application of it. Additionally, the use of rice husk as a soil amendment should also be taken into consideration to control permeability and compaction. It is recommended to use rice husk because of its efficiency and it’s available in the area of the Dakawa Irrigation Scheme.

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Research article

Tourist Perceptions and Willingness to Pay for Biodiversity Conservation at Nam Nao National Park, Thailand's Newest ASEAN Heritage Site

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Abstract ASEAN Heritage Park (AHP) designation is one of several tactics that have been used in Southeast Asia for promoting biodiversity conservation to achieve sustainable development goals. However, public awareness of this program is limited despite its initiation in 1978. This study examined tourist perceptions of Nam Nao National Park (NNNP), Thailand's most recent AHP. It estimated tourist willingness to pay (WTP) for biodiversity conservation at NNNP and identified factors that influenced their decisions. Data were collected from visitors during September to October 2024 using a self-administered questionnaire, along with interviews with park officers and onsite observations. A total of 209 visitors participated in the study, 5% of whom came from overseas. Nearly half of the respondents (45%) identified as ecotourists but lacked understanding of one key aspect: supporting local livelihoods. Most respondents were first-time visitors at NNNP who came for nature-based recreation but had never heard of AHP prior to their trip. Yet, they expressed positive opinions about building conservation awareness, encouraging participation, and supporting effective park management. About 80% of the respondents were willing to pay for biodiversity conservation (with nearly 90% confidence). The average amount was 40 Baht per year (~USD $1.25), equivalent to the park entrance fee for Thai visitors. This finding suggests that visitors were willing to pay for biodiversity conservation at twice the current entrance fee. In exchange, visitors wanted their money to be spent on forest restoration and fire-break construction. Lastly, a generalized linear model identified type of tourist (i.e., ecotourists), travel frequency (i.e., frequent visitors > 5 times), gender (female), age, and positive perception as key drivers of WTP (p-value < 0.05).

Keywords ecotourism, biodiversity conservation, ASEAN heritage park, tourist perception, willingness to pay

INTRODUCTION

As one of the world's largest industries, tourism contributed almost USD 10 trillion to the global economy, making up 9.1% of the total global gross domestic product (World Travel and Tourism Council, 2024). Yet, tourism is also responsible for environmental deterioration, cultural erosion, and social disparities (Kumar et al., 2023). Ecotourism is a prominent alternative, defined as "responsible travel to natural areas that conserves the environment, sustains the well-being of local people, and involves interpretation and education" (The International Ecotourism Society, 2015). This concept integrates conservation efforts, community development, educational initiatives, and the promotion of nature-centric activities (Samal and Dash, 2023). Taman Negara National Park in Malaysia exemplifies the eco-conscious practices of indigenous communities (Bakar and Zainon, 2021), while Way Kambas National Park in Indonesia contributes an estimated USD 353,360 annually to local economies (Cusack et al., 2021). Unfortunately, negative outcomes such as environmental pollution, economic leakages, and social disturbances remain common (Toro et al., 2021). Despite the presence of ecotourism in protected areas, biodiversity loss and ecosystem degradation persist, indicating the need for additional management approaches.

Initiated in 1978, the ASEAN Heritage Park (AHP) program aims to promote biodiversity conservation and sustainable livelihoods across Southeast Asia (Kim et al., 2019). Designated AHPs must adhere to specific criteria, including ecological completeness, representativeness, conservation importance, naturalness, uniqueness, and species significance (ASEAN Centre for Biodiversity, 2020). Protecting these sites is essential for the well-being of ASEAN citizens. The AHP's regional action plan requires participating countries to implement integrated conservation and development projects that promote sustainable livelihoods, active community participation, cultural exchange, and responsible tourism practices, while ensuring that management efforts align with AHP's criteria to protect habitats, biodiversity, and livelihoods through approved management plans (ASEAN Centre for Biodiversity, 2015, 2020). Since its inception, 57 national parks and nature reserves across 10 ASEAN countries have been designated as AHPs.

In Thailand, nine national parks were designated as AHP, including Khao Yai National Park – the World Heritage (ASEAN Centre for Biodiversity, 2024). These AHPs demonstrate ongoing efforts to balance ecotourism and biodiversity conservation. For example, Khao Yai National Park has implemented environmental education programs and active visitor management to reduce ecological disturbances, while Kaeng Krachan National Park promoting community involvement through forest patrolling and nature interpretation activities (Rattanawanawong et al., 2022; Sirivadhanawaravachara, 2024). These efforts offer useful references for understanding conservation-oriented management practices within Thailand's AHP network.

In August 2023, Nam Nao - Phu Kradueng National Park Complex was designated as Thailand's eighth AHP. This declaration underscores its ecological significance including old-growth forests, diverse flora and fauna, and unique landscapes. Phu Kradueng National Park is a well-known destination for mountain hiking, while Nam Nao National Park (NNNP) attracts those who are interested in camping and nature-based recreation. Despite its popularity, NNNP faces some significant management challenges, such as invasive species, habitat degradation, human-wildlife conflict, and pressures from economic development. Recently, a four-lane highway was proposed as part of the ASEAN East-West Economic Corridor, connecting Thailand with Myanmar and Laos. This mega construction project is expected to negatively affect NNNPs biodiversity and ecosystems. Conservation efforts can address tourism-related challenges such as waste management, increased resource consumption, and human-wildlife conflict.

OBJECTIVE

Responses from tourists and park officers were measured to determine the effectiveness of the AHP designation at NNNP. Recognition of NNNP as an AHP might influence tourist donations and contributions toward biodiversity protection. Therefore, this study examined tourist perceptions and knowledge of NNNP's AHP status. It also measured their willingness to pay (WTP) for biodiversity conservation at the park and identified factors that influence WTP decisions.

METHODOLOGY

This study was conducted at NNNP in Phetchabun province, northern Thailand. Data were collected using a questionnaire*, in conjunction with interviews with park officers and onsite observations. Yamane's formula, with a degree of error between 5% and 10%, was used to determine sample size. Moreover, to measure the amount of WTP using a contingent valuation method (CVM), Cameron et al. (1989) recommended a sample size between 200 and 2,500 for a simple statistical tolerance formula. In this study, we aimed to collect data from at least 200 visitors, including those from

* The research questionnaire was approved by the Center for Ethics in Human Research, Khon Kaen University, with the Research Code HE673218 and Reference No. KKU 660201.2.3/2940 on 05 June 2024.

abroad. The CVM, commonly used to value non-market goods, especially environmental and biodiversity resources, was applied in a bidding game format (Davis, 1963). It allows the respondents to easily identify and evaluate their WTP according to the given hypothetical conditions. Moreover, at the other end of the spectrum, respondents were invited to state a specific amount of money in an open-ended format. The value of this technique is its simplicity and suitability for field-based surveys (Akhtar et al., 2017; Odihi et al., 2021). A self-administered questionnaire, available in Thai and English, consisted of the following sections: 1) socioeconomic characteristics; 2) knowledge and perception of the AHP program; 3) perception of NNNP's AHP status and expectations; 4) perception of current management activities at NNNP; 5) experiences at NNNP and views on ecotourism; and 6) WTP for biodiversity conservation. Data analyses, including descriptive statistics, t-test, one-way analysis of variance (one-way ANOVA), and a generalized linear model, were performed using SPSS version 28.01 (IBM, 2021).

RESULTS AND DISCUSSION

Visitor Socioeconomics and Tourism Experience at NNNP

A total of 209 visitors completed the questionnaire, including 11 individuals (5%) from overseas. This finding was unexpected, considering the season and the fact that NNNP is less internationally recognized compared to other national parks in Thailand such as Khao Yai, Doi Inthanon, Phi Phi, and Similan Islands. The majority of respondents were female (57%) and under the age of 24 (76%). This age distribution is compatible with the nature of NNNP as a well-known site for activities that attract younger people. This group was largely composed of college students (69%), showing that NNNP appeals to those who have sufficient time. Most visitors reported a monthly income of less than 10,000 Baht (77%). Despite limited budgets, NNNP's affordability makes it a popular destination for young people who seek nature-based experiences (Mäntymaa et al., 2021).

About 47% of the sample were first-time visitors at NNNP, while 9% had visited more than five times during the past five years. The presence of repeat visitors suggests high visitor satisfaction (Shapoval et al., 2021). Primary reasons for visitation include education (24%), sightseeing (21%), hiking (20%), and camping (10%). These findings indicate that NNNP serves both educational purposes and caters to those interested in a variety of nature-based activities. Most of the respondents (69%) traveled with friends while 20% came with family members.

Tourist Knowledge and Perception towards the AHP Program and NNNP's Status

Most visitors (67%) had not heard of the AHP program before visiting the park. Knowledge was assessed by asking individuals to select "yes", "no" or "not sure" in response to questions and statements describing the purpose, criteria, and general information about the AHP. Responses were converted into scores: 0 for incorrect answers, 0.5 for indecisive responses, and 1 for correct answers. Summed scores were then classified into levels of knowledge: low = 0.00-0.49, medium = 0.50-0.79, and high = 0.80-1.00. Despite being unfamiliar with the AHP program, the overall average score of respondents was 0.81, indicating a high level of knowledge. Respondents recognized landscape protection, cultural preservation, sustainable tourism promotion, regional conservation efforts, and educational opportunities as the main purposes of the program. However, they lacked a clear understanding of how ecotourism could protect biodiversity and nature. Moreover, visitor knowledge about specific AHP designation criteria, such as conservation and ecology, was high (0.88), reflecting a basic understanding of its core objectives. In contrast, their general knowledge about the program was moderate (0.62). For instance, visitors did not know the total number of AHPs or the fact that NNNP had recently been designated prior to their visit.

Furthermore, respondents were asked to express their perception toward NNNP's AHP status using a 5-point Likert scale, ranging from "strongly agree" to "strongly disagree". They were also asked whether AHP status had influenced their actions or concerns on biodiversity protection. Summed perception scores were grouped into three levels: low = 1.00 - 2.33; moderate = 2.34 - 3.67;

and high = 3.68 - 5.00. Respondents strongly agreed that declaration of NNNP as an AHP site would improve public awareness. Moreover, AHP status made them feel proud of local biodiversity, raised their awareness and sense of responsibility, and encouraged participation in biodiversity conservation. However, respondents indicated that AHP status did not influence their decision to visit the park for activities such as camping, bird watching, sightseeing, and nature study.

Perception on Current Management of NNNP and Expectations from its New AHP Status

Table 1 summarizes visitor perceptions of NNNP's management and expectations regarding its AHP status. Respondents expressed a high level of agreement with current management, especially regarding the hospitality and knowledge of park officers, well-maintained facilities and reasonable fees (e.g., entrance and camping gear rental fees). Even availability of park information (the lowest-rated item) received a high level of agreement. Despite this high level of satisfaction, respondents still expected improvements, mainly in the areas of information about forest ecosystems, vegetation and wildlife along nature trails, friendliness of park officers, and the availability of local souvenirs. They did not expect much change in English-based communication, such as signage, exhibitions, or the speaking skills of park officers, since most of the visitors were Thai nationals.

Table 1 Perceptions on current management and expectations from NNNP as the AHP

Statements	Mean Score (SD)	Agreement level
Perceptions on current management activities		
1. Park facilities (e.g., restrooms, camping areas, and visitor center) are adequate, clean, and eco-friendly	4.2 (0.8)	High
2. Staff members at NNNP are hospitable, knowledgeable and effectively communicate conservation messages	4.3 (0.8)	High
3. The entrance fee is reasonable and worth paying	4.2 (1.0)	High
4. Rental fees for tent spacing and camping gears are reasonable	4.2 (0.9)	High
5. Tourist attractions (e.g., visitor center, trails, wildlife watching, waterfalls, and scenic viewpoints) at NNNP are diverse, well-maintained, and easy to access	4.1 (0.9)	High
6. Information about the park (e.g., maps, educational materials, exhibition) is readily available and informative	4.0 (1.0)	High
7. I feel safe and well-supported by the park's emergency and first-aid services	4.1 (0.9)	High
8. The park effectively uses signage and information materials to explain the AHP designation and its benefits	4.1 (0.9)	High
Overall mean score	4.2 (0.9)	High
Expectations from NNNP as the AHP		
1. English information posts and exhibition on the park's biodiversity	3.5 (1.0)	Moderate
2. Park officers with proficient English to communicate effectively with international visitors	3.6 (1.0)	Moderate
3. Information on biodiversity and ecosystems at the nature trails	4.4 (0.8)	High
4. Local communities to actively participate in biodiversity protection and conservation initiatives	4.3 (0.7)	High
5. Well-maintained Park facilities to enhance visitor experience.	4.3 (0.9)	High
6. More educational programs about local biodiversity and cultural history of NNNP for visitors to learn	4.3 (0.8)	High
7. Friendly gesture and service mind from park officers	4.4 (0.7)	High
8. Local made souvenirs	4.4 (0.6)	High
Overall mean score	4.2 (0.8)	High

Note: Agreement level score: Low = 1.00-2.33, Moderate = 2.34-3.67 and High = 3.68-5.00

Visitor Understanding and Attitudes on Ecotourism

Nature-based activities (e.g., camping, hiking, and bird watching) play an important role at national parks in Thailand. In addition to outdoor recreation, tourists often learn about the value of nature appreciation. Subsequently, they gain awareness and concern, which can trigger actions to protect nature and biodiversity. Moreover, nature-based recreation is often perceived as ecotourism; and tourists who visit national parks frequently identify themselves as ecotourists. Yet, environmental protection is only one aspect of ecotourism. Another important component, which is often overlooked, is the improvement of local livelihoods. Visitors at NNNP were asked to classify themselves as a 'regular tourist', 'ecotourist', or 'not sure'. In addition, they were asked about ecotourism practices, including environmental protection and awareness for supporting local livelihoods such as purchasing locally made souvenirs and participating in homestay tourism. About 45% of the respondents identified as ecotourists, whereas 51% as regular tourists, and 4% were indecisive. One-way ANOVA tested the association between tourist type and ecotourism knowledge. Post hoc tests showed that ecotourists had significantly higher knowledge scores than regular tourists (mean difference = 0.54, $p = 0.008$) and indecisive visitors (mean difference = 1.18, $p = 0.022$). This finding demonstrates that tourist self-classification can play a significant role in shaping actions and attitudes toward ecotourism.

Willingness to Pay for Biodiversity Conservation and Factors Influencing Visitor Decisions

To estimate WTP for biodiversity protection at NNNP, visitors were presented with hypothetical scenarios in which the park was threatened by highway construction, agricultural expansion, invasive species, and other environmental changes. Conservation efforts, including public participation and financial contribution were described as urgently needed. Visitors were asked whether they would be willing to pay for biodiversity conservation. If so, a list of payment options was provided, starting from 20 Baht to 100 Baht, along with a blank space where respondents could write their own preferred amount if it differed from the list. Surprisingly, about 80% of the respondents expressed their WTP with 90% confidence. The average amount was 40 Baht, which is equivalent to the current entrance fee for Thai visitors. The most preferred payment method is through entrance fee collection (70%), followed by a donation box placed at the park visitor center and tour guide fee (29% and 1%, respectively). The outcome reflects visitors' preference and familiarity toward the existing payment method where their money contribution will be allocated for park management, including biodiversity conservation. On the other hand, any new payment tool, especially donation, takes time for visitors to accumulate their trust on it. Moreover, the main reasons for WTP included perceived effectiveness of conservation efforts and personal beliefs about the importance of protecting nature. Respondents who were unwilling to pay cited financial constraints as the primary reason. They also suggested that the entrance fee should already cover all necessary conservation costs. Lastly, respondents wanted their money to be allocated toward forest restoration, fire break construction, bird watching, and camping facilities, respectively.

Some factors were more influential than others in shaping WTP decisions. Logistic regression and a generalized linear model (GLM) were used to examine correlations between WTP decisions ("yes" vs. "no"), the amount of payment, and tourists' socioeconomic backgrounds. The decision to pay was significantly influenced by tourist type, perception of AHP status, and travel frequency. A GLM with a normal distribution and log link function was used to model the amount of WTP for biodiversity conservation at NNNP. The model fits the data well, with $\chi^2(13) = 47.028$, $p< 0.001$ and AIC = 2,093.099. Significant predictors (p-value < 0.05) of the WTP amount included: type of tourist (i.e., ecotourists expressed a greater amount, $B = 0.392$), gender (i.e., female visitors paid less, $B = -0.657$), travel frequency (i.e., frequent visitors > 5 times paid more, $B = 0.491$), age (i.e., older visitors paid more, $B = 0.023$), and perception on the AHP status (i.e., those who strongly agreed with the declaration paid more, $B = 0.467$).

CONCLUSION

Nature-based recreation, frequently thought of as ecotourism, is a key driver for biodiversity conservation at NNNP. Hiking, bird watching, and camping were the most popular outdoor activities at the park. Although visitors were confused about the meaning of ecotourism—particularly in reference to improving local livelihoods—they recognized their role in protecting biodiversity. Most visitors, especially those who identified as ecotourists; elderly; non-female groups; frequent visitors; and those who strongly agreed with AHP declaration of NNNP, expressed WTP for biodiversity conservation at NNNP (approximately 40 Baht) through entrance fee payments.

The AHP declaration was intended to enhance park management. However, most visitors were unaware of this international designation. Possible reasons include designation in 2023, limited promotion, and a weak connection perceived between the program and biodiversity protection. Yet, visitors quickly learned about the designation during the interview. Therefore, providing visitors with more information about the AHP program—especially its contributions to biodiversity conservation—is necessary. Increasing public awareness and engagement is essential for protecting biodiversity through ecotourism.

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Research article

Mapping Land Use Shifts in Nepal's Protected Regions: Insights for Biodiversity and Resource Management

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Abstract This study investigated the temporal dynamics of Land Use and Land Cover (LULC) changes across 13 protected areas (PAs) (12 National Parks and 1 Wildlife Reserve) and their associated buffer zones from 1990 to 2021. Data from the National Land Cover Monitoring System (NLCMS) for the years 1990, 2000, and 2010 were acquired, while random forest modeling using Landsat 7 images at the Google Earth Engine (GEE) platform was utilized for the year 2021. The data were analyzed using the Land Change Modeler (LCM) within the TerraSet IDRISI software. Total forest cover for the core areas of the 13 PAs exhibited resilience, declining from 4,731.89 km² (1990) to 4,554.87 km² (2000) before recovering to 5,021.95 km² (2021), marking a net gain of 290.06 km². Total shrubland area fluctuated, peaking at 298.24 km² (2010) but declining to 252.47 km² (2021). Total grassland area experienced dramatic shifts, plummeting to 1,723.04 km² (2010) before rebounding to 3,088.57 km² (2021). Total agricultural land area peaked at 207.62 km² (2010) but sharply contracted to 82.33 km² (2021). Total barren land area expanded by 65% (1990–2000) but stabilized at 2,203.70 km² (2021). Total built-up areas surged 179-fold (0.19 to 34.08 km²), reflecting anthropogenic encroachment pressures. Total snow/glacier cover recovered from a low of 2,276.57 km² (2000) to 2,997.39 km² (2021). Buffer zones exhibited contrasting trends: total agricultural land area expanded steadily (1,322.24 to 1,407.36 km²), total shrubland area doubled (92.75 to 211.90 km²), and total barren land area plummeted 90% (488.07 to 46.40 km²). Total built-up areas grew tenfold (3.87 to 32.54 km²), highlighting urbanization pressures. Total grassland area rebounded from x (1990) to 941.19 km² (2021). Total snow/glacier coverage was halved post-2010 (419.83 to 244.61 km²). In summary, the core areas demonstrated biodiversity recovery, demonstrated by forest regeneration and reduced agriculture, while buffer zones faced intensified land use from agriculture and urbanization uses and climate impacts. These findings highlight the delicate balance between conservation and development pressures in Nepal's protected areas. They offer valuable insights for planning and policy, stressing the need for targeted interventions to address human impacts while preserving ecological connectivity. Given Nepal's diverse landscapes, from tropical lowlands to Himalayan ranges, these insights can guide sustainable management both locally and globally.

Keywords Land Use Land Cover (LULC), protected areas, conservation, Nepal, remote sensing, buffer zones, ecological monitoring, biodiversity

INTRODUCTION

Land use and land cover (LULC) changes in protected areas play a crucial role in impacting the conservation and ecological integrity of these environments. Protected areas such as national parks (NPs), animal reserves and nature sanctuaries, and conservation areas are established to safeguard biodiversity, protect endangered species (Zhou et al., 2025), and maintain ecological equilibrium by providing a sanctuary for a wide variety of animals, including rare and endangered species. These areas contribute to sustaining essential ecosystem activities, including water purification, carbon sequestration, soil stabilization, and climate regulation. Nonetheless, they are susceptible to the impact of human activities, including local development and ecotourism (Ramaano, 2024). The repercussions of LULC modifications can be far-reaching, encompassing habitat alteration, loss of biodiversity, and changes in ecosystem services. Effective monitoring of LULC in protected areas is imperative for biodiversity conservation, the preservation of ecological services, and sustainable resource management (Wade et al., 2003).

Human activities, notably unsustainable tourism, have a significant impact on LULC changes in protected areas, with potentially far-reaching environmental consequences. The development of tourism infrastructure, such as hotels, resorts, roads, and recreational facilities, often necessitates extensive land alteration and deforestation, resulting in habitat loss and fragmentation (Gössling, 2002). These transformations not only diminish biodiversity but also affect the natural landscape and ecological services. Both natural processes and human activities influence the LULC dynamics in these areas, emphasizing the necessity of understanding these changes for designing effective conservation programs. Habitat fragmentation, deforestation, and land degradation can all adversely affect plant and animal life, resulting in species extinction and genetic diversity loss. Conservationists can identify critical areas requiring protection and restoration efforts by continuously monitoring LULC changes (Pickering and Hill, 2007).

Protected area ecosystems offer a wide range of crucial services, including soil stabilization, carbon sequestration, water purification, and climate management. The extent of land cover directly influences these services. For example, wetlands and forests are essential for maintaining natural carbon sinks and hydrological cycles. Protected areas, by trapping carbon, are also pivotal in attempts to mitigate climate change. Alterations to LULC can disrupt these services, leading to adverse effects on the environment and society. Routine monitoring allows for early detection of such changes, enabling swift action to safeguard these vital ecological functions. Tracking changes in LULC helps in evaluating carbon sequestration capacity and devising strategies to enhance it. Understanding LULC dynamics also aids in identifying vulnerable areas and developing management strategies to increase resilience, contributing to climate adaptation efforts (Roy et al., 2022).

Resources within protected areas are pivotal for the livelihoods of residents, particularly in developing and the least developed countries, offering nature-based tourism (ecotourism) and biodiversity conservation. Effective monitoring of LULC can assist in developing sustainable land management methods that strike a balance between conservation efforts and the needs of local communities. By providing data on the prevalence of human activities like farming, grazing, and tourism, LULC monitoring enables the design of solutions that address community needs with minimal negative environmental consequences. Its primary goal is to preserve the ecological integrity of protected areas while ensuring sustainable resource extraction. Detailed and accurate LULC information supports the development of successful conservation initiatives, land use planning, and regulatory frameworks. This valuable LULC information can be harnessed by policymakers to implement measures aimed at reducing negative impacts and fostering long-term growth (Marion and Leung, 2001).

In Nepal, there are 20 protected areas including 12 National Parks (NPs), 6 conservation areas, 1 wildlife reserve,1 hunting reserve, and 13 buffer zones, extending from lowland Terai to high mountains, which covers 23.39% of the country's total land area and contributes to in-situ conservation of ecosystems and biodiversity across the country (DNPWC, 2024). This study is particularly important due to the country's exceptional geographic and ecological diversity. Nepal has a wide range of ecosystems, from tropical forests in the lowlands to alpine meadows in the high Himalayas, creating a global biodiversity hotspot. Preserving the country's protected areas is crucial for conserving its unique biodiversity, including numerous endemic and endangered species such as the snow leopard, the red panda, and the Bengal tiger. Despite its enormous tourism potential, Nepal faces challenges such as a lack of recreational centers, insufficient transportation and communication, a shortage of skilled labor, pollution management issues, inadequate advertising, poor tourist destinations, low-quality lodging, and security concerns (Badal and Kharel, 2019). Furthermore, these regions are experiencing growing pressures from human activities, climate change, and natural disasters such as landslides and floods. Monitoring LULC changes in Nepal's protected regions can aid in recognizing and addressing these dangers, thus guaranteeing the ongoing preservation of its distinct wildlife and ecosystems.

Furthermore, the economy of Nepal and the livelihoods of numerous rural communities are intricately connected to natural resources and ecosystem services. The effective monitoring of LULC can play a vital role in the development of sustainable land management practices that strike a balance between conservation endeavors and the requirements of local populations. This is imperative for attaining long-term ecological sustainability and socio-economic advancement in Nepal. Moreover, Nepal faces significant vulnerability to the effects of climate change, with its glaciers and snowpacks serving as critical sources of water for millions of people. Understanding LULC dynamics holds the utmost importance for climate adaptation strategies, facilitating improved water resource management and mitigation of disaster risks from glacial and snowpack melt.

OBJECTIVES

The objectives of this study were to quantify the observed changes of LULC in protected areas of Nepal every ten years from 1990 to 2021, and to identify their impacts on conservation. The analysis sought to answer how the conservation strategies can be evaluated and how to measure their impact on biodiversity, ecosystem services, and sustainable resource management, thereby providing pivotal data to inform policy decisions and effective conservation strategies.

METHODOLOGY

Study Area: The research focused on 13 protected areas with established buffer zones, which are designated areas within protected regions with specific resource use restrictions to enhance conservation (Table 1 and Fig.1). Pandit et al. (2018) defined a buffer zone as an area within the protected area that has restrictions on resource use and specific measures to enhance its conservation value.

Table 1 Selected National Parks, Wildlife Reserve, and Buffer Zones

	National parks with their buffer zone	Year established	Abbreviation used
1	Chitwan NP and Buffer Zone	1990	CNP
2	Lamtnag NP and Buffer Zone	2000	LNP
3	Sagarmatha NP and Buffer Zone	2010	SNP
4	Bardiya NP and Buffer Zone	2000	BNP
5	Shey-Phoksundo NP and Buffer Zone	2000	SPNP
6	Makalu Barun NP and Buffer Zone	2000	MBNP
7	Shuklaphanta NP and Buffer Zone	2010	SUNP
8	Parsa NP and Buffer Zone	2010	PNP
9	Rara NP and Buffer Zone	1990	RNP
10	KoshiTappu Wildlife Reserve and Buffer Zone	1990	KTWR
11	Khaptad NP and Buffer Zone	2010	KNP
12	Banke NP and Buffer Zone	2020	BKNP
13	ShivaPuri NP and Buffer Zone	2020	SNNP

Source: DNPWC 20024

Nepal's geographical setting spans between 26°-31°N and 80°-89°E, bordered by China and India, with elevations ranging from 60 m above sea level in the Terai to 8,848.86 m at Mount Everest's peak. This topographical diversity creates distinct ecological zones, from the subtropical Terai lowlands to the alpine Himalayas, all influenced by the South Asian monsoon (June-September). The country's ecoregions support rich biodiversity: the Terai features tropical forests housing Bengal tigers and rhinoceros; the mid-hills contain temperate forests with red pandas and Himalayan black bears; and the alpine zones provide habitat for snow leopards and Himalayan tahr. The country as a whole received 91.2% of the typical annual precipitation of 1570.4 mm. The average maximum temperature of Nepal was 27.9°C (0.6°C above than normal annual maximum temperature) and the average minimum temperature was 15.6°C (0.5°C above than normal annual minimum temperature) in 2023 (DHM, 2023), supporting over 6,000 flowering plant species, 800 bird species, and 180 mammal species.

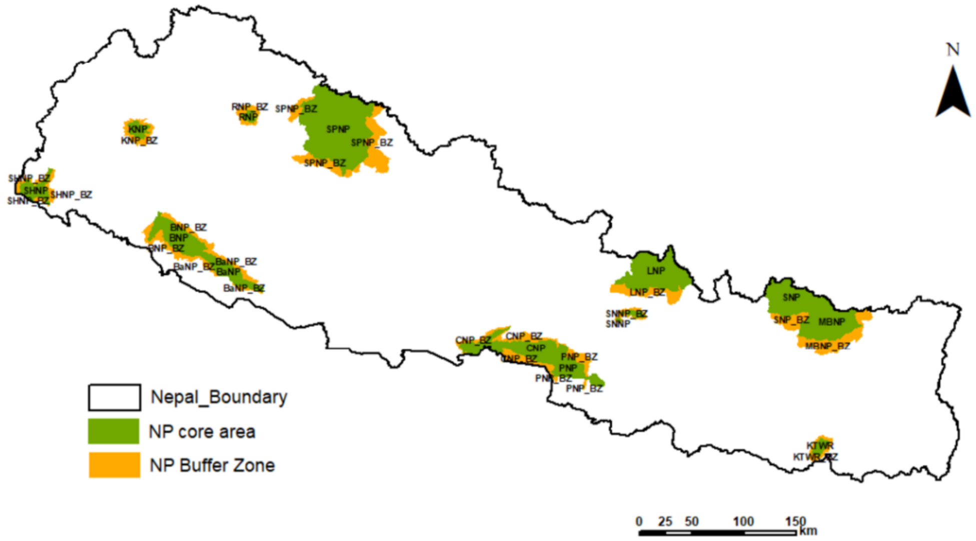


Fig. 1 Shapefile showing the selected protected areas of Nepal

Data Acquisition and Processing

The study utilized secondary data, which was generated through the National Land Cover Monitoring System (NLCMS) for Nepal, developed by the Forest Research and Training Centre (FRTC) under the Ministry of Forests and Environment, Government of Nepal (FRTC, 2024). The system utilizes readily accessible remote-sensing data from the Landsat 7 satellite and operates on a cloud-based machine learning architecture within the Google Earth Engine (GEE) platform. It facilitates the generation of annual land cover maps employing a standardized classification system, ensuring uniformity and reliability, which can be used for land management initiatives in Nepal. We used NLCMS data for 2000, 2010, and 2019. For 1990, we received maps from the UN Food and Agriculture Organization in Nepal (FAO-Nepal), which they also acquired from the International Centre for Integrated Mountain Development (ICIMOD). Data and maps for 2021 were generated using GEE, where we utilized the former generated maps as a training sample supplemented by using Google Earth images using a random forest supervised classification method in GEE. The accuracy of the map for 2021 was over 80 % kappa coefficient.

Land Change Modeler

The Land Change Modeler (LCM), integrated within the TerraSet IDRISI software platform (Clark Labs, 2020), offers a robust framework for quantifying transitions between land cover categories. This tool enabled us to analyze and visualize changes in land use over time, facilitating the identification of areas undergoing transitions from one land cover class to another. By employing a variety of analytical techniques, such as Markov chains and cellular automata, LCM allowed for the comparison of land cover losses, gains, and net persistent areas across different time periods. The user-friendly interface and comprehensive analytical capabilities made this a valuable tool for our study.

RESULTS AND DISCUSSION

Overview of Land Use Land Cover Change within the Study Areas

The assessment of LULC changes in the 12 NPs and one wildlife reserve between 1990 and 2021 demonstrated substantial temporal dynamics (Table 2. Between 1990 and 2021, land use patterns exhibited significant shifts. Forest area initially declined from 7,467.59 km² (1990) to 7,133.85 km² (2000) before recovering to 7,654.86 km² (2021). The shrubland area showed a steady increase from 338.34 km² to 464.37 km² over the same period. Grassland area experienced a decline, reaching 2,317.25 km² (2010), but rebounded sharply to 4,029.76 km² (2021). In contrast, agricultural land area peaked at 1,598.67 km² (2010) before declining to 1,489.69 km² (2021). Barren land area surged to 3,041.22 km² (2000) but later decreased to 2,250.10 km² (2021), while water body area steadily diminished from 170.43 km² to 150.23 km². Snow/glacier coverage fluctuated throughout the period, settling at 3,242.00 km² (2021). Built-up areas exhibited exponential growth, expanding from 4.06 km² to 66.63 km². Meanwhile, unclassified areas saw a sharp decline from 46.65 km² to 1.60 km², reflecting advancements in classification accuracy.

Table 2 Land use land cover area over the study period

Land use/Years	1990	2000	2010	2021
Forest	7467.59	7133.85	7169.29	7654.86
Shrubland	338.34	392.41	410.61	464.37
Grassland	3469.97	3109.28	2317.25	4029.76
Agriculture area	1508.33	1534.10	1598.67	1489.69
Barren area	1903.22	3041.22	2906.26	2250.10
Water body	170.43	159.07	161.00	150.23
Snow/glacier	3075.95	2562.15	3362.67	3242.00
Built-up area	4.06	4.74	10.46	66.63
Unclassified	46.65	47.64	48.33	1.60

Note: Area in km²

Changes Occurred in the Land Cover Classes

A total of 54 transitions from one land use to another were identified. However, less than 3 km² were excluded for further analysis between the studied years (1990 and 2021), revealing complex patterns of land use change. The priority classes where the transition occurred are within forest, grasslands, shrublands, agriculture, waterbodies, builtups, and snow/glaciers.

The results were also interpreted using loss, gain, net change, and net persistence (Figs. 3 and 4), which were generated from using the LCM tool. Forest area exhibited a net gain of +364.29 km², indicating expansion, while Shrubland and Grassland showed gains of +83.80 km² and +775.29 km² (the largest net increase), respectively. Agriculture remained stable with a marginal net gain of +6.29 km². In contrast, the Barren area experienced the most substantial net loss (−569.03 km²), followed by Water body (−10.90 km²) and Unclassified areas (−45.95 km²), the latter nearly reduced. Snow/glacier expanded significantly (+698.47 km²), a notable deviation from global glacial retreat patterns, and Built-up areas surged by +62.52 km², reflecting rapid urbanization.

The study reveals significant transitions in land cover patterns during the period of study. The most significant change was from forest to shrubland, affecting 470.86 km² of area. The reverse transition from shrubland to forest occurred over 80.0145 km². Forest to grassland conversion was substantial at 310.38 km², with grassland to forest reclamation observed across 158.6835 km². Agricultural transitions were noteworthy, with 117.55 km² of forest converted to agriculture and a larger area of 246.2985 km² transitioned from agriculture back to forest. Barren areas saw bidirectional changes, with 27.30 km² of forest becoming barren and 55.8045 km² of barren land reverting to forest. Minor transitions included forest to water bodies and water bodies to forest.

Shrublands experienced both gains and losses across various categories, with the largest conversion being from grassland to shrubland, covering 1,675.44 km². Other major transitions included grassland to barren areas, snow/glacier, and forest. Smaller transitions occurred with agriculture, water bodies, snow/glacier areas, and built-up zones. Overall, the data suggests a net loss in grassland area, with the most significant transformations occurring in grasslands and barren areas.

Water bodies experienced both gains and losses across various categories, with the largest conversion from water bodies to shrubland. Snow/glacier areas underwent significant transitions across various land cover types, with some areas gaining snow/glacier coverage while others lost it, indicating potential impacts of climate or land use changes on glacial environments.

The data indicates a significant expansion of built-up areas across various land cover types, with agriculture and barren areas experiencing the most substantial transitions to built-up land. Grasslands also saw notable conversions, with 13.84 km² transitioning to built-up.

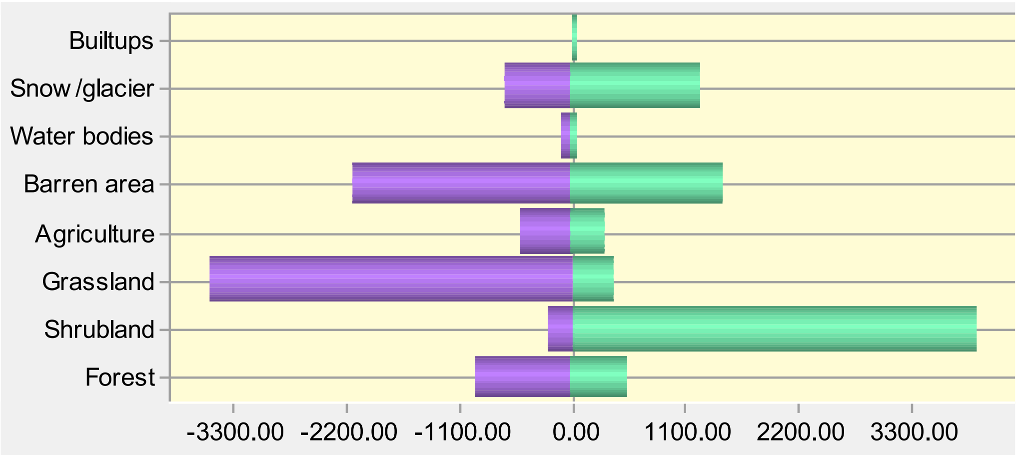


Fig. 3 Loss and gain in each class type from 1990-2021 for the selected PAs

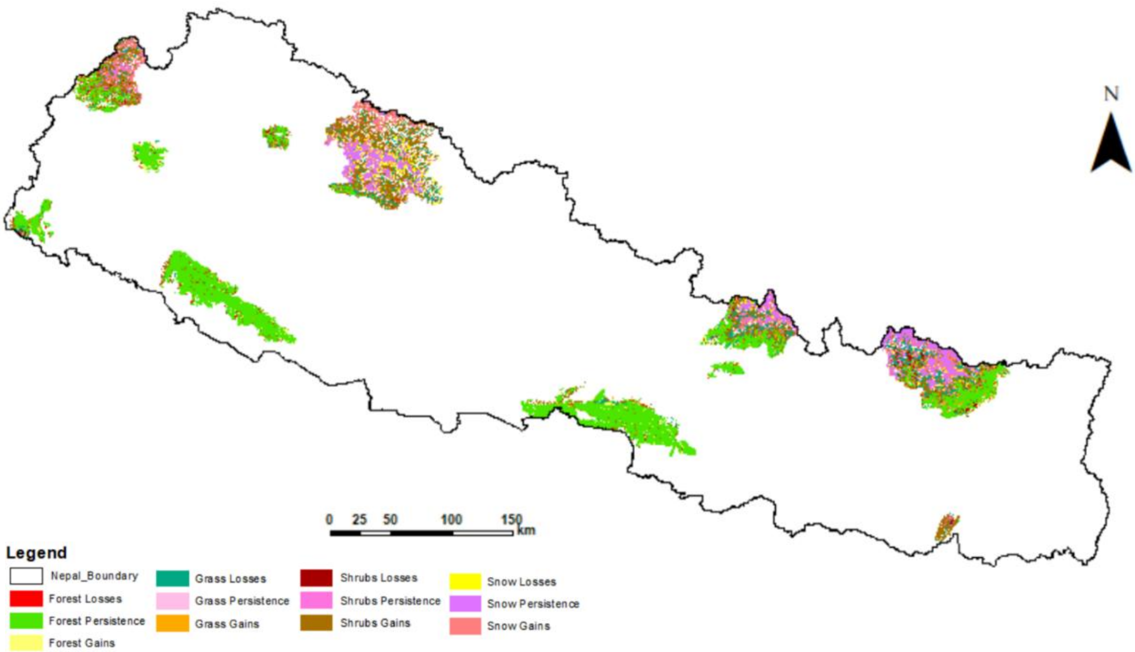


Fig. 4 Spatial map showing loss and gain

Forest, shrub, grass and snow/glacier from 1990-2021 for the selected PAs

Results for Individual National Parks

The clipped tool used in the ArGIS pro for the individual NP results (Fig. 5) interpreted that, between 1990 and 2021, forest cover remained the dominant land type across all national parks, with slight increases in CNP (1369.29 to 1449.05 km²) and BarNP (1186.19 to 1263.80 km²), while remaining stable in SNP and MBNP. Shrubland expanded notably in SNP (18.22 to 209.30 km²) and BarNP (22.10 to 73.14 km²), suggesting vegetation regeneration or land use changes.

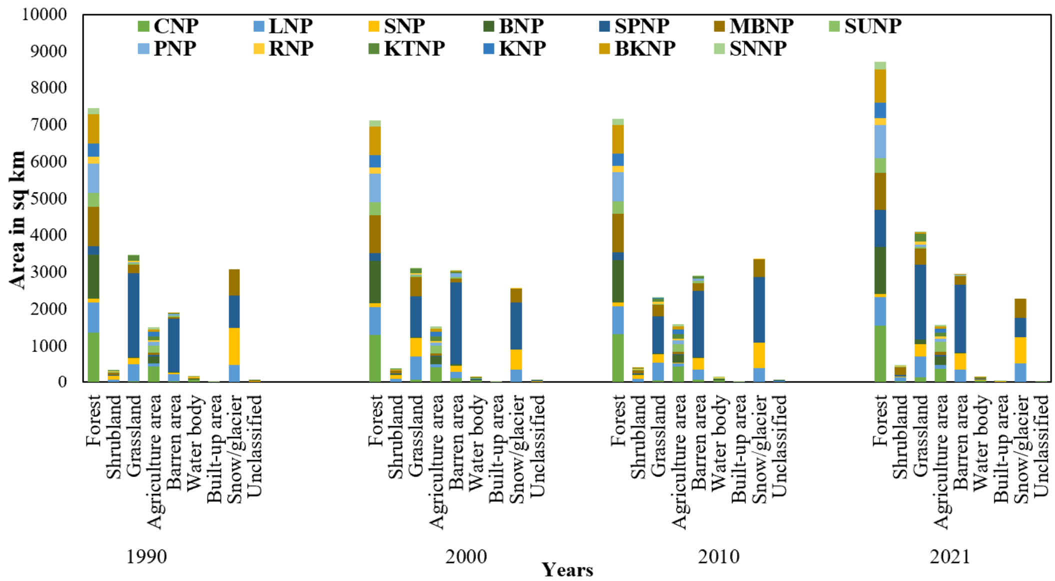


Fig. 5 Loss, persistence, and gain observed in the four main class types

Grassland declined significantly in SNP (115.78 to 45.81 km²) and CNP (88.60 to 66.26 km²), likely due to land conversion. Agricultural areas decreased across most parks, particularly in SNP (115.78 to 67.41 km²), indicating reduced cultivation. Barren land increased in SNP (64.94 to 166.52 km²) and SPNP (25.70 to 91.91 km²), possibly due to glacial retreat or land degradation. Water bodies and built-up areas showed minimal change. Snow/glacier cover became more distinct from 2000, particularly in SNP and MBNP, reflecting improved classification and potential climate influences. Unclassified areas declined sharply, highlighting enhanced mapping accuracy. Overall, SNP and BarNP exhibited dynamic shifts in shrubland and barren land, while CNP and MBNP remained forest-dominated with moderate variations.

Table 3 LULC categories in the core area for the study periods

	LULC	1990	2000	2010	2021	Trend
1	Forest	4731.89	4554.87	4583.08	5021.95	
2	Shrubland	245.59	287.82	298.24	252.47	
3	Grassland	2604.20	2388.70	1723.04	3088.57	
4	Agriculture area	186.09	161.17	207.62	82.33	
5	Barren area	1415.15	2331.06	2243.04	2203.70	
6	Water body	115.77	106.47	108.35	111.60	
7	Snow/glacier	2808.99	2276.57	2942.84	2997.39	
8	Built-up area	0.19	0.24	0.52	34.08	
9	Unclassified	37.23	38.13	38.41	0.96	

Overall Trend Changes in the Core Areas

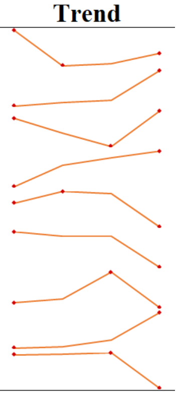
Between 1990 and 2021, the 13 NPs showed dynamic land-cover transitions (Table 3). Forest cover experienced a net increase—from 4731.89 km² in 1990 to 5021.95 km² in 2021—even though it receded to 4554.87 km² around 2000 before recovering. Shrubland and agricultural areas both fluctuated: shrubland grew from 245.59 km² in 1990 to 298.24 km² by 2010 and then declined to 252.47 km² by 2021, while agricultural land peaked at 207.62 km² in 2010 (after falling to 161.17 km² in 2000) and then shrank sharply to 82.33 km² by 2021. Grassland area fell steeply from 2604.20

km² in 1990 to 1723.04 km² in 2010 before rebounding dramatically to 3088.57 km² by 2021. Barren land expanded markedly between 1990 and 2000 (from 1415.15 km² to 2331.06 km²) and then declined slightly to 2203.70 km² by 2021. Snow and glacier cover declined from 2808.99 km² in 1990 to 2276.57 km² in 2000 but increased in the following decades (reaching 2997.39 km² by 2021). Built-up area grew dramatically (from 0.19 km² in 1990 to 34.08 km² in 2021). Water bodies remained relatively stable (115.77 km² in 1990 vs. 111.60 km² in 2021), and unclassified land remained minor and roughly constant (around 37–38 km² through 2010, nearly zero by 2021). Overall, these trends indicate notable gains in forest and built-up areas and a complex pattern of gains and losses in other land cover types over the 31 years.

Overall Trend Changes in the Buffer Zone Areas of the Study Sites

The analysis of LULC changes in the buffer zone areas of 13 selected PAs in Nepal between 1990 and 2021 highlights notable transformations distinct from those observed in the core protected areas. Forest cover exhibited an overall increase from 2735.70 km² in 1990 to 2632.91 km² in 2021, despite an initial decline observed in 2000. Shrubland expanded markedly, more than doubling from 92.75 km² in 1990 to 211.90 km² by 2021. Grassland cover showed a decreasing trend until 2010 but later rebounded, ultimately reaching 941.19 km² in 2021, surpassing its 1990 extent. Agricultural land steadily increased across the decades, rising from 1322.24 km² in 1990 to 1407.36 km² in 2021, indicating continued cultivation pressure in buffer zones. In contrast, barren areas witnessed a dramatic decline from 488.07 km² in 1990 to just 46.40 km² in 2021, possibly due to land rehabilitation or conversion to vegetated cover. Water bodies showed a marginal decline, while snow/glacier coverage initially increased, peaking at 419.83 km² in 2010, but subsequently decreased to 244.61 km². Built-up areas experienced substantial growth—from 3.87 km² in 1990 to 32.54 km² in 2021—highlighting rapid infrastructure development in the peripheries of protected areas. Unclassified land declined sharply, reflecting improved categorization or land use stabilization. Collectively, these patterns indicate dynamic land transformations in buffer zones, with efforts for conservation, land management, and human-wildlife interactions in Nepal's protected area network.

Table 4 LULC categories in the buffer zone area for the study periods

	LULC	1990	2000	2010	2021	Trend
1	Forest	2735.70	2578.98	2586.22	2632.91	
2	Shrubland	92.75	104.59	112.37	211.90	
3	Grassland	865.76	720.57	594.22	941.19	
4	Agriculture area	1322.24	1372.93	1391.05	1407.36	
5	Barren area	488.07	710.16	663.23	46.40	
6	Water body	54.66	52.60	52.65	38.63	
7	Snow/glacier	266.96	285.58	419.83	244.61	
8	Built-up area	3.87	4.50	9.94	32.54	
9	Unclassified	9.42	9.51	9.92	0.64	

DISCUSSION

The overall transition analysis of land cover classes between 1990 and 2021 across the 13 PAs (whole areas) in Nepal reveals dynamic and multidirectional land transformations, indicative of both ecological processes and anthropogenic interventions. Forest areas were predominantly converted into shrubland and grassland, with notable transitions also occurring toward agriculture, barren land, and, to a lesser extent, built-up areas and snow/glacier. Shrubland exhibited a high degree of conversion into forest, grassland, barren land, and agriculture, suggesting its transitional nature within the landscape mosaic.

Grassland experienced substantial shifts, primarily transitioning into shrubland, barren land, and snow/glacier, indicating potential ecological succession or climatic influences. Agricultural land was largely transformed into forest, shrubland, and barren areas, while some of it also transitioned to built-up areas, highlighting pressures from land abandonment or urban expansion. Barren areas were converted into shrubland, snow/glacier, and to a lesser extent, forest and agriculture, pointing to potential re-vegetation or geomorphological changes.

Snow/glacier areas underwent notable transitions to barren land, shrubland, and grassland, while also gaining area from forest and grassland, likely reflecting climate-induced cryospheric dynamics (Thapa et al., 2021). Water bodies experienced conversions to and from various classes, including forest, barren land, and shrubland, suggesting seasonal or long-term hydrological alterations. Built-up areas expanded at the expense of forest, shrubland, and agriculture, underscoring developmental pressures within protected landscapes. These patterns collectively reflect the complexity of land system dynamics within Nepal's protected areas, driven by natural succession, climatic variability, and socio-economic change.

The change analysis in the core areas for the studied period indicates considerable ecological dynamics. Core forest cover showed a net gain over the period, reflecting positive conservation outcomes, despite a dip in 2000. This success has played a highly significant role as a result of community management. For instance, Nepal’s community forests span roughly 2.3 million hectares and are managed by more than 22,000 user groups that include 3 million households—nearly 57% of the nation’s population (Pandey and Pokhrel, 2021). The Government of Nepal is focusing more on transferring the national forest management to community-led forest management in the future.

In contrast, the grassland area declined significantly until 2010 but rebounded sharply by 2021, possibly due to active habitat restoration and management practices (Budhathoki et al., 2024). Likewise, shrubland areas experienced overall decline, suggesting reduced human activity within the core zones. Barren areas expanded in the early years, followed by a slight contraction, while built-up areas increased rapidly, although they remain relatively limited in total area. Snow and glacier coverage exhibited moderate variability, increasing in recent years. These trends emphasize ongoing ecological transitions in core zones and highlight the impact of conservation policies and climate-related factors on land cover dynamics.

Additionally, between 1990 and 2021, land use and land cover (LULC) changes in the buffer zones surrounding twelve national parks and one wildlife reserve indicate intensified human–landscape interactions. The buffer zone Forest area fluctuated but generally increased, suggesting reforestation or natural regeneration efforts. Notably, shrubland and agricultural areas expanded substantially, indicating persistent livelihood dependence on land resources. Grasslands, after an initial decline, recovered to exceed 1990 levels, potentially due to local management initiatives. A dramatic reduction in barren land points to successful land reclamation or conversion to productive uses. Built-up areas rose sharply, reflecting increasing settlement and infrastructure development. Snow and glacier coverage varied, while water bodies showed a slight decline. These transformations underscore the growing pressure on buffer zones and the urgent need for integrated conservation and development approaches to sustainably manage these transitional landscapes.

The study suggests implementing integrated conservation approaches that combine strict protection measures with community-based management, sustainable tourism development, and climate change adaptation strategies.

CONCLUSIONS

This research highlights several major findings with significant implications for protected area management in Nepal. First, while forest conservation efforts have shown success, the substantial loss of grasslands and expansion of shrublands indicate a need for ecosystem-specific management approaches. Second, the rapid increase in built-up areas demonstrates the growing pressure of development on protected areas, requiring stronger regulation and sustainable tourism planning. Third, the changes in snow/glacier coverage and water bodies suggest vulnerability to climate change impacts, necessitating adaptive management strategies. The study recommends implementing integrated conservation approaches that combine strict protection measures with community-based management, sustainable tourism development, and climate change adaptation strategies. Priority should be given to grassland ecosystem restoration, controlling infrastructure development in sensitive areas, and strengthening buffer zone management policies. Future conservation success will depend on balancing ecological preservation with local community needs while adapting to climate change impacts. These findings can inform conservation policies not only in Nepal but also in other regions facing similar protected area management challenges.

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Research article

Impact of Dietary and Self-sufficiency Changes on Nitrogen Load in the Kasumigaura Watershed

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Abstract Recently, dietary change has been increasingly recognized as a viable strategy to reduce nitrogen pollution. This is because raising animal-based proteins results in significantly higher nitrogen loads compared to raising (cultivating) their plant-based alternatives. In Japan, there has been a rise in animal-based food consumption in recent decades, which could have detrimental effects on water quality. However, dietary changes are rarely considered in watershed environmental conservation. Given Japan's low food self-sufficiency of 38%, shifting diets could improve both domestic and international water quality. Therefore, the aim of this study was to evaluate whether dietary changes among the Japanese population could result in nitrogen load reduction and water quality improvement in the Kasumigaura watershed. Firstly, nitrogen load from each point source and non-point source was quantified by examining various nitrogen flows, using land-use data to capture the contributions from different sources. This analysis also incorporated food production-related anthropogenic nitrogen from crops and livestock. The estimated nitrogen load in 2020 was around 4,403 tons/year, and it was a reasonable value compared with previous research. Then, the impact of dietary and self-sufficiency changes on the nitrogen load was estimated. The results suggest that the reduction of animal proteins has significantly lowered the nitrogen load in the watershed, therefore offering a promising approach to improving water quality.

Keywords nitrogen pollution, water quality, dietary change, eutrophication, Kasumigaura watershed

INTRODUCTION

Nitrogen pollution has detrimental effects on water quality. When excess nitrogen enters bodies of water, it leads to excessive algae bloom, resulting in degraded water quality and loss of aquatic biodiversity. Current food production practices were recently recognized as the largest contributors to water's nitrogen pollution, particularly related to the use of synthetic fertilizers and animals' release of fecal waste (Shindo et al., 2009). Despite nitrogen´s negative effects on the environment, its use in agriculture remains essential for feeding the global population, as it supports higher crop yields. While sustainable agricultural practices, such as precision fertilization or indoor farming, offer promising solutions, their implementation can be costly or difficult to implement. Therefore, one of the recently proposed solutions to nitrogen pollution has been a change in one´s dietary habits. This is related to the fact that raising/cultivating certain food groups results in higher nitrogen release into the environment, such as animal-based proteins, compared to plant-based proteins. This results from feed requirements and fecal waste production (Leach et al., 2012). Such impact is measured through a unit called a nitrogen footprint (NF). This measure shows the dietary-related yearly nitrogen emissions per capita. Food production-associated nitrogen emissions are calculated through the multiplication of an individual´s yearly protein intake by a virtual nitrogen factor (VNF). This factor varies largely according to each food group. The higher the VNF value, the greater the emissions associated with the food production of that specific food group. With a shift of dietary intake to less nitrogen-intensive food, it can possibly reduce nitrogen load, which could help eutrophicated areas that are found across the globe. Xian et al. (2021) demonstrated that an increase in livestock product barriers significantly contributes to water environment degradation in China. In the case of Japan, multiple studies have explored the link between eating habits and nitrogen pollution (Oita et al., 2017; Oita et al., 2020; Shibata et al., 2014; Shindo et al., 2009). Shindo et al. (2009) conducted an initial study to identify that one of the causes of higher nitrogen flows, which is a movement of nitrogen through the environment, was higher consumption of livestock products by the Japanese population. This contributed to Japanese waters quality decrease. Their intake increased dramatically in the last decades, with daily animal-based protein intake rising from 30% of overall daily protein intake to 53% [19.5g/day in 1961 to 37.3g/day in 2011; (FAO, 2015)]. Subsequently, Oita et al. (2020) explored the impact of this Japanese dietary switch in more detail. The authors found that between 1961 and 2013, the NF of Japan increased by nearly twofold, due to increased preference for livestock diets. A study by Oita et al. (2017) highlights the importance of dietary changes in lowering nitrogen emissions. This study compared NF of the current Japanese diet with NF of various dietary scenarios. The authors analyzed the average Japanese citizens´ diet using data from Japan's food balance sheet, representative of the whole of Japan (MAFF, 2020a). The results showed that most NF-reducing dietary patterns were those that replaced livestock protein with legumes, fish, and seafood. It reduced nitrogen emissions by 45% while maintaining the same level of protein intake as the current diet. Understanding dietary impacts requires considering both national and localized scales. However, due to food production and trade data being available at a country level, studies have focused on the national scale. But, it is also important to consider the impacts of dietary changes on a smaller scale, such as at the watershed level, as nitrogen pollution tends to be a localized problem. Despite this, dietary changes are not researched or considered in watershed environmental conservation strategies. This study is designed to point out the importance of considering dietary impact on this scale. For example, the Kasumigaura watershed in Japan experiences algae blooms caused by nitrogen pollution. The lakes of the watershed are only 4 meters deep, which makes them susceptible to eutrophication caused by various sources. Despite improvement from the past due to control measures of point and non-point sources, the nitrogen in the watershed still remains above environmental standards. This was mostly attributed to non-point agricultural influence, such as fertilizer application or inefficient manure disposal management.

OBJECTIVE

The aim of this study was to evaluate whether dietary changes among the consumers of food products from the Kasumigaura watershed could result in nitrogen load reduction and water quality improvement in the Kasumigaura watershed. The research seeks to answer the following questions:
(1) What is the current nitrogen load of the watershed in 2020?
(2) What is the impact of dietary change on the nitrogen load?

METHODOLOGY

Study Area

The Kasumigaura watershed was chosen as the target area. It covers a third of Ibaraki Prefecture with an area of approximately 2,157 km^2. The average annual temperature of the area is 14 degrees Celsius, and rainfall is approximately 1300 mm annually (Matsushita et al., 2006). Current land-use patterns of the watershed are paddy field (24%), upland crop (21%), forest (20%), urban area (17%), water (12%), golf course and other (6%), through land-use analysis (Fig.1). Land-use analysis used data by Ministry of Land, Infrastructure, Transport and Tourism (2024) from 2016, assuming that the land-use area has not significantly changed compared with the current state. With agricultural land being the dominant landscape, the watershed is one of the largest food producers in the country, largely supplying its citizens and other prefectures. In addition, due to this proximity to Tokyo, it experienced a severe population decline and industry establishments since the 1960s, with population increasing from approximately 700,000 citizens in the 1960s to almost 1,000,000 residents in the early 2000s (Statistics Bureau of Japan, 2020). However, the population movement has stabilized, and now the population decreased to 937,300 in 2020 (Ibaraki Government, 2022).

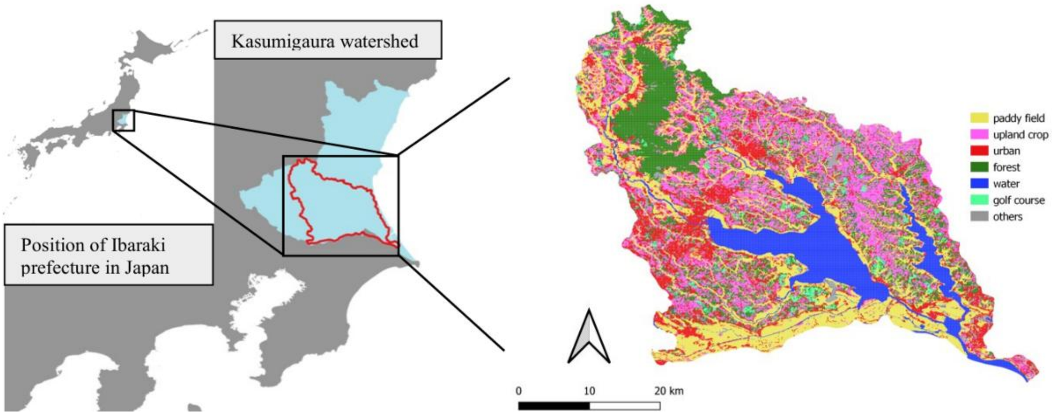

Fig. 1 Location of Kasumigaura watershed and its land-use (MLIT, 2024)

Current Nitrogen Load Quantification

This study focused on the year 2020 because it is the most recent year for which comprehensive nitrogen loading unit data were available. Comparable datasets for previous years were either unavailable or incomplete, making 2020 the most suitable reference point for analysis. Various nitrogen flows were analyzed to understand the extent of food production impact. In the case of point sources (domestic wastewater, industry and factory, and general workplace), their exact value was taken from an official report by the Ibaraki Government (2022). For non-point sources such as urban areas, forests, water, and others, their value was calculated based on their nitrogen loading unit/ha provided by the Ibaraki Government (2022), then multiplied by their area defined by land-use analysis. The method of Makoto et al. (2005) was used to calculate the nitrogen load of upland crops and paddy fields. Basic data for these calculations, such as crop type and area, were obtained from MAFF (2020a). The nitrogen loading unit for upland crops was averaged from top crops in Ibaraki Prefecture and applied to the watershed's upland crop area determined by land-use analysis. For paddy fields, the entire area was directly identified through land-use analysis. Livestock numbers of the watershed were estimated by dividing the total livestock population of Ibaraki Prefecture based on the watershed's proportion of Ibaraki's total area, and this value was multiplied by their emission unit (Ibaraki Government, 2022; MAFF, 2020a).

Impact of Dietary Changes on Current Nitrogen Load

It is important to establish the self-sufficiency of the watershed´s food products, to identify the extent of the impact of its consumers' dietary changes. It is assumed that all the watershed´s food production consumers have an average Japanese citizen's dietary intake, due to the prefectural data limitation. The food groups were created based on their similar nitrogen load impacts (Shibata et al., 2014). Self-sufficiency estimation was divided into 3 groups: livestock, livestock feed crops, and crops for human consumption (crops). Figure 2 further explains the process for each group´s calculation. In case of livestock, total protein supplied by the watershed was based on livestock numbers and their edible weight (MAFF, 2020a). Edible weight was calculated according to each livestock product (MAFF 2020a, 2020b; 2020c). In case of crops, total protein supplied by the watershed was based on their edible weight through the yield of each crop type (MAFF 2020a). In contrast to livestock and crops intended for human consumption, the self-sufficiency of livestock feed was estimated using dry matter (DM) as a measure. The amount of DM feed required to produce one kilogram of

animal products varies by livestock type and was calculated using feed conversion ratios (MAFF, 2020b; 2020c). To assess the impact of eating habits on food production-related load, 2 alternative scenarios were analyzed. Analyses only focus on the nitrogen load to the watershed, not all virtual nitrogen, such as in similar studies (Oita, 2017; Oita, 2020). The purpose is to measure yearly water quality impact more directly. Moreover, the usual calculation considers more processes, such as crop processing or household waste. However, this study considers only synthetic fertilizer use and manure, as they are the largest contributors.
Scenario 1: Livestock protein is fully replaced by legume protein grown within the watershed. This scenario aims to analyze the most nitrogen-reducing eating pattern (Shindo, 2014; Oita, 2017). Scenario 2: The watershed is fully self-sufficient in producing animal feed, with no change in food production or diet. This scenario seeks to demonstrate that although animal feed production is not a direct dietary change, it is linked to dietary choices, as it is driven by demand for animal products.

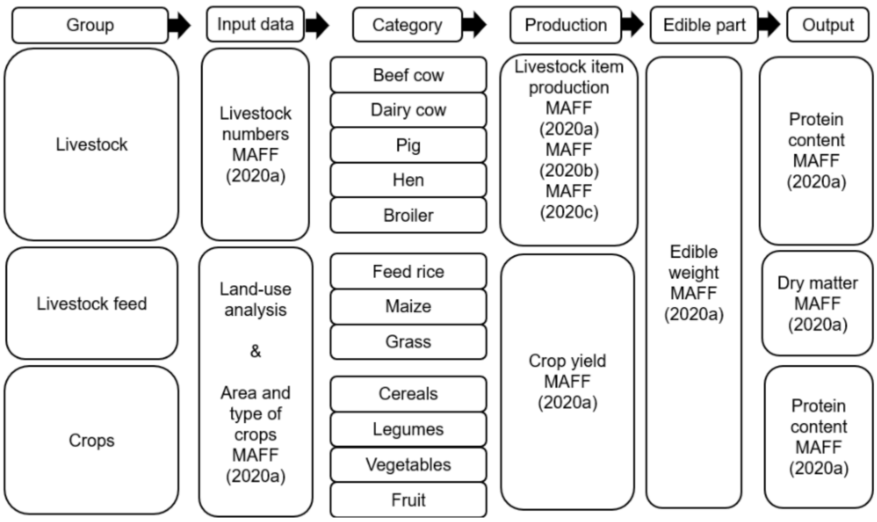

Fig. 2 Methodology of self-sufficiency calculation flowchart

RESULTS AND DISCUSSION

Current Nitrogen Load Quantification

Estimation of nitrogen load (Fig.3) correlated with previous research, 4,343.5 tons/year reported by the Ibaraki Government (2022) in 2020. The discrepancies in the results could be due to the omission of mineralization or biological fixation. Results show that food production had the largest impact on the load (total 1,668 tons/year).

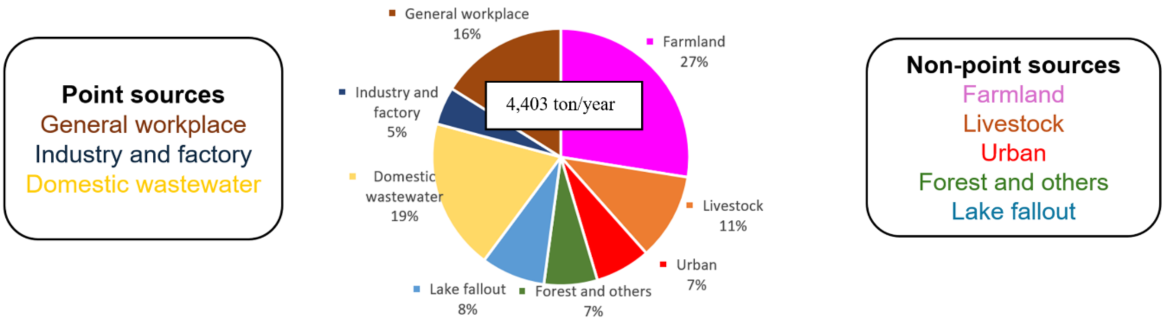

Fig. 3 Estimated nitrogen load per year 2020

While internal sources like sediment resuspension also release nitrogen, our findings suggest that current agricultural inputs have a greater impact (Havens et al., 2001). This underscores the importance of targeting food production in policy-making. Farmland consisted of 514.4 tons/year from paddy fields (12%) and 671.1 tons/year from upland crops (15%). An additional 482.2 tons/year was attributed to livestock (11%). Usually, it is assumed that manure is applied onto farmland as fertilizer. However, its distribution rate is low due to barriers such as the labor force, making it still a large nitrogen load source (Ibaraki Government, 2022). Fish and seafood were not considered as their loading is low in the watershed (Ibaraki Government, 2022).

Impact of Dietary Changes on the Current Nitrogen Load

Table 1 shows the protein supply and self-sufficiency of various food groups for the watershed´s population of 973,300 citizens. The study only focuses on the nitrogen impact of the population that consumes food products from the watershed. It is vital to distinguish between the self-sufficiency production of various food groups, as these can vary (MAFF, 2021). Protein supply in the watershed is self-sufficient in cereals, vegetables, fruits, beef, and eggs, as they can supply all the watershed´s population (Table 1). Their additional supply is possible to export to other parts of Japan or abroad. Despite intensive livestock production, the watershed cannot supply its citizens with a sufficient amount of animal products apart from beef and eggs, suggesting that other livestock products are imported from other prefectures or abroad, correlating with other studies (Oita et al., 2020; Shibata et al., 2014). This dependency on imports for animal products may increase in the future, particularly with a growing preference for animal-based diets, which could drive up livestock production and further exacerbate this external reliance. This could be potentially beneficial to watersheds, but not favorable to their food security. On the other hand, the domestic supply may also increase, as the government aims to increase food self-sufficiency to 45% by 2030 (MAFF, 2021). This might worsen nitrogen pollution in the watershed. In addition, it was found that the watershed is not self-sufficient in animal feed. Results showed that the watershed produces 63,271 tons/year of feed (DM), which only makes up 14.3% of the required feed (441,327 tons/year of DM) for the watershed´s livestock, according to the watershed´s feed production (MAFF, 2020a). This indicated that most of the virtual nitrogen footprint related to livestock production is generated externally, likely in another country, as domestic animal feed self-sufficiency is low, around 25% (MAFF, 2021). This could be viewed positively for the watershed´s water quality; however, it is still contributing negatively to global nitrogen pollution.

Table 1 Protein supply and self-sufficiency (973, 300 people) among food groups

Food group	Yearly protein supply of the watershed (kg)	Yearly protein intake per citizen (kg)	Number of people supplied by the watershed (persons)	Self-sufficiency (%)
Cereals	16,324,000	6.57	2,484,627	265
Legumes	1,116,000	3.61	309,141	33
Vegetables	10,549,000	1.42	7,428,873	793
Fruits	707,000	0.33	2,142,424	229
Beef meat	1,079,000	1.10	980,910	105
Pork meat	741,000	2.34	316,667	34
Chicken meat	184,000	2.77	66,426	7
Eggs	6,789,000	2.08	3,263,942	348
Milk and its product	1,574,000	2.99	526,421	56

Moreover, analyses of two scenarios revealed that dietary changes impact on the nitrogen load. Figure 4 illustrates the results of scenario analyses compared with food production-related nitrogen load.

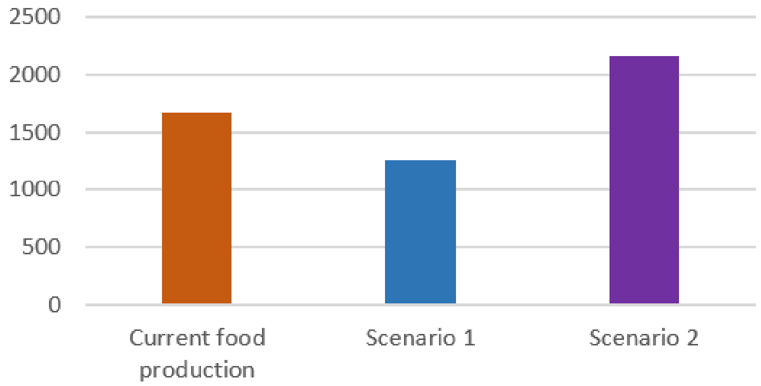

Fig. 4 Scenario analyses of nitrogen load changes (ton/year) from food production

Scenario 1 depicts a decrease of nitrogen load by 416 tons/year, which is a significant impact with a decrease of 46%, despite most of the feed being imported, as most of the livestock-related nitrogen footprint usually comes from feed crop fertilizer. This decrease is due to the elimination of nitrogen load from manure and all the feed crops, which would mean that all the animals would be removed from the watershed. Moreover, it could be argued that the biological fixation of legumes will add additional nitrogen into the soil, which was not considered. However, we based our analysis on the fact that legumes tend to have the smallest nitrogen among the food groups, implying that previous studies also did not consider biological fixation in nitrogen load calculations. Furthermore, scenario 2 analysis revealed an increase in nitrogen load in the case of feed self-sufficiency, correlating with previous research (Alexander et al., 2016). In such a case, nitrogen load rose to 2,160 tons/year, which is more than 492 tons/year compared to the current nitrogen load. However, the distribution of manure into farmland could mitigate this increase by lowering the load associated with livestock by 482,2 tons. Therefore, a scenario with manure distribution should be further researched. Contrasting scenarios, scenario 2 has an increase of nitrogen load of 908 tons/year compared to scenario 1. These results align with previous research from other countries and Japan, which all demonstrated potential water quality improvement with legume as an alternative protein (Poore and Nemecek, 2018; Xian et al., 2021). It is essential to consider other dietary scenarios, as a fully plant-based pattern might not be realistic, as it would mean that all the animals would have to be removed from the watershed. That is why further research should consider a partial dietary shift, such as 30% or 50%. Similarly, future investigations should also focus on partial feed self-sufficiency shift (such as 30% or 50%), as a full shift is not realistic. Moreover, combinations of various scenarios and dietary patterns should be taken into account.

CONCLUSION

This study represents a pilot investigation of the predicted impacts of proposed dietary changes on nitrogen loads on the Kasumigaura watershed scale. The load in total was 4,403 tons/year of nitrogen in the year 2020, with a large amount of 1,668 tons/year caused by food production. Scenario 1 decreased the load by 416 tons/year by replacing livestock products with legumes, while feed self-sufficiency in scenario 2 increased the load by 492 tons/year. The study showed that dietary changes had a significant impact and greatly reduced the nitrogen load. A key finding is that by replacing livestock in the watershed with legumes, nitrogen load can be largely reduced. It advances current knowledge and nitrogen pollution strategies to recognize the importance of plant-based, focused dietary changes. To promote such eating shifts in Japan, policy implementation should focus on alternative protein sources through education, incentives, and accessibility improvements, while addressing cultural and socioeconomic barriers. Combined with practical strategies like simple cooking methods and food movements, such strategies could reduce nitrogen loads and environmental impacts. In this study, an overall nitrogen footprint could not be included due to data limitations, such as a lack of food manufacturing-related data in the watershed. Therefore, further research is needed to fully understand the role of fecal waste management, biological fixation, mineralization, various food groups' self-sufficiencies, and other kinds of dietary changes.

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Technical Report

A Quarter Century of International Development Cooperation at the Institute of Environmental Rehabilitation and Conservation: Achievements and Future Challenges to Education for Sustainable Development

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Abstract Education for Sustainable Development (ESD) aims to empower learners to make informed decisions and to take responsible actions for environmental integrity, economic viability, and social and community development for present and future generations. ESD is holistic and transformational and enables people and local communities to learn the values, behaviors, and lifestyles required for positive societal transformation and a sustainable future. From its inception in 2000, the Institute of Environmental Rehabilitation and Conservation (ERECON) began promoting ESD through its multiple extension and research activities. ERECON continued these efforts and supported the United Nations Decade of Education for Sustainable Development from 2005 to 2014, including the establishment of the Regional Center of Expertise, Greater Phnom Penh (RCE GPP) in 2009. ERECON collaborates with multiple formal and informal educational organizations in Asian countries to promote ESD. ERECON's extension projects collaborate with RCE GPP and are related to afforestation and organic farming based on natural resource circulation, which aims to promote carbon capture and storage in forest and agricultural areas as well as sustainable rural development with income generation for local communities. ESD has become the fundamental methodology for approaching and educating local populations. ERECON relies on ESD and hosts workshops and trainings with local residents and communities prior to implementing extension activities. Additionally, ERECON's Research Center focuses on and guides the academic and scientific activities of its partner, the International Society of Environmental and Rural Development, utilizing ESD's best practices. In 2025, ERECON celebrated its quarter-century anniversary. Under UNESCO's new global framework 'ESD for 2030' for the 2020-2030 period, ERECON will continue to use and promote ESD towards overcoming challenges and achieving the United Nations Sustainable Development Goals in targeted local communities in Asian countries.

Keywords international development cooperation, ERECON, ESD, SDGs

INTRODUCTION

The Institute of Environmental Rehabilitation and Conservation (ERECON) is an international, non-profit organization founded in April 2000. ERECON aims to contribute to the sustainable use of natural resources in Asian countries. The organization pursues environmental rehabilitation, conservation, and education in order to create harmony between agricultural and urban development and the natural environment. ERECON conducts four non-profit programs including programs for; 1) environmental rehabilitation and conservation, 2) sustainable use of natural resources, 3) environmental education, and 4) other programs for achieving ERECON's aims. ERECON has also conducted select extension and research projects each year since 2000, mainly related to afforestation and organic farming based on natural resource circulation to promote carbon capture and storage in forest and agricultural areas as well as sustainable rural development with income generation for local residents and communities. These projects are always guided by the tenets and best practices of Education for Sustainable Development (ESD).

In the occasion of 25th Anniversary of ERECON, this report was summarized to demonstrate the utilization of ESD as an approach and enabler for multi-stakeholder and community engagements, to highlight ERECON's quarter century of achievements and international development activities supported by ESD, and to define future challenges and recommendations.

EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD)

1. Concept of Sustainable Development

The concept of sustainable development was first discussed and defined at the United Nations Conference on Environment and Development, UNCED, also referred to as the 'Earth Summit,' which was held in Rio de Janeiro, Brazil in June 1992. The UNCED was held on the occasion of the 20th anniversary of the first 'Human Environment Conference' which was held in Stockholm, Sweden in 1972, and brought together political leaders, diplomats, scientists, media representatives, and representatives of non-governmental organizations (NGOs) from 179 countries to focus on the environmental impact of human socio-economic activities. At the same time, the 'Global Forum' of NGOs was held in Rio de Janeiro, bringing together representatives of various NGOs, who presented their visions for the world's future in relation to the environment and socio-economic development.

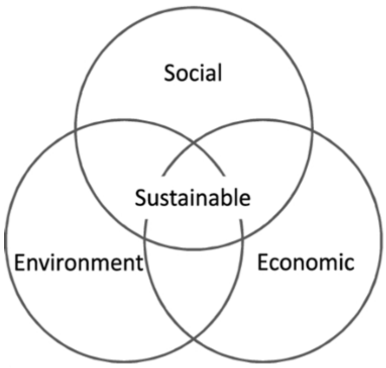

Fig. 1 Concept of sustainable development

The UNCED highlighted how different social, economic, and environmental factors are interdependent and evolve together, and how success in one sector requires action in other sectors so that successes can be sustained over time. The conference stated that the concept of sustainable development (Fig. 1) was an attainable goal for the world's population regardless of whether they were urban or rural dwellers, and whether challenges were addressed at the local, regional, national, or international level. It also recognized that integrating and balancing economic, social, and environmental concerns in meeting short- and long-term needs is vital for sustaining human life on the planet and that such an integrated approach is possible. The conference further recognized that integrating and balancing economic, social, and environmental dimensions required new perceptions of the way we produce and consume, the way we live and work, and the way we make decisions.

The conference noted the criticality and importance of producing a broad agenda and a new blueprint for international action on environmental and development issues to help guide international cooperation and development strategies and directions for the twenty-first century (United Nations, 1992). ERECON fully embraced this UNCED perspective and has upheld it for the past twenty-five years.

2. Education for Sustainable Development

Table 1 highlights ERECON's achievements corresponding to the United Nations (UN) and more specifically, related to ESD. The United Nations Decade of Education for Sustainable Development (DESD), (UNESCO, 2005), established by the UN General Assembly in December 2002, ran from 2005 to 2014 and was led by UNESCO with a focus on integrating sustainable development principles into education worldwide. Its efforts continue to this day under the Global Action Program on ESD, 2015 - 2019 (UNESCO, 2015). The goal of the initial DESD proposed by the Japanese government and recommended by many Japanese NGOs was to integrate sustainable development principles into all aspects of education and learning. This goal was reinforced by ERECON and other Japanese NGOs at the World Summit on Sustainable Development (WSSD) held in Johannesburg in 2002. Subsequently, the Regional Centers of Expertise (RCE) on the ESD movement were launched by the United Nations University.

In 2015, the Global Action Program on ESDs was broadened to focus on education's role in achieving relevant Sustainable Development Goals (SDGs) established by the United Nations. SDG 4.7 is directly supported by ESD, and it states that 'by 2030, ensure all learners acquire knowledge and skills needed to promote sustainable development, including among others through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship, and appreciation of cultural diversity and culture's contribution to sustainable development.' (citation?)

The current DESD framework for achieving the 17 SDGs by 2030 is steered by the United Nations Educational, Scientific and Cultural Organization, UNESCO (UNESCO, 2020).

Table 1 ERECON's achievements corresponding to United Nations and ESD events

Year	United Nations / ESD Events	ERECON Achievements
1972	United Nations Conference on the Human Environment	Researchers were conducting research and education at the University of Tokyo, the Tokyo University of Agriculture, and the Tokyo University of Agriculture and Technology
1992	United Nations Conference on Environment and Development, UNCED	
2000	ERECON Initiatives/ Institutional Structuring towards ESD capacity.	ERECON was founded as an NGO, independent of universities and other stakeholders
2002	World Summit on Sustainable Development	ERECON was registered as a Non-Profit Organization (NPO) by the Tokyo Metropolitan Government, Japan
2005-2014	United Nations Decade of Education for Sustainable Development, DESD	ERECON led and implemented multiple extension programs for sustainable development in Asia
2009	ERECON Initiatives/ Institutional Structuring towards ESD capacity.	ERECON established the Regional Center for Expertise, Greater Phnom Penh, partnering with the Royal University of Agriculture (RUA) and Tokyo University of Agriculture (TUA)
2010	ERECON Initiatives/ Institutional Structuring towards ESD capacity.	ERECON established The International Society of Environmental and Rural Development (ISERD) to promote ESD partnering with RUA and TUA
2013	ERECON Initiatives/ Institutional Structuring towards ESD capacity.	ERECON Headquarters registered its Research Center with the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan as an official research organization
2015-2030	Creation of Sustainable Development Goals, SDGs	ERECON supports and implements multiple extension and ESD programs with various research partners focusing on sustainable development in Asia
2020-2030	Decade of Education for Sustainable Development, ESD	

3. Regional Centers for Expertise, RCE

Regional Centers for Expertise (RCE) is an approach for multi-stakeholder and community engagement and for networking among educational institutions, community, governmental and non-governmental agencies, businesses, and other organizations that work together to advance ESD. 'Centre' refers to an entire region's designation as possessing expertise in ESD as determined by the United Nations University (UNU). The UNU currently supports 154 RCEs around the world.

Specific to Cambodia, the recent and rapid population increase caused many challenges to the environment and the quality of life, education, and health of its citizens. Approximately 75% of the Cambodian population lives in rural communities with approximately 65% of the rural population engaged in agricultural production primarily centered on smallholder farms. Many smallholder farmers have limited financial success and limited education, and many are living near or in poverty. Many school-age children work on family farms and their education opportunities are limited. The quality of education in rural schools is poor and insufficient compared to urban schools and few rural children achieve academic success. The child and family's livelihood are dependent on agriculture including its current challenges and the evolving challenges of climate change, population growth, and related. Famers' technological capabilities and adoption are limited especially related to pesticide or inorganic fertilizers with chemicals released from farmlands to downstream water sources causing multiple problems for the natural environment and human health. As such, ESD in Cambodia's agricultural sector is critically important for rural farm communities, especially for school-age children. ERECON established the RCE Greater Phnom Penh in 2009, partnering with Cambodia's Royal University of Agriculture and the Tokyo University of Agriculture, to ensure and increase opportunities to build the public's awareness and perception of the importance of harmony between agricultural practices and natural environment conservation (Mihara et al., 2012; Tabucanon and Mihara, 2016).

The 'Roadmap for the RCE Community 2021-2030' developed by the UNU-IAS, defines the long-term vision and mission of the RCE community (UNU-IAS, 2022). The roadmap highlights four strategic priority areas for the current 10-year period including, 1) serving as local and regional ESD hubs and demonstrating and teaching leadership for innovation, 2) strengthening the association of RCE activities with the ESD framework and achievement of SDGs, 3) expanding knowledge sharing and outreach, and 4) monitoring the progress of RCE achievements. Accordingly, ERECON's management of the RCE Greater Phnom Penh remains critical with continued efforts to generate, accelerate, and mainstream ESD, and to contribute to the realization of the UN's SDGs in Greater Phnom Penh.

ERECON'S EXTENSION AND RESEARCH PROGRAMS FOR PROMOTING ESD

Since its inception, ERECON promoted ESD through its extension and research activities (ERECON, 2023; 2024), and since 2009 in collaboration with the RCE GPP.

1. ERECON's Extension Programs

ERECON's extension projects are primarily related to afforestation and organic farming based on natural resource circulation, which aims to promote carbon capture and storage in forest and agricultural areas as well as sustainable rural development with income generation for local people and the community. ESD is the fundamental methodology and approach for partnering with teaching and training local populations. ERECON holds local workshops and trainings with people and community stakeholders before implementing extension programs. ERECON's notable extension program achievements from 2023 to 2024 are highlighted below.

Program on Environmental Rehabilitation and Conservation:
- Project on Greening for Satoyama Regeneration in Eastern Cambodia
- Project on Promoting Reforestation for Rehabilitating the Rural Environment in Kampong Cham Province, Cambodia

Program on Sustainable Use of Natural Resources:
- Project of Community Development through School Construction and Renovation in Tboung Khmum Province, Cambodia (Fig. 2)

Program on Environmental Education:
- Project on Promoting School Environment Greening aiming for Forest Environmental Education in Tboung Khmum Province, Cambodia
- Project on Promoting Reforestation and Education for Sustainable Development in Siem Reap Province, Cambodia (Fig. 3)
- ESD Training through Reforestation in Cambodia
- International Green Volunteer Training in Cambodia

Fig. 2 School construction for community development in Tbuong Khmum Province

Fig. 3 Forest resource mapping by local residents in Siem Reap Province development

2. ERECON's Research Programs

In March 2013, Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) registered the Research Center of ERECON Headquarters as an official research organization. In order to support ERECON's extension programs, various research projects have been conducted by the ERECON Research Center. Multiple research projects, including three Grant-in-Aid for Scientific Research (KAKENHI) projects, were conducted in the 2023-2024 program year including:

Promoting Research for ERECON Extension Programs in Program on Research Promotion:

- Research on the Effects and Challenges of Community Development in International Cooperation Projects through School Construction
- Monitoring School Plantation Site from GIS Application to Monitor the Health of the Planted Species
- Tourism Development Impact Evaluation from a Land Use Perspective: Relationship Between Ecotourism and Ecosystem Services
- Practical Study on Formation of Low-Carbon and Recycling-Oriented Society for Carbon-Neutral Initiative
- Research on Effects of Forest Environmental Education on Awareness and Attitudes of Local Students in Relation to Tree Survival Rate
- Study on Assessment of Deforestation and Community Impact: Lessons from an Environmental Awareness Program in Siem Reap Province, Cambodia

Managing ISERD and Organizing ICERD for the Program on Research Promotion:

In 2010, the International Society of Environmental and Rural Development (ISERD) which was established with ERECON support, served as a founding member. ERECON leverages its Research Center to serve as the ISERD Secretariat which it has successfully led since 2010. Additionally, the Research Center of ERECON Headquarters has functioned as the organizer or co-organizer of the annual International Conference on Environmental and Rural Development (ICERD) in collaboration with ISERD and other partner organizations (Fig. 4). Information which has been shared at the ICERD conferences can be applied and adapted by local residents in the target areas of implementing extension projects.

Fig. 4 Opening ceremony of the 15th ICERD held in Khon Kaen, Thailand

Editing and Publishing IJERD for the Program on Research Promotion:
The International Journal of Environmental and Rural Development (IJERD) is a multidisciplinary, peer-reviewed journal published semi-annually by the Research Center of ERECON Headquarters. IJERD is dedicated to publishing peer-reviewed, original research papers and technical reports covering topics such as the environment, agriculture, forestry, ESD, and sustainable rural development. IJERD is edited by an Editor-in-Chief and Managing Editors, and is guided by Editorial Advisory Board Members affiliated with various reviewers from ISERD. All research articles published in IJERD Volumes 1 to 15 were uploaded to J-STAGE with assigned Digital Object Identifiers (DOIs). The articles have provided many scientific outcomes, beneficial information, and recommendations applicable not only to research but to various extension activities including local and regional projects supported by ESD and involving local people and communities.

3. Lessons Learned and Challenges for ERECON's Extension and Research Programs

Current educational opportunities in the rural areas are insufficient, and the poverty of farmers is a barrier for children to continue their study at elementary or secondary schools. Also in rural communities, agricultural chemicals from inorganic fertilizers are released from farmlands to downstream water sources, causing environmental and health problems. As such, ESD in the agricultural sector is vital for local communities. Accordingly, ERECON has been implementing ESD projects in agricultural fields supported by RCE Greater Phnom Penh. Although these projects provide opportunities to increase the public's awareness and perception of the importance of the harmony between agricultural practices and natural environment conservation, the low literacy rate of senior residents challenges the outreach, success, and outcome of these projects.

CONCLUSIONS

ERECON celebrated its quarter century anniversary in 2025. Under the new global framework 'ESD for 2030' promulgated by UNESCO for the period of 2020-2030, ERECON continues to embrace and promote ESD toward achieving SDGs in the targeted local communities in Asian countries.

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We express heartfelt and special gratitude to all collaborated organizations and governmental and non-governmental organizations worldwide. Our quarter century of research and extension programs would not have been possible without their generous financial support.

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Technical Report

Structure and Financial Characteristics of ERECON: Extension and Research Integration

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Abstract The Institute of Environmental Rehabilitation and Conservation's (ERECON) financial structure highlights its unique position among Japanese NGOs. Since its establishment in 2000 and its transition to a Non-Profit Organization in 2002, ERECON has primarily relied upon grants and donations, with annual revenue exceeding 100 million Japanese Yen (JPY) in both 2018 and 2023. The Japan NGO Center for International Cooperation reports that ERECON operates with 100 - 300 million JPY annually as do 15.9% of the total Japanese international cooperation NGOs. A distinctive characteristic of ERECON is its ability to develop extension programs based on the research outcomes, as seeds for extension, which is rare among NGOs. Since ERECON's 2013 designation as a MEXT-accredited research institution, ERECON began various Grants-in-Aid for Scientific Research, contributing to extension programs as well as financial diversification. Further unlike most NGOs that depend solely on external activity with its funding, ERECON successfully integrates research outcomes and its outreach, extension program, ensuring financial stability while maintaining its mission related to environmental rehabilitation and rural development. Despite challenges such as limited financial and human resources, ERECON's financial structure and strategy—balancing traditional NGO funding with research grants—sets it apart in the sector. ERECON's ability to sustain and expand its financial resources is critical in reinforcing its role as a leading model for Japanese NGOs integrating research outcomes and extension programs for practical development purposes.

Keywords organizational structure, financial characteristics, extension, research

INTRODUCTION

The Institute of Environmental Rehabilitation and Conservation (ERECON) has emerged as a significant contributor and leader in the sustainable development and environmental conservation sector. ERECON evolved from a research group focusing on the Mekong River Basin in Thailand to now focus on and have a broad commitment to address important environmental challenges throughout Asia (ERECON, 2023a.; ERECON, 2023b.; ERECON, 2024a.; ERECON, 2024b). Japan recognized ERECON as a non-governmental organization (NGO) in April 2000, and as a

Non-Profit Organization (NPO) in February 2002. This report aims to explore ERECON's current organizational structure and financial characteristics, focusing on the integration of its Extension and Research programs. The report also aims to derive key lessons learned and to offer actionable recommendations for an effective and sustainable financial-organizational model applicable to similar NGOs. The report highlights ERECON's unique ability to integrate research outcomes, as seeds for extension program, a rarity among NGOs, and its role in fostering international academic collaboration through initiatives and partnerships such as that with the International Society of Environmental and Rural Development (ISERD). As ERECON manages its ongoing financial challenges and constraints, its innovative approach to blending research with extension and practical application activities serves as a model for sustainable rural development strategies.

ORGANIZATIONAL DEVELOPMENT AND FINANCIAL INSIGHTS

Foundation of ERECON and Structural Development

Table 1 demonstrates ERECON's evolution and history from a research group to an NGO, to an international NPO. ERECON's mission to define best practices and to contribute to the responsible and sustainable use of natural resources in Asia includes environmental rehabilitation, conservation, and education, which promote harmony between the agricultural sector and the natural environment and between urban and rural development.

Table 1 ERECON's history

Date	Event / Milestone
April 1990	Research group was formed for field activities focusing on the Mekong River Basin
April 1999	Research groups from three universities located in Tokyo joined together to foster environmental studies
April 2000	ERECON was established and recognized as an NGO
Feb. 2002	ERECON recognized as an NPO with the authorization of Tokyo Metropolitan Government
April 2006	ERECON Southeast Asia Office was established in Pathum Thani Province, Thailand
October 2007	ERECON Cambodia Branch was established in Phnom Penh, Cambodia
March 2010	International Society of Environmental and Rural Development was established mainly by ERECON
April 2010	ERECON Philippines Branch was established in Bohol, Philippines
April 2011	Functions of ERECON were divided into 3 Centers; Extension, Research and Administrative Centers
March 2013	Research Center of ERECON received designation as a Scientific Research organization from MEXT

In 2011, the functions of ERECON Headquarters were divided into three centers: the Extension, the Research, and the Administrative Centers, as shown in Fig. 1. This restructuring clarified the distinct roles of the Extension and Research Centers. Notably, in 2013, the Research Center was accredited by the Ministry of Education, Culture, Sports, Science, and Technology (MEXT) as an organization eligible for receiving and managing research grants. At the end of 2024, ERECON employed approximately 8 full-time paid staff and 9 part-time paid staff. The Board of Directors comprises 9 members who meet annually to oversee the organization's strategy and direction, in addition to the Managing Board with President, Executive Directors and contracted consultant representatives, totally 6 members. Annual expenditures closely align with revenue and best practice, with 82% allocated to programming activities and only 18% allocated to administrative operations (FY 2023 results).

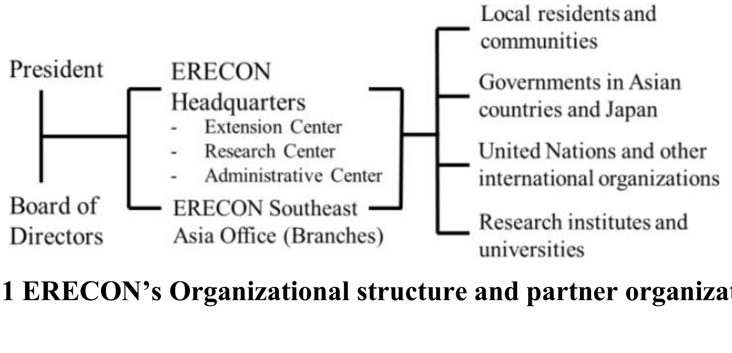


Fig. 1 ERECON's Organizational structure and partner organizations

ERECON's Financial Landscape among Japanese NGOs

ERECON's historical revenue is presented in Fig. 2. Fiscal year 2024 figures are estimated and not actual results. Revenue for the most recent fiscal year of 2023 was 113.6 million JPY which includes that Grants and Similar Funds contributed 65.3% of revenue, Donations accounted for 29.3% of revenue, and Business/Contracted Projects accounted for 5.3% of revenue. While donations are not designated for specific use, grants and contracted projects have designated scope and purposes. The total revenue from grants and contracted projects was 79.9 million JPY, with 92.9% of this revenue coming from extension projects and 7.1% from research projects. This breakdown indicates that ERECON prioritized to extension projects, as it has been the first aim of the organization. Subsequently, research projects are also indispensable for supplying the seeds or the directions to the extension projects. Accordingly, the integration between research activity and extension activity is the most crucial, as the outcomes from research projects would indicate the adequate ways for the project implementation of extension activities. Also, this integration contributes to multi-sourced revenue and financial flexibility to support extension activities while maintaining its foundational research base. In terms of grants and commissioned funds, 94.4% were received from domestic foundations and funds within Japan, while 5.6% were received from international organizations. The 2023 figures follow historical trends and indicate that ERECON relies primarily on Grants and Similar Funds and Donations as its primary revenue sources. However, it is important to note that there were annual fluctuations in revenue. A significant decline from 2013 to 2016 was attributed to the conclusion of major grant projects. The more recent decline from 2019 to 2022 was primarily due to the impact of the COVID-19 pandemic. Since its establishment, ERECON's revenue has shown an increasing trend, exceeding 100 million JPY in fiscal years 2018 and 2023, with the fiscal year 2024 estimated to also exceed 100 million JPY.

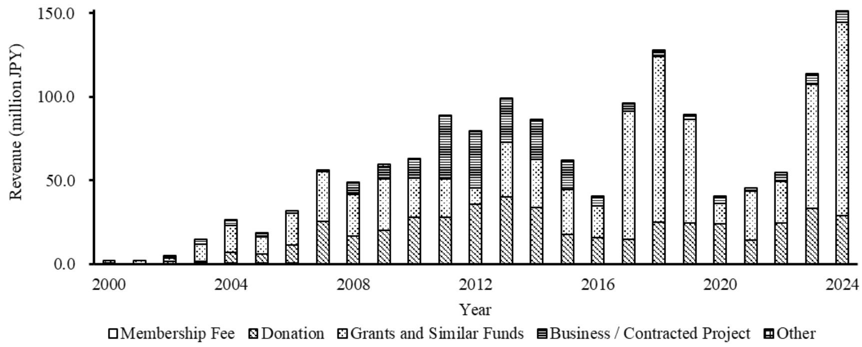
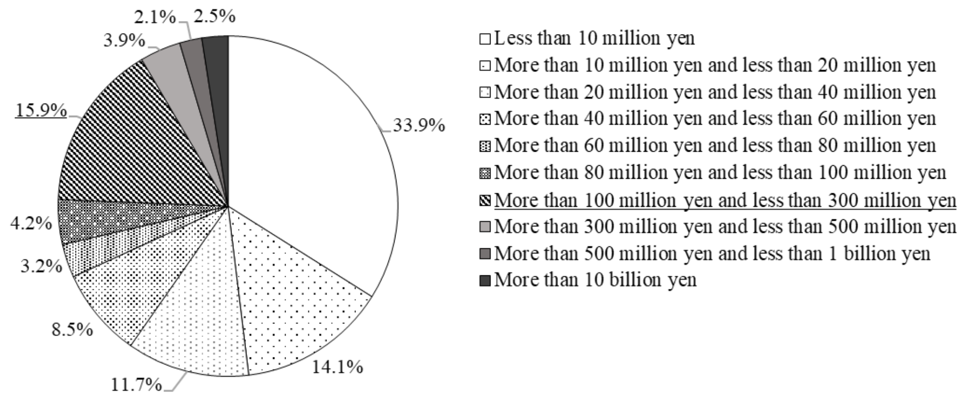


Fig. 2 The trend and breakdown of ERECON's revenue



Based on Data Book on NGOs in Japan 2021 – NGO in Figures (JANIC, 2021)

Fig. 3 Annual revenue size of Japan's International Cooperation NGOs

In 2021, the Japan NGO Center for International Cooperation (JANIC) conducted a survey which was summarized in the "Data Book on NGOs in Japan 2021 - NGO in Figures." The results include that 96 of 283 or 33.9% of international cooperation NGOs operated with annual revenue of less than 10 million JPY as shown in Fig. 3. Forty-five organizations, or 15.9% had annual revenue ranging from 100 million to 300 million JPY which represented the second most common revenue tier. As such, ERECON's revenue scale places it within this tier.

ERECON's trends in revenue to conduct research are presented in Fig. 4. ERECON's predecessor research group valued and placed a strong emphasis on extension programs based on research outcomes which ERECON continues to support. In contrast to ERECON's current funding, the predecessor group had almost no institutional income and relied solely on individual contributions and personal resources. Furthermore, due to an initially weak financial foundation during its early activities, a significant proportion of the funding came from research-related grants. After obtaining NPO status in 2002, and shifting its focus to extension activities, small-scale grants for extension projects became the primary source of ERECON's funding. As a result, revenue to conduct research remained at zero from fiscal years 2005 to 2013. However, since its 2013 designation as a research institution eligible for MEXT Grants-in-Aid for Scientific Research, ERECON began to be awarded grants to conduct research. Revenue to conduct research is quite rare among NGOs, highlighting ERECON's unique position.

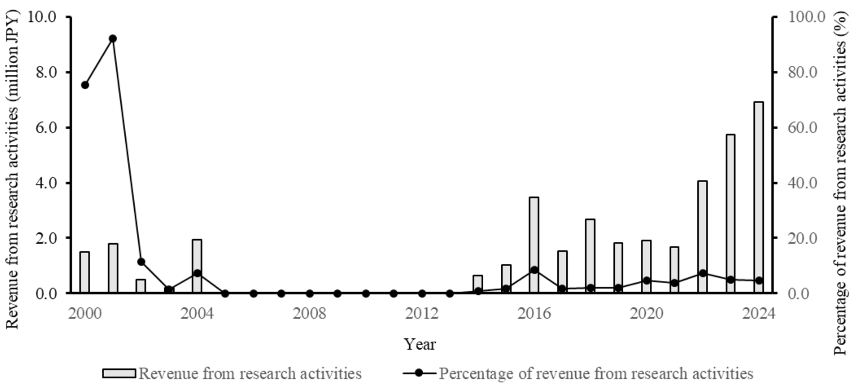


Fig. 4 ERECON trends in revenue to conduct research

ADVANCING SUSTAINABLE DEVELOPMENT THROUGH EXTENSION-RESEARCH INTEGRATION

Contributions to International Academic Collaboration

ERECON plays a pivotal role in advancing international academic discussions and the implementation of practical and sustainable development strategies. ERECON's strongest partnership is with ISERD which ERECON contributed to establish in 2010. ISERD's mission is to contribute to sustainable rural development through social and economic development in harmony with the natural environment and to support the potential for capacity building of local institutions and stakeholders in the rural area supported by academic capabilities and strategies. Over the past 15 years, ISERD has focused on promoting practical approaches to rural development in developing countries and facilitating collaborations among universities, research institutions, and local communities.

The technologies and methods implemented in developing countries must be carefully evaluated from multiple perspectives focusing on customization to meet local infrastructure, education and training capacities, adoption, and other variables to ensure their effectiveness and sustainability. Additionally, it is essential to recognize that the number of researchers and research institutions directly addressing local issues in developing countries is limited further challenging country-by-country successes.

Challenges also remain prevalent within the broader international cooperation NGO sector. As highlighted in JICA's 2008 publication, "Understanding Japanese NGOs from Facts and Practices," many NGOs face significant constraints in financial and human resources (JICA, 2008), which limit their capacity to engage in research activities. Furthermore, and inclusive of ERECON, only 19 of 2,057 or 0.9% of MEXT-accredited research institutions in Japan are NPOs (MEXT, 2024). This underscores the rarity of NGOs that successfully integrate research with extension.

Pioneering Research-Extension Synergy

ERECON is a unique NGO that effectively bridges research and extension activities.

Note: Tboung Khmum Province, Cambodia (August 2024)

Fig. 5 International workshop and symposium on sustainable rural development

ERECON's model includes research that generates evidence-based knowledge, while extension applies this knowledge to real-world, rural contexts through local and participatory approaches. This synergy enhances both academic relevance and real-world and field impact. This model was demonstrated in August of 2024, when ERECON conducted an International Workshop and Symposium on Sustainable Rural Development in Tboung Khmum Province, Cambodia. As demonstrated in Fig 5, ERECON organized collaborative workshops with researchers and local community residents and facilitated social surveys and data collection by applying Participatory Rural Appraisals (PRAs), which informed sustainable rural development strategies. Researchers presented their findings at the symposium fostering dialogue and strategic planning among the researchers and ERECON.

ERECON recognizes the value and potential of young researchers who are motivated by a commitment to community benefit as well as to their academic recognition and growth. ERECON supports young researchers as they engage with residents to uncover latent potential to define, develop, and contribute to sustainable rural development. Such initiatives in the International Workshop underscored the transformative role that ERECON plays in linking academia with real-world challenges. More broadly, ERECON collaborates with local educational and research institutions as well as communities to contribute to regional development through sustainable agriculture and environmental protection initiatives. These activities align with the fundamental goals of the Regional Centre of Expertise (RCE) model to promote sustainable development. The International Workshop was conducted within the framework of RCEs and in particular, partnered with the RCE Greater Phnom Penh to foster knowledge exchange and collaborative development.

LESSONS LEARNED, CONCLUSIONS AND RECOMMENDATIONS

ERECON's 25 years of experience highlights the value of integrating academic and research outcomes with grassroots extension activities. Financial diversification through a blend of extension funding and research grants has enabled ERECON to remain resilient and focused on its mission.

Key lessons learned and conclusions:

・Institutional credibility: The importance of institutional credibility, e.g., experience as an NPO and designation as an organization eligible for Grants-in-Aid for Scientific Research, is crucial in securing long-term funding.

・Internal collaboration: The significance of collaboration among extension, research, and administrative activities cannot be overstated.

・Strategic partnerships: Forming strategic partnerships with RCEs and other agencies and organizations, aids in regionalizing and operationalizing research.

Recommendations:

・Research accreditation: Similar NGOs should seek research accreditation to provide academic/ scientific background for extension activity, and to broaden their funding sources.

・Promote collaboration: Active promotion of cross-sectoral collaboration is essential.

・Strengthen internal structures: Fostering internal structures for financial monitoring and strategic planning should be prioritized.

CHALLENGES AND OPPORTUNITIES AHEAD

ERECON's dual focus on extension and research missions and objectives is unique among Japanese NGOs as demonstrated by its rare status as one of the few MEXT-accredited research institutions among NPOs. While financial and resource limitations remain ongoing challenges, ERECON's innovative approach to integrating academic and practical, real-world efforts is a model for addressing complex global issues. ERECON's long-term focus and commitment to fostering sustainable rural development through research-extension synergies holds immense potential to influence policies, practices, and the broader landscape of international cooperation and contributions from ERECON and other NGOs.

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