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Contents

Research article

Simple Weir Types and Their Prospects for Small-Scale Irrigation Development in Northern Zambia

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Abstract In Zambia, simple weir technology is increasingly gaining popularity as an alternative method for river water diversion among rural small-scale farmers. The now widely-adopted technology was first introduced in the Northern Province region of Zambia to promote small-scale irrigation in local communities. These small-scale facilities are constructed across the width of the river using forest materials such as poles, twigs, thatching grass, and tree bark strips. These types of irrigation structures produce an adequate head of water enough for the diversion of water from the river into a canal conveying water for irrigation. However, simple weirs that farmers have been constructing with forest materials are observed to experience challenges such as breaching, and often break down and collapse within six to seven months. Therefore, the objective of this research was to investigate the characteristics of simple weirs constructed by farmers on a self-help basis for community-based small-scale irrigation schemes in the Luapula, Muchinga, and Northern Province regions of Zambia. We observed the simple weirs constructed before the start of irrigation season (May) and simple weirs built in the operational phase (May-November) and we characterized simple weirs as 1) single-line weir, 2) inclined weir, 3) trigonal weir, and 4) double-line weir. The results show an improvement in the irrigated area by small-scale farmers since the introduction of simple weirs. The findings revealed that challenges that were often encountered on the simple weirs were not solely caused by river flooding, but also by compromises in the construction, inconsistencies in maintenance, and lack of measures to sustain and protect the weirs. It was also observed that simple weirs in operation were regularly maintained and repaired during the irrigation season. Despite the challenges farmers were experiencing with the simple weirs, farmers persistently conducted maintenance activities, replaced worn-out poles and thatching grass and de-silted before the start of the irrigation season.

Keywords simple weir types, small-scale irrigation, river water diversion, arid land

INTRODUCTION

Most of the smallholder farmers live in rural areas in sub-Saharan Africa (SSA) and constitute about 70% of the continent's population in the bracket of poor people (Sakaki and Koga, 2013). This group of farmers is viable, but marginalized and vulnerable since they entirely depend on seasonal rainfall for their agricultural activities. Rainfed farming practiced by small-scale rural farmers produces a low agricultural yield that is frequently influenced by weather-induced changes. The problems associated with rainy season farming are numerous and not limited to 1) farming within 3-4 months in which to produce enough food crops to last up to the following harvest and 2) during the dry season, there is a prevalent shortage of fresh and nutritious crops**.** Based on the mentioned challenges, smallholder irrigation is promoted in SSA as a strategic intervention to enhance agricultural production, productivity, and farm household incomes (Osewe et al., 2020). To accelerate smallholder irrigation development in rural areas in SSA, low-cost irrigation technologies like river diversion simple weirs have been widely promoted for gravity irrigation. One of the gravity irrigation methods that has become popular in rural areas in SSA is river water diversion. The Southern Africa region is cited with a potential irrigable area of more than 3 million hectares (Xie et al., 2021) for river water irrigation schemes.

Simple weirs have been used in establishing community irrigation schemes in rural areas in Southern African countries such as Malawi, Mozambique, and Zambia (Lautze et al., 2017). In the northern region provinces of Zambia, small-scale local farmers construct simple weirs on the rivers in the dry season (May-November). The simple weir irrigation technology has increasingly become one of the irrigation methods among smallholder irrigation farmers in the rural areas in Zambia (Luapula, Muchinga, and Northern provinces) (Colenbrander et al., 2012). This is because simple weirs are community demand-driven technologies, relatively cost-effective, and adaptable to rural environments with the potential for gravity irrigation (suitable topography and surface flowing rivers). In Zambia, surface water from rivers and springs are the primary sources of water accessed by farmers for small-scale irrigation. Farmers have been accessing irrigation water using manually operated technologies like watering cans, buckets, and 20-25ltr plastic containers. However, this type of irrigation has less impact on the irrigated area expanded and irrigation production. Simple weirs have been introduced to develop small-scale irrigation in Zambia. The simple weir irrigation technology has attracted the attention of the majority of small-scale farmers in the rural area.

However, most of the simple weirs constructed by farmers themselves do not continue functioning throughout the irrigation season as many of them are either breached, partially destroyed, or washed away and needed to be either repaired, rehabilitated, or reconstructed after the annual floods. Farmers claim that, based on their experiences with simple weirs, the contributing factors to the challenges experienced include high peak discharges, weakness of structures, small canal intake, and excessive accumulation of sediment particles upstream of the weirs. Since the introduction of simple weirs as an alternative method of irrigation in the northern region of Zambia a decade ago, to date little information has been disseminated on the performance and challenges of these types of small-scale irrigation facilities.

OBJECTIVE

To explore the prospects of the simple river water diversion weirs constructed by local communities for small-scale irrigation in the northern region of Zambia by 1) characterizing the simple weirs structures, construction, and materials 2) studying the challenges of simple weirs, 3) assessing the effectiveness of simple weir maintenance during and before the irrigation seasons, and 4) assess the impact of the simple weir on small-scale irrigation development.

METHODOLOGY

Study Area and Data Collection

The study was conducted in Zambia's northern provinces shown in Fig.1. Geographically, Zambia lies in the tropics at an elevation of 1,200m above sea level with a sub-tropical climate due to its latitude and high-altitude location. The climate in Zambia is characterized by three distinctive seasons all year, dry and hot (August to November), dry and cool (May to August), and a wet rainy season (December to April). Zambia is divided into three agroecological zones with Zone III, covering the northern region of Zambia, receiving the highest amount of rainfall between 1,000 mm to 1,500 mm per year (Brigadier et al., 2015). The rainy season increases both in intensity and duration from the southern region to the northern region. In Zambia's northern region, surface flowing water is sufficient to support dry-season irrigation.

Fig. 1 Location of Luapula, Muchinga, and Northern Provinces in Zambia

The collection of primary data was conducted through discussions and interviews with agricultural extension officers, farmer groups, and simple weir users. The study reviewed the literature on small-scale irrigation development, focusing on low-cost irrigation technologies in rural areas in Zambia. The primary data used in this study was collected from 55 sites in three provinces. The study area was clustered into three provinces and 55 simple weirs were randomly selected from Luapula province 22 sites (72 participants), Muchinga province 15 sites (31 participants), and Northern province 18 sites (69 participants). 172 simple weir users participated in the discussion in Table 1. The data was collected between August 20th and November 30th, 2022.

Table 1 Location of simple weir sites, number of simple weirs, and users who participated

Province	Number of simple weirs and sites	Number of simple weir users who participated
Luapula	22	72
Muchinga	15	31
Northern	18	69
Total	55	172

Simple Weirs Small-Scale Irrigated Agriculture

During the seven-month dry season, small-scale farmers resort to irrigation to supplement rain-fed agricultural production. Vegetable growing is the common system of agriculture between May and December in rural areas in Zambia. This type of agriculture during the period is the principal livelihood for the majority of the people in the region. Crops that are produced using simple weir irrigation include cabbage, tomatoes, onions, watermelons, carrots, and Irish potatoes. These crops are generally irrigated and widely cultivated on sites supplied with river water diverted by simple weirs.

RESULTS AND DISCUSSIONS

Characteristics of the Simple Weir Types

In Zambia, simple river water diversion structures are usually constructed of simple materials of poles, thatch grass, and clay soil bunds (Food and Agriculture Organization, 2014). Although simple weirs are generally constructed for one irrigation season, they are viable facilities. Farmers are usually advised to dismantle the weirs as a coping strategy to flood damage and store material to avoid depletion of forest for the reconstruction in the following irrigation season. Figure 2 shows four simple weir types that are conventionally used for irrigation and are part of improved methods for small-scale irrigation (Bekele et al., 2006).

(1) Single-line weir: It consists of a single line of wooded poles constructed across the width of a river. This weir type is suitable for rivers which are wider and shallower. It is recommended on hard riverbed foundations.

(2) Inclined weir: This weir has one main pole placed horizontally across the width of a river and supported by riverbanks of relatively the same height. It is recommended on rivers which are slightly deeper and

(3) Trigonal weir: The weir consists of several tripod stands constructed with round poles. The tripod stands are aligned across the width of the river to form a weir. This weir type is suitable on rocky riverbeds.

(4) Double-line weir: This weir type has two parallel lines of poles constructed across the river, spaced at 0.2-0.5 m. The space between the parallel lines is filled with clay soil to minimise water loss by seepage.

Fig. 2 Characterization of simple weir types and constructions methods: (1) single-line weir, (2) inclined weir, (3) trigonal weir, (4) double-line weir

Single-Line Weir

Single-line simple weirs are constructed using round forest poles (0.8-0.1 m diameter) and adult wrist-size bundles of thatch grass (Fig. 2-1). A single row of poles is embedded vertically into the riverbed across the width of a river. According to available data, the intra-spacing of poles ranges between 0.5 to 1 meter from each other across the river. The wooden poles are connected by purlins tied across using tree bark strips. The weir is reinforced at the base of the pole line by ramming clay soil. Thatching grass is used to reduce water seeping through the weir. The weir causes the water level to rise upstream and diverted into the canal off-taking on its upstream side.

Inclined Weir

The inclined weir is constructed where the narrow and straight river section has a good formation of riverbanks on both sides and relatively the same height. One pole (0.2-0.3 m diameter) is used as a cross member where slanted poles (about 0.1 m in diameter) are supported (Fig. 2-2). The cross-member pole is placed horizontally across the river to the preferred flood height and anchored by the riverbanks. The slanted fixed poles are approximately inclined at 60^0 angles to the river flow. The slated poles are connected using the purlins and covered with thatching grass to minimize water loss downstream. Clay soil is compacted at the base to provide anchorage and reduce seepage. The water rises above the historical flood level and is diverted into the canal conveying irrigation water.

Trigonal Weir

This type of weir is recommended on riverbeds with stones or hard rock foundations. A single tripod is constructed using 3 by 2 m (approximately) long poles and tree bark strips. The three poles are connected at the top of one end. The front with two long poles covered with thatch grass faces upstream, the other pole shunts downstream to provide stability. Several tripods are constructed and later aligned in a single line across the river to form a weir (Fig. 2-3). Water is prevented from being lost through seepage using the thatching grass. Depending on the width of a river two or more tripods can be erected across. During the rainy season, the tripods are removed from the river channel and stored for use in the following irrigation period.

Double-Line Weir

The double-line weir has two parallel rows of round poles placed vertically into the riverbed (Fig. 2-4). The space between the two parallel rows of poles across the river is approximately 0.2 to 0.5 meters (Food and Agriculture Organization (FAO), 2015). The space between the two rows of poles is filled with clay soil to reduce water loss through leakage. The double-line weir impounds flowing river water in a small earth pond formed upstream. Water is diverted from the ponds and supplied downstream to the fields. The double-line weir can also be used as a fishpond. Apart from diverting water for irrigation, the double-line weir can also be used as a crossing point.

Analysis of Reasons for Adoption of Simple Weirs for Irrigation

Information and farmers' experiences in Figs. 3 and 4, were collected from different sites between 2014 and 2017. Figure 3 summarises the reasons farmers expressed about the simple weir as a technology for irrigation. The findings of this study included exploring the motivation and interest of the local farmers in simple weir irrigation. The results show multiple reasons presented in Fig. 3 for using simple weirs for small-scale irrigation development. The responses presented are based on the information collected from the farmers. It was found that about 26% of the population of small-scale farmers using simple weirs stated easy construction, and 19% mentioned the use of local materials of forest products like poles and thatch grass in the construction of simple weirs as a motivating factor. 15% of simple weir users' interest in simple weir was about enhancing household livelihood while 14% of the farmers stated agricultural activities throughout the year, a vital reason (Bjornlund et al., 2019). About 13% of the farmers expected improvement in the area irrigated while other farmers stated a reduction in manual labor required to lift water for irrigation from the source to the crops. The reasons given by farmers for adopting simple weirs for irrigation purposes substantially varied. These responses were noted during the site visits and interviews. The responses farmers advanced according to (Colenbrander et al., 2012) represent the solutions seen by farmers as most promising for developing low-cost irrigation systems in rural areas. According to the responses of the farmers interviewed, easy construction, livelihood diversification, and increasing land under irrigation have been the basis for adopting simple weirs in the northern region of Zambia.

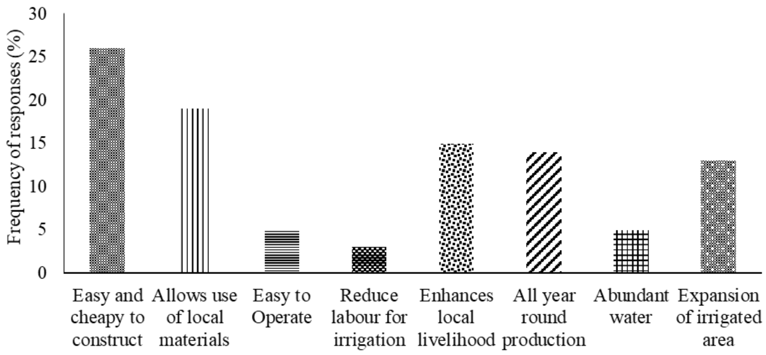

Fig. 3 Farmers' responses on the adoption of simple weirs

Analysis of the Attributing Factors to Stagnant Development of Small-Scale Irrigation and Low Adoption of Simple Weirs in the Northern Region

Figure 4 summarises the responses of the farmers from the study sites with simple weirs used for irrigation in the northern region province of Zambia. The responses varied with 18% of the farmers stating weir breaching challenges, 17% of the farmers expressing weir leakages as their concern, and 27% of the farmers mentioning high labour demand for repair and maintenance as challenges (Dakpalah et al., 2018). While 5% of the farmers stated deforestation as more poles are required to be harvested for construction from the forest. Fig. 4 Farmers' responses collected from simple weir sites.

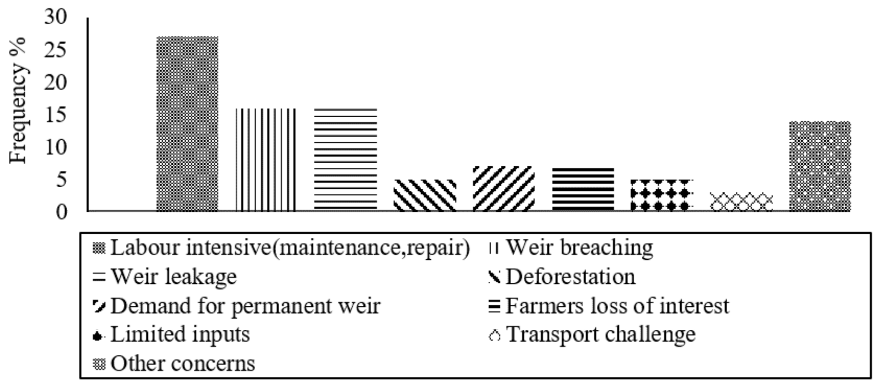

Fig. 4 Farmers' responses collected from simple weir sites

Analysis of the Maintenance Activities of Simple Weirs by Farmers

Figure 5 shows the flood damage control strategy farmers practice at the end of the irrigation period (December). Based on the observation during the site visits, it was observed that about 7% of the total number of weirs were deliberately dismantled, 47% partially dismantled and 50% of the total number of the weirs remained un-dismantled. Though dismantling of weirs during the off-season is recommended as a flood damage control measure, it is not implemented on all simple weirs because weirs are sometimes used to divert river water to supplement rainfall during dry spells.

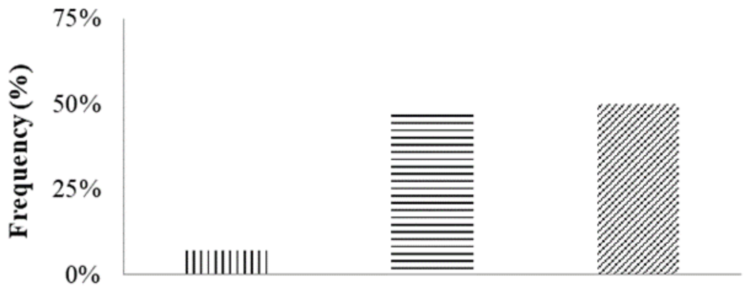

Fig. 5 Maintenance activities carried out on simple weirs by farmers

Simple Weir Impacts in Promoting Small-Scale Irrigation in Northern Region

Figure 6 refers to the period between 2014-2016, in which 876 hectares were brought under irrigation using simple weirs. In 2014, 2015, and 2016, the land expanded for irrigation in hectares was 292, 214.6, and 369.4 respectively. In 2016, there was a significant increase in the area brought under irrigation largely due to farmers' increasing interest in simple weirs and farmer-to-farmer knowledge sharing and skill transfer (Japan International Cooperation Agency (JICA), 2017).

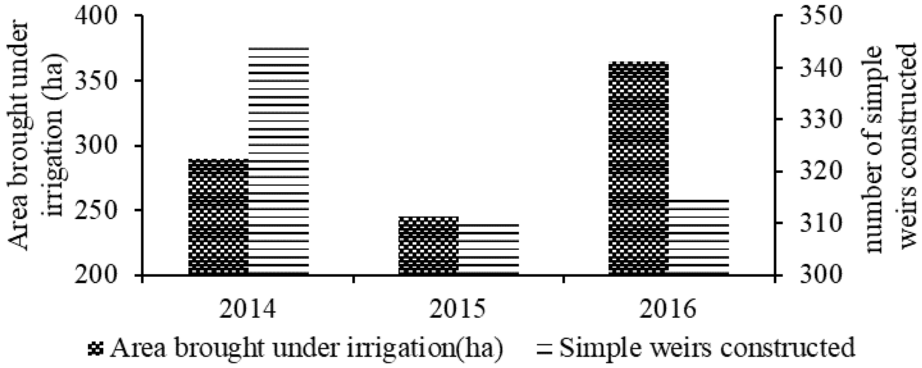

Fig. 6 Number of hectares irrigated by diverting river water using the corresponding number of simple weirs

CONCLUSION

This study focused on the simple weirs that have been introduced in the northern region of Zambia. Simple weirs characterized by four types single, line, double line, inclined, and trigonal weirs are increasingly becoming popular in small-scale irrigation development in the northern region rural areas in Zambia. The use of simple weirs to divert river water for irrigation is relatively ‘’new’’ in Zambia. The use of locally available materials of forest materials and the need to supplement household income and food requirements has motivated the majority of small-scale farmers in the northern region to engage in dry season irrigation (May-December). Despite the promising results in enhancing irrigation water accessibility, there are still some structural challenges with simple weirs. This study suggests the need for improvement in the construction and selection of construction materials for simple weirs.

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Research article

Development of a Simple-Concept Water Allocation Model at the Farm-Block-Level for Efficient Water Management

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Abstract It is crucial to establish appropriate water management in agriculture. Due to financial difficulties, it is also necessary for farmers to work together with government agencies in water management. Existing water allocation models, however, require much effort to collect data. They are also black boxes difficult for farmers to understand, which may discourage farmers from participating in irrigation planning. In this study, we attempted to construct a farm-block-level water balance model with a simple tank model concept and easily collectible data. The model consists of two parts that reproduce the water distribution process from the farm block intake to each field (Canal Tank Model; CTM) and the water balance process in the paddy field (Paddy Tank Model; PTM), respectively. The model coefficients were identified using data from 2002 to 2003, and the model validity was evaluated using data from 2004 and 2005. The CTM coefficients were identified for 2002 and 2003 because of the different land use patterns. The CTM runoff coefficients and hole heights were changed on days when the farmers were considered to have operated diversion ratios significantly. The PTM coefficients were identified using the SDFP method and trial and error referring to the groundwater level. However, the PTM seepage holes were fixed to the corresponding values that the vertical seepage was approximately 5 mm/d based on the on-site survey. As a result, despite the arbitrary water manipulation by farmers, the same CTM coefficients for 2002, 2003, 2004 and 2005, when the land use pattern was similar, were able to reproduce the water allocation well. This water allocation model can be used to estimate the optimal delivery water management rate and to quantitatively evaluate the excess water withdrawal resulting from the labor reduction in water management.

Keywords water balance model, excess water withdrawal, participation irrigation management (PIM), prediction of water demand

INTRODUCTION

More than 90% of the total irrigation water is used for rice production (Khepar et al., 2000). However, the Organization for Economic Cooperation and Development (OECD) has addressed the idea that irrigation water is consumed unproductively and inefficiently (Fujimoto and Tomosho, 2003). On the other hand, recently, participation in irrigation management (PIM) is under great practice around the world. This method is for all farmers to get enough water, which is difficult to achieve with a top-down system, because of the financial pressure to maintain the irrigation system and the difficulty of taking care of fringe in the system by only the government (Saito, 2010). Yamamoto (2005) recommended that water use efficiency during abnormal dry spells should be improved by promoting PIM in paddy field irrigation in the Asian monsoon region. Irrigated water allocation models or water balance models become one of the decision-making support systems for SVP (Shared Vision Planning) in PIM. Murase and Kawasaki (2004) suggested that when consensus gets formed, optimization and equity become essential factors. Trade-offs achieve equity among the interests of stakeholders under optimized conditions. It suggests that equity is only contented once optimization is contented for water allocation. Then, the water balance components need to be quantified through field experiments. However, quantifying water balance components are often complicated because of the excessive time and expenditure involved in the execution (Khepar et al., 2000), especially in developing countries where water scarcity is a common phenomenon and optimized water allocation is strongly demanded.

In addition, the water balance model in a small district at the end of an irrigation system in which farmers' water demand finally needs to be met should be simulated to make satisfactory decision-making. In the case of open ditches, taking water into paddy fields is related to each other field. Thus, the degree of freedom of water management in each paddy field declines (Toyota et al., 1984). Toyota et al. (1984) declared that this agreement between water management in ditches and fields greatly affected water intake into paddy fields. Hence farm-block-level analysis was necessary. The smaller the analysis area, however, the more significant the impact of human disturbance, making it difficult to simulate water allocation in small-scale fields. The delivery water requirement would differ from the degree of each farmer's diverging operation at a small canal (Furuki et al., 1979). This large human activity impact caused a few model developments of simulating water allocation at a farm-block level.

To explain human activity with a physical model could be a fault, but a statistical model might be acceptable. The tank model could reproduce this uncertainty, described as a semi-physical and semi-statistics model.

OBJECTIVE

This paper aims to develop a conceptual water allocation model acceptable to some land-use and irrigation systems changes and access to understanding decision-making processes. This model calculates the water balance and allocating process in the small-scale paddy fields area through the semi-physical and semi-statistic tank model.

METHODOLOGY

Target Area

The study area is typical paddy fields (farm-block-level, about 30 ha) located in the middle area of the Chikugo River in Fukuoka Prefecture, Japan (Fig. 1).

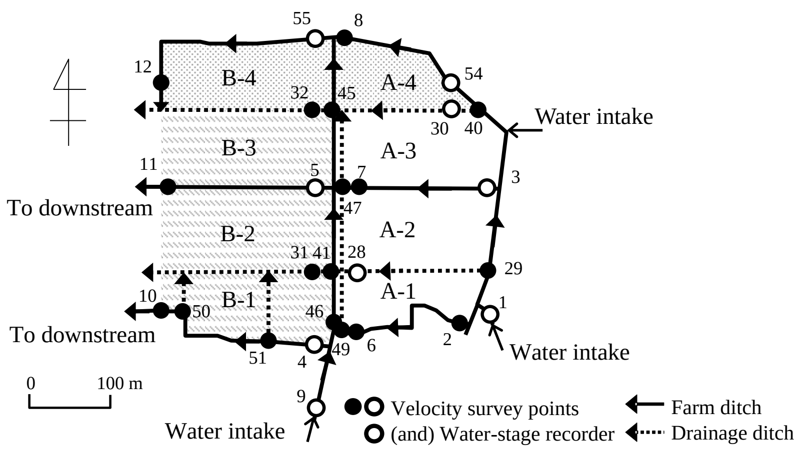

Fig. 1 The irrigation system and survey points in the study area

The number indicates each branch or release point. Irrigation started from three points (Nos.1, 3, and 9). The black and white circles show the survey points where water discharge was measured weekly. The water-stage recorders were installed at the white circle points. The different colored hatches describe the targeted areas for irrigation intakes water from three points.

The area was separated into A- and B-blocks by north and south roads. Moreover, each block was broken into four sub-blocks corresponding with field-block-level by north and south running farm roads and ditches. Each sub-block was regarded as one big paddy lot in this research. The study area had changed its crop planting (land-use) pattern. The land-use pattern was similar in 2002 and 2004 when the whole B-block cultivated the soya bean, and in 2003 and 2005 when part of the B-block (B-2 and B-3 sub-block) was used for the soya bean. The land-use changes made the water allocation complex and significantly affected the model parameters.

Measurement of Water Flow in Ditches

A propeller current meter and water stage recorders measured the water velocity and water level in only one direction in a branch point in the ditches (Fig. 1, B-direction). The former measurement was conducted once every week and the latter were recorded hourly. The scale observed the water level simultaneously with the propeller measurement, multiplied by velocity to estimate the observed discharge. The balance equation calculated the water discharge in the other direction (D-direction) in a branch point from the observed discharge, which is also considered an observed flow in the model. The water level measured hourly by the water stage recorder was converted to the discharge by using the following approximate formula obtained from the relationship between the weekly measured flow and the water level:

$$Q = \alpha h^{\beta} \tag{1}$$

where Q is discharged, h is measured water level, α and β are coefficients of approximate expression.

Measurement of Water Balance in Paddy Fields

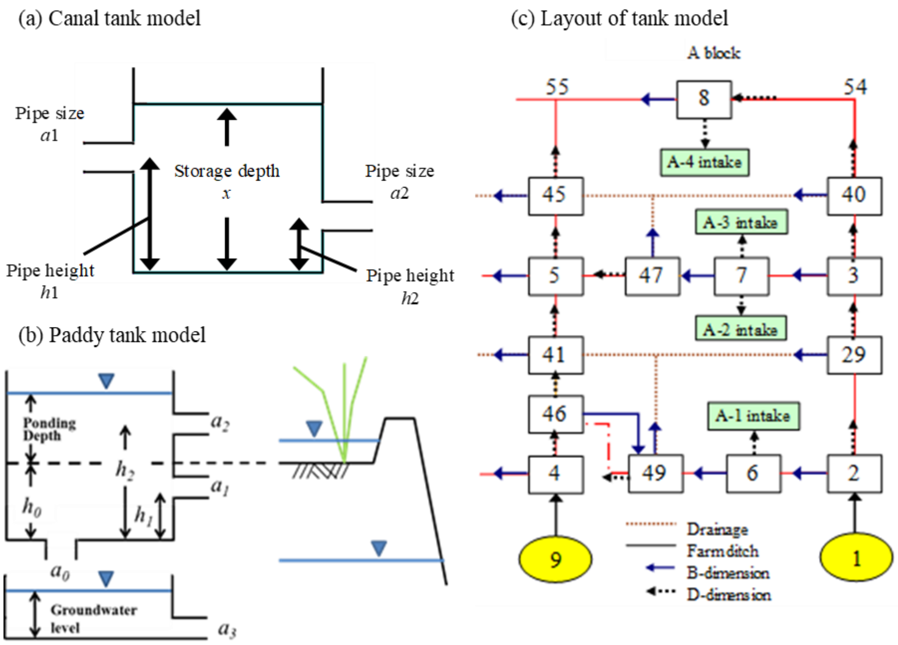

Fig. 2 The structure of the canal tank model (CTM, a), paddy tank model (PTM, b) and its layout in the allocation model (c)

Each CTM was installed at the branch point and PTM was placed in each block. B-direction was where water velocity was measured, and D-direction was where the water flow was calculated by water balance.

We targeted three paddy fields from A-2, B-2, and B-3 sub-blocks. The ponding water depth was measured hourly by a data logger. The precipitation (R) was observed at the nearby A-2 sub-block.

The elevation of the overflow weir at the outlet was measured weekly because a farmer did not frequently operate the outlet and used to calculate the amount of water release (Q_{out}) by overflow computing. Evapotranspiration (ET) was estimated by multiplying the ET ratio and potential ET by the Penman method from meteorological data. Percolation (P) was estimated by the water balance equation as:

$$P = Q_{in} + R - ET - Q_{out} + \Delta h \tag{2}$$

where Δh was a variation of ponding depth. All values were averaged or totaled daily. N-type water requirement survey evaluated the groundwater recharge from paddy fields. The vertical percolation was about 5 mm/d at the middle point in the field free from levee seepage. The groundwater level was measured hourly near No.1 (which was used to calibrate the paddy tank model). The amount of water runoff from paddy fields at block level was estimated from observed discharge in the drainage ditches (Fig. 1) by outflow minus inflow in the drainage.

Model for Water Allocation Through Ditches

The whole water distribution process in the study area was represented in two parts; in ditches and inside paddy fields. At the first step of computation of water allocation, the canal tank model (CTM, Fig. 2a) described the water distribution process through ditches, CTM installed at each branch point (Fig. 2c). The pipe size in CTM represented the water dividing rate at a branch for each direction, including wastewater ratio (e.g., branch point No.3). The outflow y_i from each i-th number of a pipe was computed as:

$$y_i = a_i(x - h_i)^{1.5} \quad (x \geq h_i) \tag{3}$$

where a_i is the coefficient of discharge, x is the storage water depth, h_i is the pipe height, and an output flow occurs only when the storage water depth is higher than the pipe height.

The parameters were calibrated manually but in a rational manner. The water-dividing operation depends on the land-use pattern and rice growth stage (e.g., rooting, ripening, etc.); thus, the pipe size parameter was determined by each period manual to consist of observed discharge. The biggest impacts on the water allocation operation were mid-summer drainage and water stopped before maturation. The timing of changing parameters was decided from the paddy water depth of the survey fields. The heavy rain causing excess irrigation water also changed the drainage operation at water release points. CTM parameters were calibrated in 2002 and 2003 (calibration period) and validated in 2004 and 2005. The parameter determined in 2002 was applied to 2004 with a similar land-use pattern year, and the parameter in 2003 was applied to 2005 for the same reason.

Model for Water Balance in Paddy Fields at Sub-Block-Level

The paddy tank model (PTM) structure is shown in Fig. 2 bottom left. The pipe of a_0 represented a vertical percolation reaching the groundwater: a_1 represented a lateral percolation through the levee draining to the drainage ditches: a_2 described water release from a surface and a_3 was for groundwater flow. The sum of lateral percolation and the water release defined the runoff from paddy fields. This simple model can adapt to a flexible scale. For example, Jayadi et al. (2000) applied one PTM to 300 ha paddies. In this study, PTM described block-level paddy fields, i.e., A-block and B-block.

The input data for PTM were precipitation, ET, and paddy water intake calculated from CTM. The target output for determining parameters was the groundwater level (GWL). SDFP (Kadoya and Nagai, 1980) and the trial-and-error method decided the parameters. The vertical percolation a_0 was determined without the optimization method because the N-type water requirement was about 5 mm/d; therefore, a_0 was estimated at 0.070 or 0.075. The ponding depth, the height of the levee, and the outlet overflow weir height in the site were considered to decide the storage depth in the upper tank. The parameter calibrated by data in 2002 and 2003 was applied to data in 2004 and 2005 for testing the versatility. As with CTM validation, the identified model coefficients for 2002 were applied to the coefficients in 2004, when land use was similar, and the coefficients identified in 2003 were applied to the coefficients in 2005. Hereafter we call 2002 and 2003 a calibration period and 2004 and 2005 a validation period.

RESULTS AND DISCUSSION

Applicability of CTM

The simulated water allocation through irrigation ditches by CTM in calibration terms showed good agreement with the observed flows (Fig. 3a), especially at the endpoint of the irrigation system No. 55 (Fig. 2c) where recorded hourly flow (absolute errors was 5.5 mm/d). No. 46 reproduced reverse flow when a reversal of hydrodynamic gradient occurred between adjacent branches, and water flowed through the irrigation ditch opposite the normal flow direction.

CTM well-predicted water allocation in 2004 and 2005 (Fig. 3b, absolute error at No.55 were 6.3 and 18.0 mm/d, respectively), indicating that CTM has robust reproducibility to some extent regardless of drought season or rainy season because 2002 was drought and 2004 was rainy season. Also, good agreement suggested that water allocation operation was similar when the land use pattern was similar.

The CTM concept is apparent, simple, and easy to customize. CTM merely requires discharge data in irrigation ditches. Taniguchi and Satoh (2006) described that grasping the actual water usage required a series of observations of quantitative water allocation and enormous instruments and efforts. CTM can be one of the resolutions for these problems. Resource Division Planning Department Kyushu Agricultural Administration Office (1997) applied the CTM to about 4,600 ha district in Kasegawa, Saga prefecture, to analyze water distribution. The more the command area becomes extensive, the more the number of operation points changing the water-diverging ratio increases. Consequently, diversion operation increases its randomness and decreases the effect on the tank parameters, leading the parameters to be decided at one value. CTM has to be improved in the following two aspects. First, the present CTM could not precisely explain the reverse flow that occurred frequently and extensively. Second, long-term data needs to be collected to increase the accuracy of CTM's prediction.

Applicability of PTM

The estimated GWL from PTM demonstrated well fitted with the observed value, shown in Fig. 4a. PTM also simulated the water runoff from A-block and its relative error was around 50% and 28% in 2002 and 2003, respectively (Fig. 4b). An unsteady flow and seepage from the weir shutter were an obstacle to measuring the drainage discharge, causing some outlier values, and leading to the fitting error being worse. However, the calculated flow reproduced the other observed trend well, and the identified parameters could be used for prediction.

The prediction of GWL and runoff from paddy fields, shown in Fig. 4, demonstrated good agreement with observed values and proved PTM’s versatility. However, although simulated GWL in 2004 well matched with observed GWL, the predicted runoff had difficulties at reproducibility. The relative error of runoff in 2004 was about 200% due to the failure to reproduce the small observed values in the denominator of the relative error equation. The high error in 2004 was caused by using the same parameter through 2004 and 2005 even though the land use pattern changed. However, the prediction in 2005 showed good fitting simulation both for GWL and runoff.

Future development was that the model's sensitivity to land use should be improved. In this study, the block level was considered to be one paddy tank. However, the sub-block could be regarded as one paddy tank to improve sensitivity, and the model would deal with various land use patterns in more detail. Furthermore, the paddy lot management schedule should be taken for calibrating PTM parameters into account. The PTM coefficient could be changed according to the rice growing stage or water management schedule.

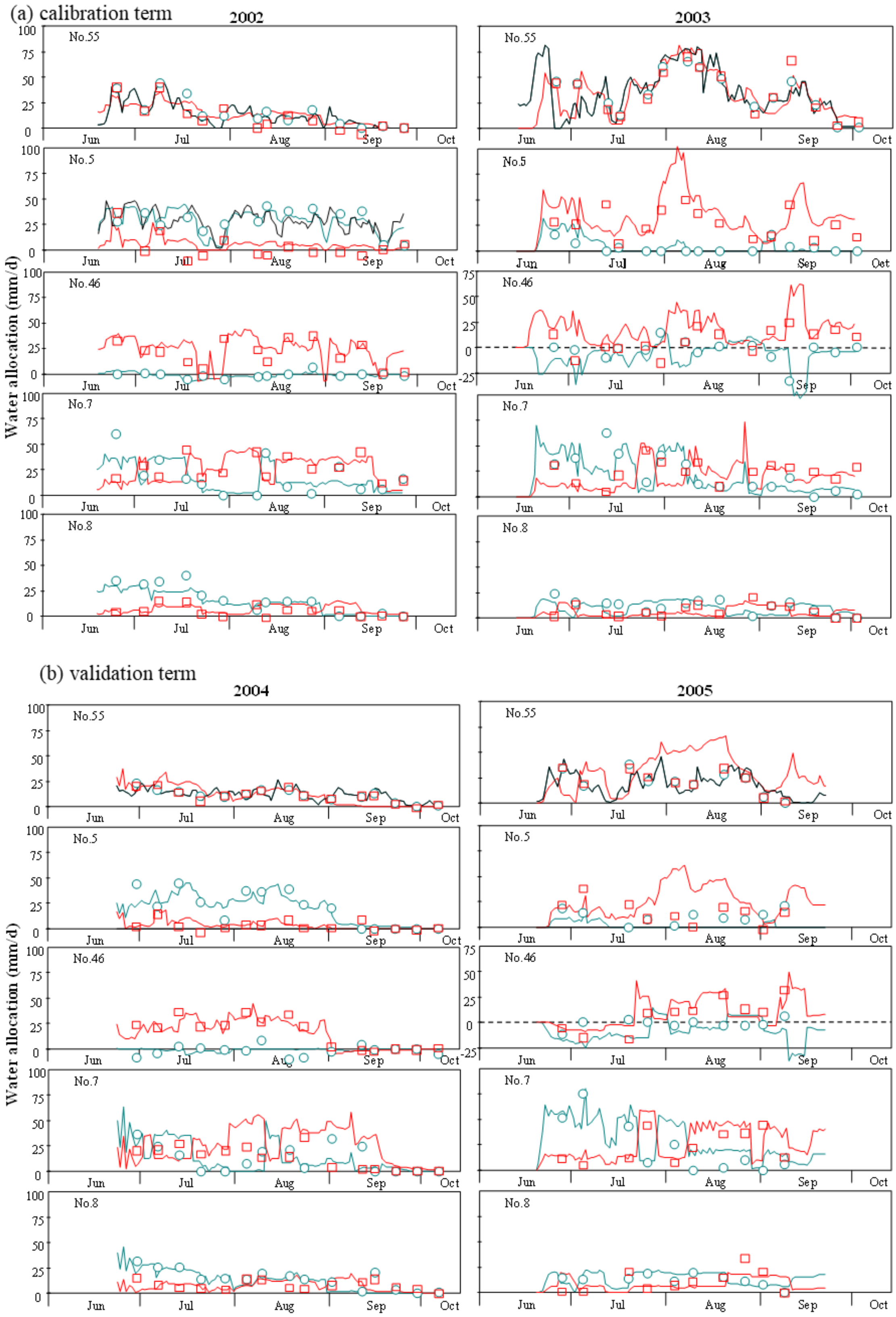

Fig. 3 Water allocation in ditches

The black solid line, outline of a green circle, and red square stand observed flow in the B-direction and D-direction, respectively. The green and red solid lines represent CTM's simulated values in B- and D-direction, respectively. The minus value at No.46 demonstrates the reverse flow.

In this study, the simulation model was developed to predict water allocation and balance with easily available data at the farm block level. Kuo et al. (2006) calculated the water demand of paddy and upland crops by CROPWAT designed by Smith (1991) at the ChiaNan Irrigation Association that could estimate the soil moisture but not include the paddy lot water management or delivery water management, thus could not evaluate the water productivity. The present model in this study can estimate and consider both lot water management from PTM and delivery water management from CTM. The proposed model can also apply to farm and large-scale levels, including complex land use areas.

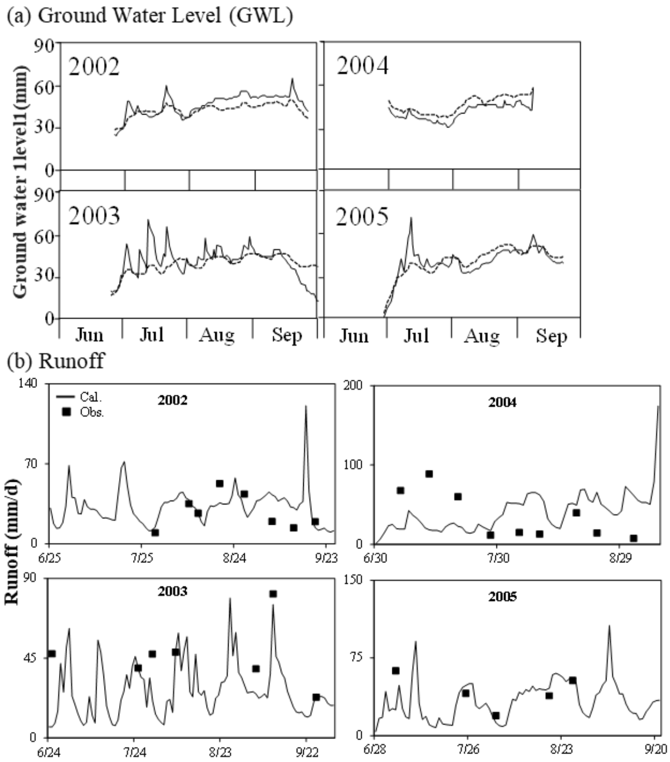

Fig. 4 Comparison between calculated and observed GWL (a) and water runoff (b) from paddy fields in the calibration term (2002-2003) and validation term (2004-2005)

Solid lines are calculated and dotted lines are observed values (a).

The developed model becomes a decision-making support system for SVP (Shared Vision Planning) in PIM. Murase and Kawasaki (2004) suggested that optimization and equity were essential for forming consensus. The equity is comforted by trade-offs among stakeholders' interests under optimized conditions. This model can optimize water management or land use patterns by simulating the water balance and allocation process. Thanks to the tank model's semi-physical characteristics, the participant intuitively understands the operation of the water diversion and water balance component to which the model parameters correspond.

CONCLUSION

This study calculated water balance through irrigation ditches and paddy fields in the area using understandability concepts and accessible collecting data by connecting the canal tank model (CTM) to the paddy tank model (PTM). An easily understandable and collectible data structure is essential for the decision-making process. The present model parameters are consistent and capable of predicting water allocation and balance with similar land use patterns. For example, a simulation by CTM and PTM under a scenario of saving irrigation water because of a lack of precipitation could predict how the groundwater level would change. If the groundwater level could be predictable, it could avoid wet or drought injury to the crop.

Using available data for this type of study is important because it is difficult to gather large amounts of actual data on water allocation at every branch of the irrigation system every week for several years. This paper aims to build a model based on a simple tank model concept and data that can be easily collected. The data used in this study spans from 2003 to 2005. Nonetheless, we have demonstrated that it is possible to develop an accurate model for our intended purpose, as the method of collecting actual data has remained consistent even today. In the future, the remaining issue is to accommodate the changing land use, and the PTM parameters should be calibrated at each paddy, upland, and greenhouse (Kato, 2005). To some extent, the tank model parameters have generality attributed to the semi-physical character, which means that human activity to change irrigation management can be reproduced by the present model.

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Research article

Clarification of Water Use under the Complicated Irrigation System and its Modeling in the Boribo-Bamnak River Basin, Cambodia

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Abstract Effective, equitable, and sustainable management of water resources in river basins requires clarification of the current river basin situation and potential water use and water balance challenges. This study performs a water balance calculation involving an analysis of the appropriate water distribution of the Boribo-Bamnak River basin in Cambodia. This river basin covers the Boribo and Bamnak basins, both of which are interlinked by the Bamnak headworks. Together, this constitutes an integrated irrigation and drainage system. The Soil and Water Assessment Tool (SWAT) model was used to simulate rainfall-runoff in the Boribo-Bamnak basin over a study period of nine years (2010-2018), whereupon a simulated daily streamflow was applied to the water balance computation in the river basin according to the water distribution ratio at Bamnak headworks. The SWAT model yielded NSE, PBIAS, and RSR values of 0.55, 9.70, respectively, and 0.67 for model calibration. It also obtained values of 0.51, 3.70, and 0.70 for model validation of the three quantitative statistics, NSE, PBIAS, and RSR. The results of the calculated water balance indicate that although the Bamnak and Boribo Rivers have abundant water in the wet season, they have faced water shortages in the dry season during every year of the study period except 2016. Irrigation safety during the dry season is always low (approximately 10%). Attaining a desirable safety level of 80% in all existing irrigation areas would require additional water resources of approximately 6.0×10^6 m^3 for the Boribo River basin and 10^7 m^3 for the Bamnak River basin. In light of the above findings, this study provides recommendations for coordination strategies to improve water resource management and development plans in the river basin.

Keywords water balance, water distribution, SWAT model, water shortage, irrigation, safety

INTRODUCTION

Irrigation is a mechanism for increasing agricultural production, thereby increasing the income of rural poor regions, and developing the economy. In this regard, it is a focus of the Royal Government of Cambodia as described in the Rectangular Strategy (CSIRO, 2013), a planning and development document. As a result, Cambodia has witnessed the planning and implementation of many water resources and irrigation development in recent years, many of which have focused on river basins (Masahiko, 2013). However, the rapidly increasing demand for water has intensified the competition for water resources, highlighted concerns about the equity of water allocation, the sustainability of water usage, social friction among water-user communities, and the long-term sustainability of water resources and environmental impact of irrigation (MOWRAM and JICA, 2014). Indeed, the Boribo-Bamnak River basin (MOWRAM, 2018) has been affected by a large increase in water use demand due to the expansion of irrigated areas, as well as competition for water allocation between upstream and downstream users.

Thus, it is crucial to address water use by assessing water supply and water demand for appropriate management and planning of water resources in the basin. Researchers have used many methods to assess and predict the intra- and interannual availability of water resources within a catchment. Among these methods, decision support tools, such as hydrologic models, can help researchers to develop better management strategies for local and regional water resources (Chea and Oeurng, 2017). Hydrological models have been developed to help calculate water discharge more accurately, easily, and quickly than when using traditional measurement methods. One such method is the SWAT (Soil and Water Assessment Tool) model, which is a basin-scale model integrated with ArcGIS to improve the accuracy of simulated streamflow from rainfall and the physical properties of a basin (Ang and Oeurng, 2018). Regrettably, conventional water supply-oriented simulation models are often insufficient for addressing contemporary water resource management problems (Yates et al., 2005). Therefore, this study uses the SWAT model to simulate streamflow in a catchment and then performs the computation to describe the water balance and amount of water available for allocation under current conditions.

OBJECTIVE

This study aimed to (1) predict water balances involving different scenario evaluations of water distribution at Bamnak headworks in the Boribo-Bamnak River basin, and (2) clarify current water management problems by studying water distribution at Bamnak headworks.

METHODOLOGY

Study Area

The Boribo-Bamnak River basin is located within two provinces of Cambodia, namely Kampong Chhnang, and Pursat, and has a total catchment of 1258 km^2 (Fig. 1). It covers the Boribo and Bamnak River basins, both of which are interlinked at Bamnak headworks (located on the Bamnak River, an upstream tributary of the Boribo River) and constitutes an integrated irrigation and drainage system (Fig. 2). The climate in the basin is influenced by tropical monsoon systems with distinct wet and dry seasons. The wet season, from May to November, receives approximately 90% of the total annual rainfall, ranging from 1200 mm to 1800 mm, and the dry season, from December to April, is characterized by the prevalence of hot and dry air with high potential transpiration demands. In the basin, agriculture is the predominant water-consuming sector and twelve main irrigation schemes have been developed; these have been classified into six schemes using water from the Bamnak River (Pursat Province) and the other six schemes using water from the Boribo River (Kampong Chhnang Province) as shown in Table 1.

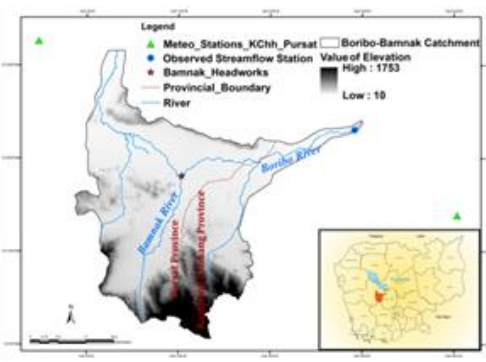

Fig. 1 Study area

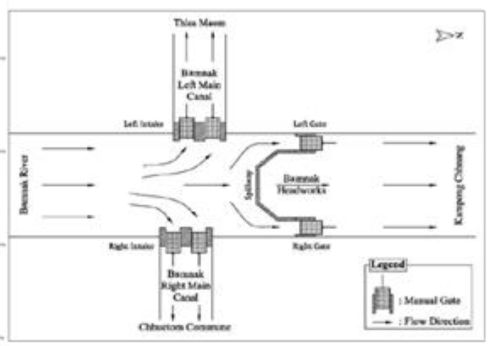

Fig. 2 Schematic Bamnak headworks

Table 1 Identified irrigation schemes in the Boribo-Bamnak River basin

No	Scheme Name	Total Command Area (ha)	Total Farmland Area (ha) Using Water Irrigated from the Target Rivers		
			EW	***W***	***D***
I. Bamnak River (Pursat Province)					
1	Bamnak	6,000	600	2,400	1,122
2	Chamkar Krouch	350	100	100	-
3	Kampong Lor	130	30	100	70
4	Thlea Maom	3,500	500	2,000	-
5	Tram Mneash	1,200	120	1,080	30
6	Trapeang Khley	300	100	200	-
	Sub-total	*11,480*	*1,450*	*5,880*	*1,222*
II. Boribo River (Kampong Chhnang Province)					
1	Achang (1)	10,300	-	1,400	750
2	Dambok Krahorm	150	-	-	150
3	Kamping Tatao	700	-	300	700
4	Lum Hach	3,289	-	3,289	-
5	O Rolus	640	-	640	-
6	O Chenhchraim	170	-	170	-
	Sub-total	*15,249*	-	*5,799*	*1,600*
	Total	**26,729**	**1,450**	**11,679**	**2,822**

(1) Including four sub-schemes: Banteay Thlok, Kum Reab, O Sanlang, and Svay Ka'er
EW: Early wet season rice, W: Wet season rice, D: Dry season rice
Sources: (1) MEIHO Engineering Inc. 2018. Final report, Survey on basic information in river basins (phase 3), JICA; (2) Field study in Cambodia, April 2022.

SWAT Modeling Approach

The SWAT model is a physically based, semi-distributed, agro-hydrological, continuous hydrological model developed to enable water resource managers to determine the most appropriate strategy or solution by considering the impact of different management practices on streamflow and non-point source pollution (Arnold et al., 1998).

In this study, the SWAT model was used to simulate, using available data, daily streamflow in the catchment of Boribo-Bamnak. Running a comprehensive SWAT model requires spatial input data including a Digital Elevation Model (DEM), land use, soil type, and meteorological data. Each data input was obtained from different sources, such as a DEM with a resolution of 30 m downloaded from ASTER GDEM2. Soil-type data with a resolution of 250 m was retrieved from the FAO soil map, and land use data were obtained from the Ministry of Water Resources and Meteorology (MOWRAM) of Cambodia. Daily meteorological data from 2007 to 2018 were provided by the Provincial Department of Water Resources and Meteorology (PDWRAM) of the Kampong Chhnang and Pursat Provinces, respectively. The observed daily streamflow at Boribo River station was required by SWAT-CUP to be calibrated between 2010 and 2015 and validated from 2016 to 2018 using the SUFI-2 method.

Irrigation Water Requirements

The irrigation water requirement (IWR) is the amount of water needed to fulfill crop water requirements after effective rainfall, thereby ensuring a disease-free crop in large fields under non-restricting soil and water conditions and adequate fertility (Solangi et al., 2022). In this study, the average five-day water requirements for proposed cropping patterns of each crop variety in the Boribo-Bamnak River basin were estimated using the following equation Eq. (1)

$$IWR = (ET_0 \times K_c + PR + LP - ER)/IE \quad (1)$$

where IWR is the irrigation water requirement for a division unit, ET_0 is reference evapotranspiration, calculated using the FAO Penman-Monteith method (FAO, 1998), K_c is the crop coefficient defined based on FAO guidelines (for the case of paddy) since there is no observed data in the basin, PR is the percolation rate (3.0 mm per day in this study, referring to JICA (2012)), LP is the land preparation requirement, estimated by assumption using two methods of direct sowing under dry soil and transplanting under wet soil, ER is effective rainfall, calculated following JICA (2012), and *IE* is irrigation efficiency, obtained from water losses during conveyance and application to the field and defined following JICA (2012).

Water Balance Study

The water balance was computed using a simplified diagram of the present condition of water resource facilities and irrigation water uses in the river basin (Fig. 3). The fundamental formula for a water surplus or deficit at a major point where a large amount of water is taken from the river is expressed as follows Eq. (2)

$$Q_{sd} = Q + Q_{rf} - Q_q - Q_{rmf} \tag{2}$$

where Q_{sd} is the surplus or deficit of water at the calculation point, Q is the river runoff from the relevant catchment area, Q_{rf} is the return flow from paddy fields to the river (17% of the irrigation demand was used in this study after JICA, 2012), Q_q is a summation of irrigation water demand, and Q_{rmf} is the river maintenance flow, which was supplied to the downstream part of the river in order to preserve the river as a part of the landscape (0.1 m^3/s/100 km^2 was applied, based on the JICA, 2012).

The water balance calculation was executed from upstream to downstream following the natural flow direction for a time unit of five days for nine years (2010–2018). To confirm the security of the irrigation water supply to the Boribo-Bamnak River basin, this calculation was performed as follows: (1) identification of the impacts of existing irrigation schemes in the basin, (2) assessment of impacts from the viewpoint of the safety levels of irrigation water supplies, and (3) assessment of the impacts of water distribution at Bamnak headworks.

An evaluation of the safety level of the irrigation water supply is made as follows (1) a water balance was performed at each scheme outlet in terms of deficit or surplus, i.e., the net available flow subtracting the irrigation water requirement (IWR), such that a deficit occurs when the net available flow is less than the IWR, (2) for each year, when the deficit was more than or equal to four continuous five-day units (20 days), this year is judged to be a deficit year, and (3) each irrigation scheme is successful if the safety level is less or equal to 1/5 (80% dependability). The formula to define the safety level at each irrigation scheme is expressed as Eq. (3)

$$Safety\ Level = (x + 1)/n \tag{3}$$

where x is the number of years with twenty-day successive deficits (irrigation failures) and n is the total number of simulated years. In this study, for nine years of successful irrigation, the 1/5 term can be stated as 2/9. Consequently, if the safety level is less than or equal to 2/9, the scheme is deemed successful, and we can determine that water resources are secured with 80% dependability.
To calculate the probability of the deficit/storage required for a safety level 1/5, we use Eq. (4)

$$y = c \times \ln(x) + b \tag{4}$$

where y is the probable deficit in x% non-exceedance, c and b are constants, ln is the natural logarithm, and x is the percentage of exceedance.

Water distribution at Bamnak headworks is an important point of the water balance calculation in the Boribo-Bamnak River basin. In this study, water distribution at Bamnak Headworks was incorporated into the water balance calculation in two ways. (1) Water was allocated equally to Pursat and Kampong Chhnang (i.e., 50% each) during the wet season (May–October) and allocated 75% to Pursat Province, and 25% to Kampong Chhnang Province during the dry season (November to April); refer to the field study in Boribo-Bamnak River basin, March 2022. (2) Water was allocated equally to Pursat and Kampong Chhnang Provinces (i.e., 50% each) either in the wet season or dry season (refer to the regular rule of fair and sustainable water distribution).

Additionally, water management was considered through a study on actual water distribution using existing data for discharge at Bamnak headworks from 2018 to 2019.

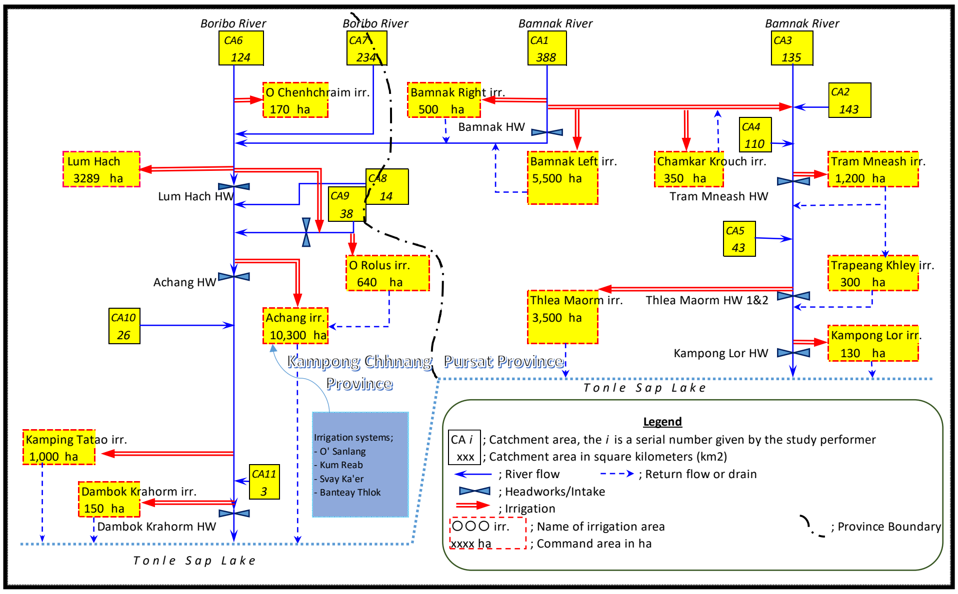

Fig. 3 Diagram of present-day water use in the Boribo-Bamnak River basin

RESULTS AND DISCUSSION

SWAT Calibration and Validation for Streamflow

Figure 4 represents the simulated streamflow for the daily time step (calibrated from 2010 to 2015 and validated from 2016 to 2018) compared with observed data. The model performance is shown to be satisfactory in terms of calibration and validation with NSE values of 0.55 and 0.51 according to the evaluation criteria of Moriasi et al. (2007). We noted, however, that the hydrological simulations did not perform well during the dry season (November-April) due to inaccuracies in the estimated discharge at the observation station. The estimated discharge was calculated *via* water level observation by applying H-Q curves produced by the River Basin Water Resources Utilization project of JICA in 2018. Because these water discharge measurements were conducted only during high-water level periods, they did not cover the entire range of water levels experienced during periods when the relationship between water level and discharge is known to be stable. This relationship was, therefore, not defined for low flow conditions.

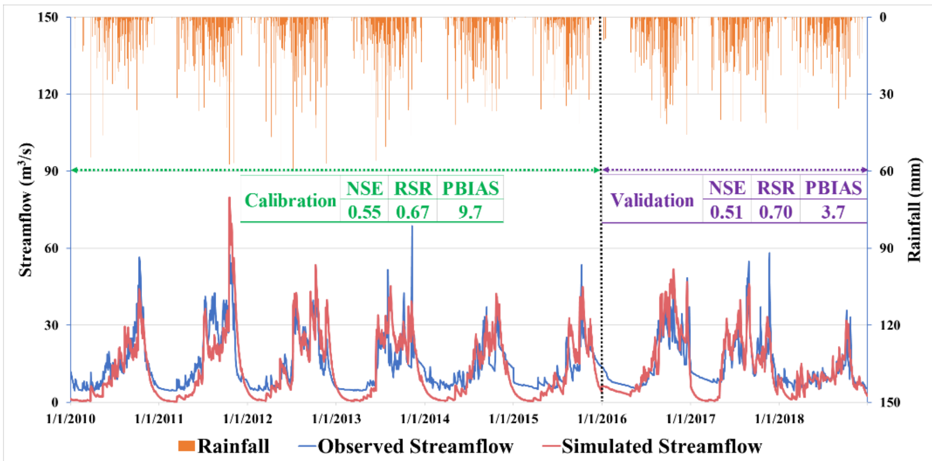

Fig. 4 Daily streamflow during the calibration and validation periods

Referring to the information about water management in the Boribo-Bamnak River basin obtained through a field study conducted in March 2022, we found that the water level in the river was very low in the upstream region, drying up in the downstream region during the dry season. This variation is known to be challenging for the farmers in the river basin and has been reported by numerous farming households located in the upstream and downstream parts of the river basin (27 households in Pursat Province and 6 households in Kampong Chhnang Province). Simulated streamflow from the SWAT model was used for the water balance study.

Water Balance Study

The water balances of the Bamnak River in Pursat Province and the Boribo River in Kampong Chhnang Province were calculated taking into consideration the ratios of water distribution at Bamnak headworks. Fig. 5 shows the results of the first case of water distribution at Bamnak headworks (wet season: Pursat = Kampong Chhnang = 50%; dry season: Pursat = 75%, Kampong Chhnang = 25%). Fig. 6 illustrates the results of the second case (wet season and dry season: Pursat = Kampong Chhnang = 50%). Water resources are sufficient during the wet season; however, water shortages frequently occur in the dry season. Indeed, a water deficit occurred annually during the dry season every year between 2010 to 2018, except for 2016. Thus, the irrigation safety is approximately 10% either in Pursat and Kampong Chhnang Province under these two ratio cases. This indicates that the Bamnak and Boribo Rivers lack sufficient water to guarantee 80% irrigation safety for existing areas of irrigation. By calculating the probability of the deficit/storage required for a safety level of 1/5, the water deficit is estimated in both cases as approximately 6 million cubic meters in Kampong Chhnang Province and 10 million cubic meters in Pursat Province.

The Bamnak and Boribo Rivers have abundant water during the wet season. The irrigation of wet season paddy was examined without dry season rice taken into the calculation; as a result, the irrigation safety during the wet season paddy was 80% in both provinces by virtue of the natural river flow alone. Under these conditions, water distribution at Bamnak headworks is not considered to be an issue during the wet season (May to October).

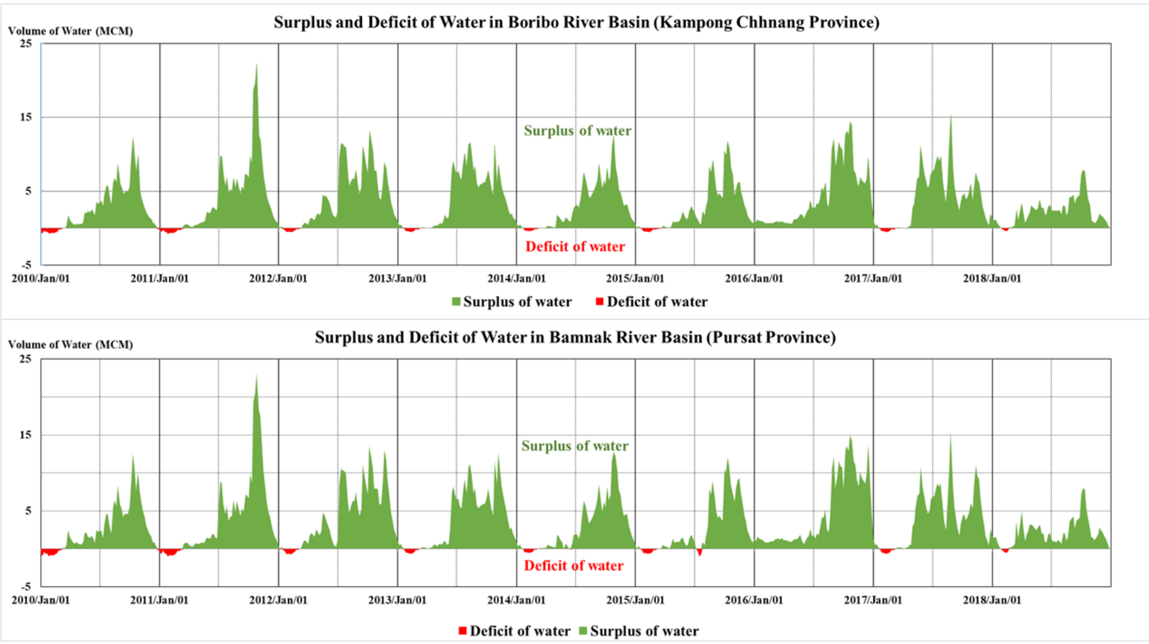

Fig. 5 Hydrograph showing surplus and deficit water between 2010 and 2018

Water allocated at Bamnak headworks: Pursat = Kampong Chhnang = 50% during the wet season; and Pursat = 75%, Kampong Chhnang = 25% during the dry season.

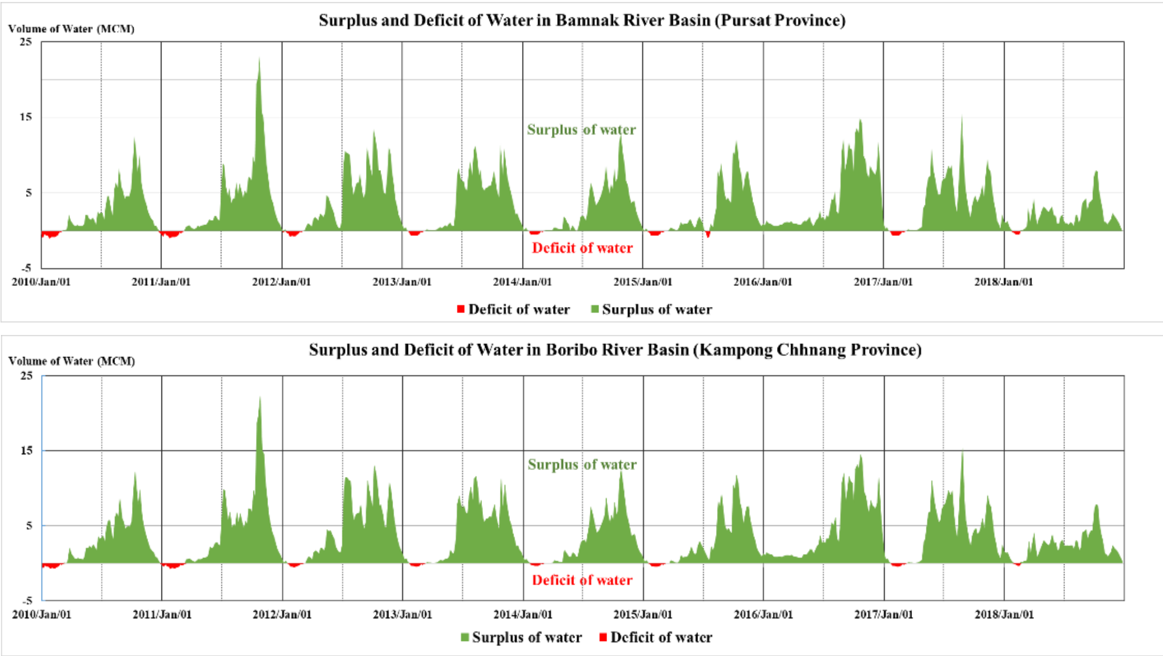

Fig. 6 Hydrograph showing water surplus and deficit between 2010 and 2018

Water allocated at Bamnak headworks: Pursat = Kampong Chhnang = 50% during the wet and dry seasons

According to our calculations, although 100% of the water was distributed to Pursat during the dry season, it was insufficient to maintain the irrigation water required for existing dry-season rice in this province (1,222 ha). Moreover, river maintenance flow in both provinces could be secured in case equitable water distribution at Bamnak was made and dry season rice in both provinces was not taken into calculation.

Water Distribution at Bamnak Headworks

The actual water distribution at Bamnak headworks was estimated based on available data for 2018 and 2019. Which were obtained from Pursat PDWRAM (recorded water level) and the JICA River Basin Water Resources Utilization project (H-Q curve). The water distribution at Bamnak headworks was found to be similar to the distribution ratio of the first case study in the water balance calculation (Fig. 7). On average, the ratios of water distribution were made as 40% and 30% to Kampong Chhnang Province, respectively, and 60% and 70% to Pursat Province, respectively, in the wet and dry seasons.

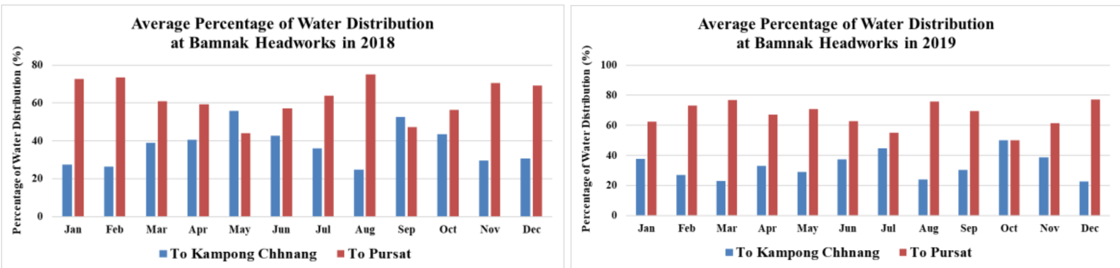

Fig. 7 Water distribution at Bamnak headworks in 2018 and 2019

To assist water management in the basin, the Bamnak headworks were constructed in 2010 by MOWRAM with the base idea of allocating 50% of the water available to Pursat Province and 50% to Kampong Chhnang Province. In practice, this concept has been difficult to realize because the total width of four intake gates to Pursat Province is 8.8 m (=2.2 × 2 × 2) when the total width of two spillway gates to Kampong Chhnang Province is 3.0 m (=1.5 × 2) (Fig. 2). Therefore, fair, and sustainable water distribution at Bamnak headworks must be made based on a consensus between province stakeholders.

CONCLUSION

This study has shown that the SWAT model is an appropriately sensitive model for predicting daily streamflow in the Boribo-Bamnak River basin. It provides insights into the importance of better analysis relationships, which depends mostly on the quality of available data and the necessity for additional hydrological observation.

The results of water balance studies in the Boribo-Bamnak River basin clearly indicate that the availability of water in the river is not sufficient to supply all water demands for existing irrigation schemes in Pursat and Kampong Chhnang Provinces. Water shortages occurred in the dry season almost every year during the study period (2010-2018). Therefore, to ensure sustainable water use in the river basin, a study of the possibility of constructing reservoir dams in the upstream region of both the Bamnak and Boribo Rivers should be considered.

In terms of water management at the Bamnak headworks, this study suggests that Pursat PDWRAM should make efforts to communicate with Kampong Chhnang PDWRAM and related local authorities, for example, the Farmer Water User Communities, in order to appropriately implement water flow operations that ensure sustainable water use while avoiding conflicts among water users.

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Research article

Improvements in Preservation Properties of Homemade-Style Pickled Cucumber in Cambodia

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Abstract Pickled cucumbers selling at wet markets in Cambodia are popular among local people. It has been reported that pickles using homemade recipes are at a high risk of spoiling and causing food poisoning, as there are no heating steps in the production process. Therefore, it is necessary to improve the hygienic conditions of the food supply to make safe pickles in Cambodia. Heat treatments using hot pack filling and pasteurization lead to microbiologically safe products and extended shelf life. This study aimed to examine the effect of heat treatments (hot pack filling and pasteurization) on preservative properties and to evaluate the acceptability of the pickled cucumbers prepared with the heating process. Pickled cucumbers prepared with and without the heating process were made using a traditional Cambodian recipe and stored at 30 °C for 7 days. The presence of total viable bacteria, coliforms, *Escherichia coli*, yeasts, and molds in the pickled products was tested during the storage periods. The samples without the heating process resulted in contamination with coliforms, *E. coli*, yeasts, and molds and were in an initial putrefactive state because of the number of total viable bacteria. On the other hand, coliforms, *E. coli*, yeasts, and molds were not detected in the samples prepared with the heating process from Day 0 to Day 7. This result indicated that the pasteurization treatment killed many spoilage microbes, including foodborne pathogens. To investigate the acceptability of the pickled cucumbers prepared with the heating process, sensory evaluation tests were performed. From the results of the sensory evaluation and questionnaire survey, there was the possibility of acceptance of the pickled cucumbers prepared with the heating process made either in Japan or Cambodia by the Cambodian panelists; however, further improvement in the softness of the pickles was commented upon.

Keywords cucumber, homemade-style pickle, pasteurization, sensory evaluation, acceptability

INTRODUCTION

Pickled cucumbers are popular pickles in Cambodia. Nearly all Cambodian people like to eat pickles in their daily diet. These pickles are mostly produced at home using traditional recipes and are usually sold at wet markets in Cambodia. The Ministry of Health in Cambodia reported that after eating these homemade-style pickled cucumbers, many people suffer from symptoms of food poisoning, including diarrhea, abdominal pain, fever, and nausea (MoH, 2016). A review report has described that important foodborne pathogens have been detected in the food supply in Cambodia (Thompson et al., 2021). Studies by Muramatsu et al. (2020a, 2020b) and Chrun et al. (2017) showed that some microorganisms could cause food spoilage and food poisoning in homemade pickled products sold at wet markets. The current preparation method for homemade-style pickles is generally as follows. Fresh vegetables are washed with tap water. Then, they are submerged in boiled water or normal-temperature water along with seasonings. The pickles are then soaked for two to four days at room temperature. The room temperature ranges from 25 to 35 °C according to the tropical climate of Cambodia. Homemade pickles are commonly stored at room temperature at approximately 30 °C during and after the production of pickles. Muramatsu et al. (2022) prepared three kinds of homemade-style pickles using traditional Cambodian recipes and evaluated the microbial quality of those pickles. The report revealed that microbial growth was observed in all pickles starting at Day 0, which poses a high risk of food spoilage and food poisoning. Therefore, we focused on the production process for obtaining microbiologically safe products. Therefore, this study aimed to examine the effect of thermal preservation methods on the microbial quality of pickled cucumbers. The heating step is considered to affect the taste of the pickled cucumber, and therefore we also investigated the acceptability by Cambodian people.

Pickled cucumbers were prepared with and without the heating process following the Cambodian homemade-style recipes. For the purpose of providing safe pickle products in Cambodia, we aimed to investigate the effect of the heating process (hot pack filling and pasteurization) on the microbial quality of cucumber pickles. The acceptability of these pickled cucumbers was examined based on sensory evaluation in Cambodia.

OBJECTIVE

The objectives of this study were 1) to examine the effect of the heating process (hot pack filling and pasteurization) on the preservative properties of the pickled cucumbers and 2) to evaluate the acceptability among Cambodian people of the pickled cucumbers prepared using the heating process.

METHODOLOGY

Materials, Production Process, and Procedure for Samples Testing

The pickled cucumbers were prepared with and without a heating process according to traditional Cambodian recipes (Muramatsu et al., 2022) as samples for the test. All ingredients and seasonings were purchased at a supermarket in Tokyo, Japan. The seasoning mixture was prepared using 30.6 grams of salt and 700 ml of water. The ingredients used to make the samples were 200 g (5 pieces) of cut fresh cucumbers, 4.5 g (1 piece) of garlic, and 1.0 g (2 pieces) of chili. All ingredients were mixed with the seasonings. Figure 1 shows the production process of pickled cucumbers with the heating process. Cucumbers were washed with tap water and wiped with a paper towel. Cucumbers with diameters of 2.2-3.2 cm were cut into lengths of 7 cm using a knife. The garlic was peeled and sliced. A piece of chili was sliced into rings. The liquid seasoning was heated to boiling. The heated liquid seasoning, 120 ml, a piece of cucumber, and a few slices of garlic and chili were placed into a glass bottle up to 3-5 mm from the bottle lid. After closing the lid of the bottle (sealing), the bottle was turned upside down. The hot glass bottle filled with seasoning and cucumber was submerged in hot water at a temperature of 80 °C. Then, the hot water was heated to boiling in a pot. After coming to a boil, the glass bottle was maintained in boiling water for 10 minutes to raise the center temperature of the cucumber to above 75 °C. After this pasteurization, the glass bottle was cooled at room temperature in an inverted state for a few hours.

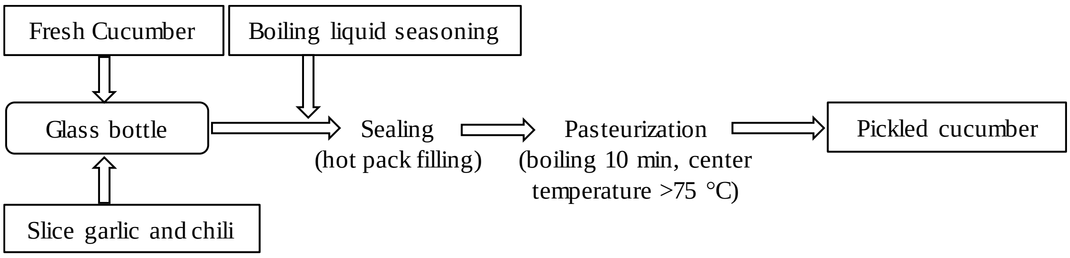


Fig. 1 Production process of pickled cucumber prepared with the heating process

The pickled cucumbers without a heating process were prepared using the same seasoning and ingredients as the heated sample shown in Fig. 1. After placing the ingredients into the glass bottle, the liquid seasoning at room temperature was added. The lid of the glass bottle was closed.

Preparation of the Samples with the Heating Process for Examination of Preservability

To examine the preservability of cucumber pickles, the samples were observed for 7 days, as the vendors who sold pickles at wet markets reported that the shelf life of their products was approximately 2-4 days according to our survey and that the products were kept for 3-4 days during preparation by the traditional recipe.

The food properties of the samples during the storage periods, the Brix values, salt concentrations, and pH of the pickle liquid seasoning, were measured by using a Brix refractometer (Atago, Tokyo, Japan), a salt meter (Horiba, Kyoto, Japan), and a pH meter (Horiba), respectively.

To investigate the safety of the samples, microbiological tests were conducted by detecting total viable bacteria, coliforms, *E. coli*, yeasts, and molds. In total, 10 g of solid and liquid pickled cucumber was mixed with 90 ml of phosphate-buffered saline (PBS) (ELMEX, Tokyo, Japan) and placed in a sterilized storage bag. To mix well, samples were crushed using a hammer. After mixing, 1 ml of the sample suspension was mixed with 9 ml of PBS. A series of diluted samples were used for the detection of total viable bacteria, coliforms, *E. coli*, yeasts, and molds in the samples. Commercial sheet-shaped, dry, and ready-made microorganism detection media with nonwoven fabric, MC-media Pad^{TM} (JNC Corporation, Tokyo, Japan), were used for the detection of microorganisms. One milliliter of sample solution at each dilution was spread onto each specific MC-media Pad^{TM}. After spreading, the MC-Media Pad^{TM} "Aerobic Count (AC)", MC-Media Pad^{TM} "EC", and MC-Media Pad^{TM} "YM" were incubated at the set temperature of 35 °C for 48 hours, 24 hours, and 25 °C for 72 hours, respectively for assessment of total viable bacteria, coliforms, *E. coli*, yeasts, and molds. After incubation, the $\log_{10}$ CFU/g was calculated using media on which there were 30-300 colonies available to count. Three repetitions were carried out for the detection.

Sensory Evaluation of the Pickled Cucumber Made in Japan and Cambodia

For sensory evaluation, we prepared pickled cucumber samples with two pasteurization times, 10 and 20 minutes, similar to the samples prepared for the examination of preservability, as shown in Fig. 1. It was assumed that a longer pasteurization provided a higher killing effect on the microbes but that the texture might be unfavorably affected. Therefore, two kinds of pickled samples were evaluated. The pickled cucumbers pasteurized for 10 minutes raised the center temperature to above 75 °C, and those pasteurized for 20 minutes raised the center temperature to above 80 °C.

We aimed to show that the pickles made in Japan following Japanese sanitation guidelines were also able to produce in Cambodia, especially by using household cooking utensils. Besides, varieties of cucumber for pickles are assumed to be different between Cambodia and Japan. And the difference may affect the texture of the pickles, especially with heating samples. It was also important that how acceptable for Cambodian people both pickles made in Cambodia and Japan. Therefore, we prepared pickles made in Cambodia and Japan using local products for sensory evaluation.

The samples made in Japan were prepared using ingredients and seasonings purchased in Japan. The samples made in Cambodia were prepared using ingredients and seasonings purchased in Cambodia. All sensory was conducted in Cambodia. The panelists evaluated 2 samples with heating for 10 and 20 minutes. Twenty panelists evaluated the samples made in Japan at the Royal University of Agriculture (RUA) in Phnom Penh, and another 20 panelists evaluated the samples made in Cambodia at a wet market in Prey Nop district in Preah Sihanouk. The purpose of sensory evaluation in this study is not a comparison pickles made in Cambodia and Japan. We aimed to investigate the acceptability of respective pickles. Therefore, no particular problem occurs when the panels were different between the products in Cambodia and Japan.

The age of the evaluating panelists was 21-28 years (average: 23 years) at RUA and 22-60 years (average: 31 years) at the wet market. The color, sweetness, sourness, saltiness, flavor, texture, and overall evaluation of each sample were quantified using a five-point hedonic scale (1: strongly dislike, 2: dislike, 3: neutral, 4: like, and 5: strongly like) for the sensory test (preference type).

RESULTS AND DISCUSSION

Examination of the Preservability of the Pickles Prepared with the Heating Process

To investigate the effects of the heating process on the quality of the samples, the nutritional properties, and microbial quality were examined. During the storage period of 7 days, the Brix value, salt concentration, and pH values were measured (Table 1). The average Brix values of the pickled cucumbers prepared with and without the heating process were 4.9 and 4.2, respectively. There is a significant difference in the value of Brix. But the difference in Brix values between pickles with heating and without heating is assumed not to affect the preservation stability of the samples. The average salt concentrations in the pickles prepared with and without heating were 4.9 and 4.3, respectively. The Brix value and salt concentration were generally constant throughout the storage period.

On the other hand, the pH value of the sample prepared with heating was 5.3 on Day 0 and 5.3 on Day 7, and that of the sample without heating was 5.5 on Day 0 and 4.3 on Day 7 (data not shown). While the pH values of the heated samples were stable, those of the nonheated samples decreased over time. This indicated that the pickled cucumber prepared without the heating process contained microorganisms producing acids in the samples.

Table 1 Nutritional properties of the pickles prepared with and without heating

Measured item	Brix (%)	Salt (%)	pH
Pickles with heating	4.9 ± 0.25 *	4.9 ± 0.20	5.3 ± 0.18
Pickles without heating	4.2 ± 0.10 *	4.3 ± 0.41	4.6 ± 0.35

(Mean ± standard deviation), the symbol (*) means a significant difference ($p < 0.05$).

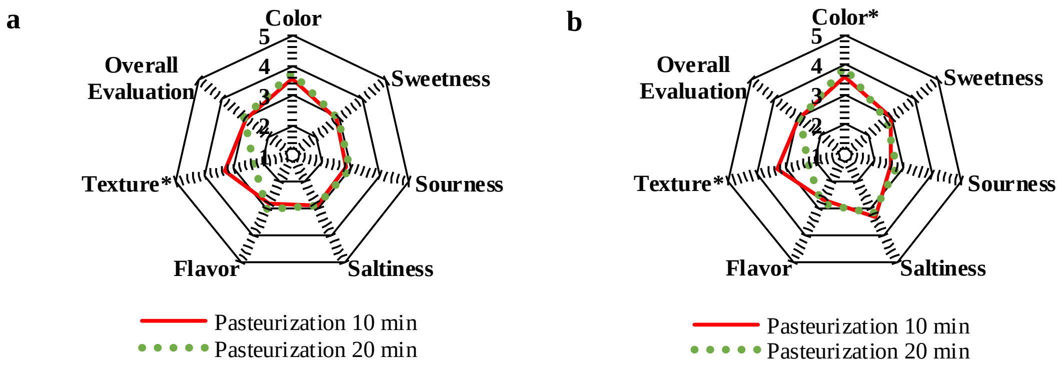
Next, we examined the microbial quality of the pickled cucumbers by measuring the number of total viable bacteria, coliforms, *E. coli*, yeasts, and molds. The total viable bacteria on Day 0 were more than 5.00 $\log_{10}$ and over 7.00 $\log_{10}$ after Day 3. Coliforms were detected in samples from Day 0 to Day 7, and there were samples positive for *E. coli*. Yeasts and molds were detected in some samples. A similar result was reported by Muramatsu et al. (2022). From the result of the experiment for measuring the microbial quality of the pickles without heating, the pickles contained unacceptable numbers of total viable bacteria on Day 3 for eating. Besides, coliforms, *E. coli*, yeast, and mold were detected. Yeast and mold can cause putrefaction. Contamination of *E. coli* implies a risk of the presence of other enteric pathogens. Enterohemorrhagic *E. coli* is classified as a severe hazard, which is life-threatening for the general population, based on International Commission on Microbiological Specifications for Foods (Matthews et al., 2017). Taking this into consideration, the pickled cucumbers without a heating process in this study were not safe for consumption.

On the other hand, coliforms, *E. coli*, yeasts, and molds were not detected in any of the samples subjected to the heating process. In addition, total viable bacteria were almost not detected throughout the storage time. The heating time for pasteurization was decided based on the effect of heating on the texture of the cucumber. Due to this, the bactericidal effect of the heated samples seemed to change depending on this condition. However, the number of CFU/g among the samples in which some total viable bacteria were detected was at most 5.00 $\log_{10}$. These results indicate that the heat treatment was effective in killing microbes, but this heating step was barely effective for some microorganisms. For food preservation, a sufficient amount of salt and/or a lower pH value is supposed to be used. Since the samples with the heat treatments, namely, the hot pack filling and 10 minutes of pasteurization, maintain their qualities sufficiently until Day 7, the process of adding heat treatments may be a suitable procedure to make safe products that do not change the traditional taste.

Sensory Evaluation of the Samples Made in Japan and Cambodia

To investigate the acceptability characteristics of pickled cucumbers during the heating process, sensory evaluation tests were performed. Fig. 2 shows the results of the sensory evaluation tests of samples (a) made in Japan and (b) made in Cambodia. The average values of each sensory item for the pickled cucumbers pasteurized for 10 min and 20 min made in Japan ranged from 2.8-3.6 and 2.4-3.8, respectively (Fig. 2a). In the overall evaluation, both the 10- and 20-minutes pasteurization samples scored approximately 3.0. There was no significant difference in accordance with the paired t-test (5% significance level) between all characteristics, except for texture. The average value of texture for the samples with 10 min of pasteurization was higher than that of the sample with 20 min of pasteurization, which was 3.4 and 2.4. This result showed that longer pasteurization affected the texture of the cucumber. However, the overall evaluation scores were both approximately 3.0. This is a representative evaluation of whether or not the sample was considered acceptable. The results indicated that the samples made in Japan were considered acceptable in the Cambodian market. Figure 2b shows the results of the evaluation of pickled cucumbers with the heating process made in Cambodia. The average scores of all evaluated items ranged from 2.6-3.6 and 2.3-4.0, respectively. Except for color and texture, there were no significant differences between the evaluated items according to a paired t-test (5% significance level).

Because the average score for color was close to 4.0, Cambodian panelists preferred the color of the sample with pasteurization for 20 min made in Cambodia. The texture of the sample with pasteurization 20 min was given a lower rating score of 2.3. The heating treatment presumably caused a change in the texture of the cucumbers. Although the average values of sourness and flavor for both samples did not exceed 3.0, the overall evaluation score given by the panelists was nearly 3.0. Based on the results, the samples pasteurized for 10 min and 20 min made in Cambodia may also be acceptable in the Cambodian market. In addition, the t-test for each characteristic used the average score between the samples made in Japan and Cambodia with 10 and 20 minutes of pasteurization. There were no significant differences. Since a similar evaluation was obtained, there did not seem to be differences in quality.



The symbol (*) means a significant difference ($p < 0.05$).

Fig. 2 Sensory evaluation of pickled cucumbers with pasteurization for 10 min and 20 min: (a) samples made in Japan and (b) samples made in Cambodia

Most Cambodian panelists commented that there was a lack of sourness for these pickled cucumbers. Some panelists commented that sweetness and saltiness were lacking. If these characteristics were to be improved, the overall evaluation would receive a higher rating. The heating treatments, hot pack filling, and pasteurization were effective in killing microorganisms and were recommended for pickle production. Although a longer heating process affected the texture (softness) of the pickled cucumbers, they received a nearly normal score on the overall evaluation from the Cambodian panelists. From the results of the sensory evaluation and questionnaire survey, there was the possibility of acceptance of the pickled cucumbers prepared with pasteurization made either in Japan or Cambodia by the Cambodian panelists; however, further improvement in the softness of the pickles was commented upon. Regarding improvements for the product, some food additives are recommended as they do not affect the softness of pickles and are effective in keeping microbiological safety.

CONCLUSION

To investigate the effect of the heating process on the preservative properties of pickled cucumber, pickles using a traditional Cambodian were prepared. While the products that did not undergo the heating process were highly contaminated by microbes, the products prepared with the heating process did not show the presence of coliforms, *E. coli*, yeasts, and molds for 7 days at 30 °C. This result showed that the heating process killed many spoilage microbes, including foodborne pathogens. The heating process is considered to be effective in providing safe products and extending shelf life. Sensory evaluation tests were conducted in Cambodia. From the results, there was the possibility of acceptance of the pickled cucumber prepared with the heating process by the Cambodian people. There were comments from panelists that further improvement in the softness of the pickles was needed.

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Research article

Reuse of Unavailable Phosphate in Soils Using Solar Cell-Powered Electrokinetic Treatment

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Abstract Electrokinetic treatment (ET) is widely used for soil remediation, specifically for removing heavy metals from soil. Till date, we have focused on the nutrients released in soils using a solar cell-powered ET, which contributes to increasing the productivity of organic farming. Previously, when a 1.5 V solar cell was used in ET, the release of ammonium ions and the growth of microorganisms were observed. However, no release of phosphate ions was observed. Thus, it is presumed that a 1.5 V solar cell is insufficient to release phosphate in soils. Therefore, this study aims to examine the effects of solar cell voltage on the release of phosphate in soils. In laboratory experiments, an anode (oxidation reaction) and a cathode (reduction reaction) were installed in andosol mixed with cow manure compost, and a 3 or 6 V solar cell was used to produce an electric current between the two electrodes. Sixty-two days after the current generation, the chemical properties of the soil were measured. The results suggest that soil redox conditions can be controlled by changing the solar cell voltage. From the pH distributions, a higher voltage of solar cells was used and a large change in pH was obtained. Furthermore, a decrease in soil redox potential was obtained by increasing the solar cell voltage. From the phosphate distributions, a 6 V solar cell is required to release phosphate in soils. It is recommended that applying ET powered by a 6 V solar cell (potential gradient: 0.12 V/cm) facilitates nutrient release in soils, which is the most important factor in organic farming.

Keywords solar cell, voltage, electrokinetic treatment, soil reduction, phosphate, organic farming

INTRODUCTION

According to the Ministry of Agriculture, Forestry, and Fisheries of Japan, organic farming is a strategy to achieve sustainable agriculture. The government has proposed many countermeasures to facilitate organic farming (MAFF, 2019). Hence, productivity-enhancing technologies and implementation systems are required.

In organic farming, because nutrients are supplied by the decomposition of organic matter, facilitating this decomposition is crucial in providing higher productivity. As the decomposition of organic matter depends on the Soil Chemical Environment (SCE), controlling SCE is imperative in enhancing the productivity of organic farming. According to Yan and Hou (2018), understanding SCE is useful for ensuring healthy soil that can sustain crop production. Therefore, to provide higher productivity in organic farming, a technology that can control the SCE to activate bacterial metabolism for enhancing the decomposition of organic matter is required.

Electrokinetic Treatment (ET) is a technology for generating a low-intensity electrical field between two electrodes buried in soils by applying a direct current or constant voltage (an external power supply). ET has been widely used for a few decades to remove contaminants, such as dyes and heavy metals (Hanay et al., 2009, Almomani and Baranova, 2013). Kim et al. (2010) reported changes in soil pH and electrical conductivity owing to ET application in soil. Additionally, ET can be used to control SCE. Previously, a battery was used to apply a direct current or a constant voltage, but now a solar system is also used as an external power supply of ET (Liu et al., 2020). However, a large potential gradient, for example, 3-5 V/cm, is commonly applied to soils, which causes large variations in the SCE. This, in turn, influences soil biology, limiting the decomposition of the organic matter.

We thought that by decreasing the potential gradient (i.e., the solar cell voltage), the effects on soil biology could be reduced. As such, in our previous study (Touch and Nakamura, 2022), a 1.5 V solar cell (potential gradient: 0.03 V/cm) was used in ET. Following the application, the release of ammonium ions and the growth of microorganisms were observed, which would also be useful for organic farming. However, no release of phosphate was observed. Thus, a 1.5 V solar cell was insufficient to release phosphate in soils. As increasing the voltage of the solar cell facilitates reactions on the electrode surface in soils, using a higher voltage of the solar cell may cause the release of phosphate.

OBJECTIVE

This study aims to examine the effects of solar cell voltage on the release of phosphate in soils. Specifically, we examined changes in electrode potential by increasing the solar cell voltage, the soil redox conditions (pH and redox potential), and nutrient release following the application of solar cell-powered ET. This was conducted by applying ET to andosol mixed with cow manure compost with a generated electric current for two months.

METHODOLOGY

Experimental Procedures and Operations

Commercial products, i.e., dried cow manure compost (fully matured, nitrogen 1.09%, phosphate 2.29%, potassium 2.28%) and andosol (volcanic derived soils with high contents of organic matter and aluminum compounds), were used in laboratory experiments. First, the compost was mixed with andosol at a volume ratio of 47% (generally, 40-60% was used). The mixture was then used in the experiments, which were conducted under three conditions without treatment (Control), treated with a 3 V solar cell (SC-3V), and treated with a 6 V solar cell (SC-6V). For Control, an electrode was installed in the mixture to measure the soil potential continuously (Fig. 1a).

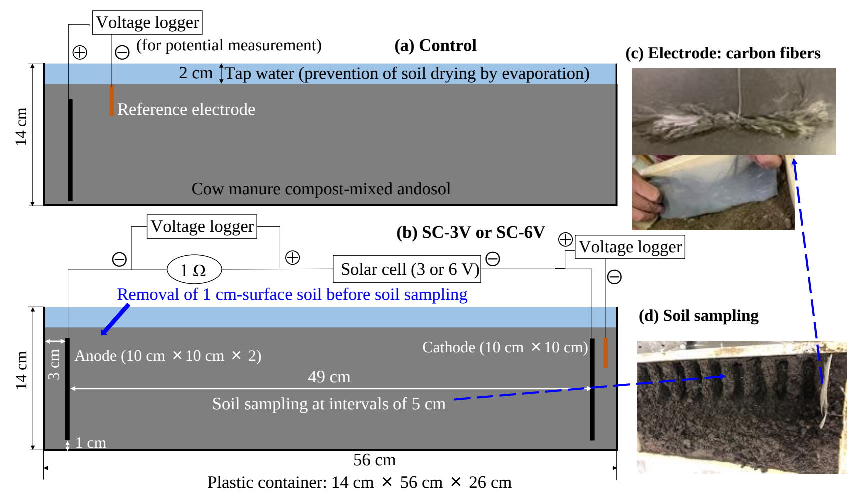

Fig. 1 Experimental devices and operations

For SC-3V or SC-6V, two electrodes were installed in the soil layer (Fig. 1b). To generate an electrical current, one electrode was connected to the positive terminal, and the other was connected to the negative terminal of a solar cell (3 V or 6 V) using the circuit shown in Fig. 1b. Different voltages of the solar cells were obtained by connecting a 1.5 V solar cell (Tamiya, 1.5 V-500 mA) in series. An external resistance of 1 Ω was loaded between the anode and solar cell. The electrode material was carbon cloth (News Company, PL200-E), which was heated at 500°C for 1 h before using it, as Nagatsu et al. (2014) suggested. The heated carbon cloth with a width of 10 cm and height of 10 cm was separated into fibers to form a brush-type electrode. The electrode was placed in a plastic net (1-mm mesh) and installed in the soil layer (Fig. 1c). The anode surface area was 0.02 m^2 (10 cm × 10 cm × 2), while the cathode surface area was 0.01 m^2 (10 cm × 10 cm). A smaller cathode surface area compared with the anode surface was made to obtain a higher reduction at the cathode.

After installing both electrodes, the container was filled with tap water. Consequently, a 2 cm water layer was formed on the soil surface, which can prevent the soil from drying owing to evaporation. The voltage at both terminals of the external resistance was measured every 15 min using a voltage logger (T&D Corp., MCR-4V) to calculate the circuit current according to Ohm's law. The current density was obtained by dividing the current by the surface area of the anode, i.e., 0.02 m^2. The electrode and a reference electrode (Toyo Corp., W-RE-7A) placed in the soil layer were connected to the voltage logger using the circuit shown in Figs. 1a and 1b to measure the electrode potential.

Analyses

Two months after the experiments started, soil sampling was conducted. The surface soil of 1 cm was removed, and pH and redox potential (ORP) were measured using a pH/ORP meter (Horiba, D-50) at intervals of 5 cm from the anode. Soil samples were collected (Fig. 1d) after pH and ORP measurements. Furthermore, each soil sample was centrifuged at 6000 rpm for 5 min (As One, CN-2060) to extract pore water. Finally, each ion concentration in pore water (phosphate, PO_4^{3-}; ammonium, NH_4^+; potassium, K^+) was measured. The ion concentration was measured using PACKTEST (Kyoritsu Corp., WAK), except for K^+ concentration which was measured using a K^+ meter (Horiba, K-11).

RESULTS AND DISCUSSION

Variations of Electrode Potential with Different Voltages of Solar Cells

Figure 2 depicts temporal changes in the electrode potential during the experiments. For SC-3V and SC-6V, the electrode potential refers to the potential of the cathode in which a reduction reaction occurs. For Control, the electrode potential decreased temporally, and mostly stabilized at -0.48 V on Day 62 after the experiment started. The low potential was observed because cow manure compost was used, and it took approximately two months for its reduction. On Days 50-60, the peak electrode potential ranged from -0.70 V (night-time) to -0.94 V (daytime) for SC-3V and -0.90 (night-time) to -1.14 V (daytime) for SC-6V.

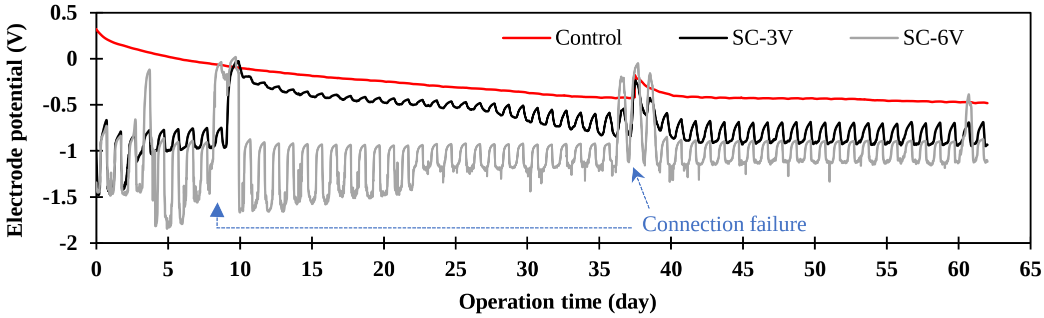

Fig. 2 Comparison of electrode potential with and without using the solar cell

Compared with the Control, more reduction was obtained when a high-voltage solar cell was used, and there was a large decrease in the electrode potential when the solar cell voltage was increased from 3 V to 6 V. This is because the reactions on the electrode are more active owing to an increase in electrical current when the voltage of the solar cell increases. As shown in Fig. 3, the current density was approximately 0.06-1.30 A/m^2 for SC-6V and 0.01-0.61 A/m^2 for SC-3V. The system current can vary using different solar cell voltages, that is, by changing the solar cell voltage, soil reduction can be controlled.

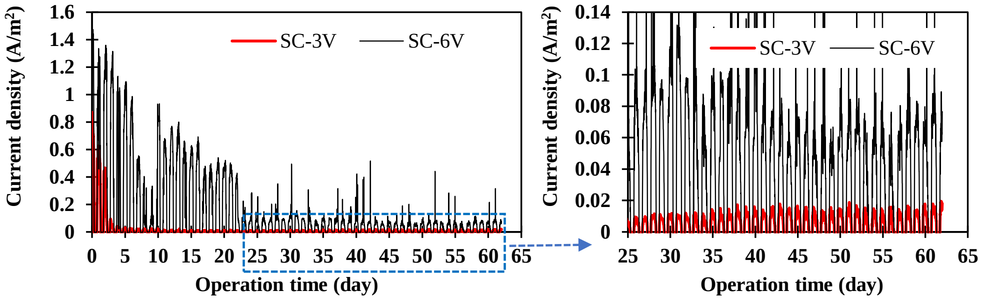

Fig. 3 Comparison of current densities generated by SC-3V and SC-6V

Changes in Redox Conditions at the End of the Experiment

Figure 4 shows changes in pH and ORP due to the current generation at the end of the experiment. In Fig. 4, 0 and 49 cm refer to the soil samples at the anode (oxidation) and cathode (reduction), respectively (SC-3V and SC-6V). In Fig. 4a, the pH at the anode was 6.21 for Control, which decreased to 6.18 for SC-3V and 3.56 for SC-6V. These decreases were caused by oxidation reactions at the anode. However, the pH at the cathode was 6.44 for Control, which increased to 6.72 for SC-3V and 7.11 for SC-6V. These increases were caused by reduction reactions at the cathode. From the pH distributions, a distance of 25 cm from the electrode were influenced by the current generation using a 3 V or 6 V solar cell.

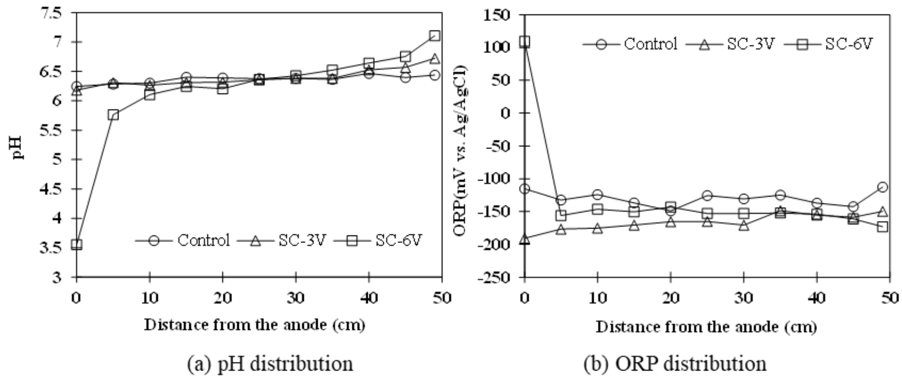

Fig. 4 Changes in pH and ORP due to current generation at the end of the experiment

Decreased soil ORP was observed on using a 3 V or 6 V solar cell compared to Control, except at the anode of SC-6V. The soil ORP ranged from -150 to -112 mV for Control and -190 to -150 mV for SC-3V and SC-6V, respectively (Fig. 4b) which disagrees with our previous study (Touch and Nakamura, 2022) that reported an increase in ORP when using a 1.5 V solar cell. By increasing the solar cell voltage, a large decrease in soil ORP can be obtained.

Nutrient Release Owing to Current Generation

The distributions of ammonium (NH_4^+), phosphate (PO_4^{3-}), and potassium (K^+) are shown in Fig. 5. The release of NH_4^+ was observed, which parallels our previous study (Touch and Nakamura, 2022). A 1.8- to 2.3-fold increase in NH_4^+ concentration was observed within 5−20 cm of the anode (Fig. 5a). However, no significant difference was observed between SC-3V and SC-6V at 10−30 cm of the anode, suggesting that a 3 V solar cell is enough to release NH_4^+ in soils. The increase in NH_4^+ concentration was low near the cathode compared with that near the anode. This is because of the reduction reactions near the cathode, which induce denitrification. In Particular, the NH_4^+ concentrations in SC-6V were lower than those of Control within 5 cm from the cathode.

No differences in PO_4^{3-} concentration were observed between Control and SC-3V (Fig. 5b), suggesting no release of PO_4^{3-} despite using a 3 V solar cell. Interestingly, a 2- to 7-fold increase in PO_4^{3-} concentration was observed within 20−45 cm of the anode for SC-6V. Within 15 cm of the anode, no increase in PO_4^{3-} concentration was observed. This was because of the release of calcium ions at this distance (Fig. 5c) following the decrease in pH (Fig. 4a), leading to the fixation of PO_4^{3-} by the calcium ions. An increase in K^+ concentration was also observed. Compared with the Control, maximum 1.3-fold (SC-3V) and 1.6-fold (SC-6V) increases in K^+ concentration were observed within 5-20 cm of the anode (Fig. 5d). However, a smaller increase in K^+ concentration was observed near the cathode (20-45 cm of the anode), except for the cathode. A decrease in sediment pH induced the dissociation of metal compounds, causing the release of metal ions (e.g., Ca^{2+}, K^+), which can fix PO_4^{3-} in littoral sediments (Touch et al., 2017; Touch et al., 2018).

In summary, applying ET powered by a 6 V solar cell can release nutrient compounds in soils, such as NH_4^+, PO_4^{3-}, and K^+. These releases are caused by the enhancement of organic matter decomposition in soils and the decrease in soil pH following ET application.

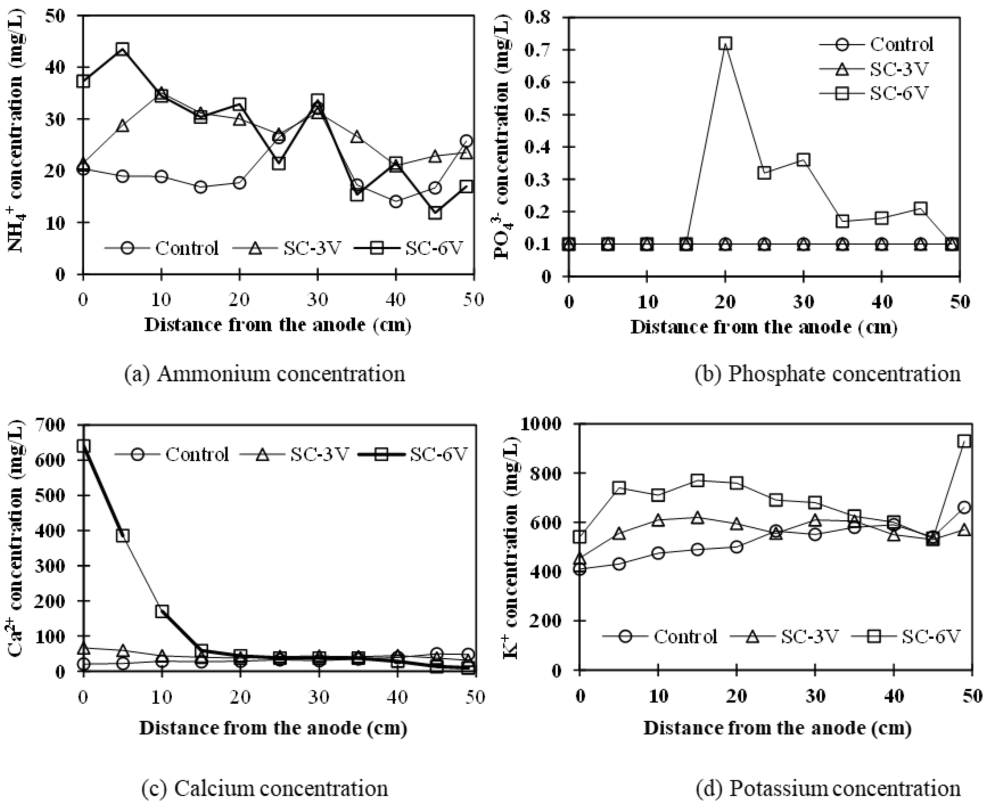

Fig. 5 Comparison of nutrient concentration distributions

CONCLUSIONS

Laboratory experiments were conducted to examine the effects of solar cell voltage on the release of phosphate in soils. Specifically, we examined changes in the electrode potential by increasing the solar cell voltage, the soil redox conditions (pH and redox potential), and nutrient release after applying solar cell-powered ET to andosol mixed with cow manure compost. The system current increased as the solar cell voltage increased, which effectively induced reactions on the electrode. By changing the solar cell voltage, electrode potential, and soil redox conditions were controlled. From the pH distributions, 25 cm from each electrode was influenced by the application of ET. A larger influence was obtained with a higher voltage of the solar cell. From the ORP distributions, a large decrease in soil ORP was obtained by increasing the solar cell voltage. Hence, soil redox conditions can be varied using solar cells of different voltages. From the PO_4^{3-} distributions, a 6 V solar cell is required to release PO_4^{3-} in soil. It was also highlighted that decreasing the pH near the anode decreased the PO_4^{3-} concentration. Finally, applying ET powered by a 6 V solar cell (potential gradient: 0.12 V/cm) facilitates nutrient release in soils.

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Research article

Impact of a Drip Irrigation System on Planning and Management of Water Delivery in a Large-Scale Irrigation Scheme in Morocco

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Abstract Increasing water scarcity is lowering the agricultural production of the Tadla region in Morocco. This necessitates the Moroccan government to actively stimulate farmers about converting their irrigation systems from surface irrigation (furrow) to drip irrigation and subsidize the investment costs by 80%–100%. Therefore, this study aimed to clarify the impact of the drip irrigation system on the planning and management of water delivery after the conversion program from surface (furrow) irrigation to drip irrigation in the Beni Amir irrigation district on the right side of the Tadla region. The water management practices before and after conversion were gathered through discussions and interviews with officials and representatives of the management team responsible for the study irrigation scheme. An open questionnaire survey was also conducted, focusing on farmers' irrigation management practices such as on-farm water distribution methods, application rate, water adequacy, and equity water satisfaction level before and after conversion, and the results were analyzed by paying attention to their farms' upstream, midstream, and downstream locations. The analysis reveals that most of the interviewed farmers indicated satisfaction with equitable water distribution. Some variations in the water management system may occur due to the conversion project, such as an increase in irrigation time and increased cost and labor in water management. These will have an impact on the CDA's (Agriculture Development Center) overall water management monitoring and planning at the tertiary canal, as well as farmers' water management labor.

Keywords water scarcity, surface irrigation, drip irrigation, water management

INTRODUCTION

Morocco is among the most water-stressed countries in the world. Since the late 1970s, Morocco has seen its water inflows (from surface water) decline, from an annual average of 22 billion m^3 between 1945 and 1978 to an annual average of 15 billion m^3 between 1979 and 2018 (World Bank, 2022). The main strategy for adaptation to climate change in this region is the conversion from surface irrigation to drip irrigation. Consequently, the region needs rational and sustainable management of irrigation water. One of the solutions to save water in this area is to optimize irrigation inputs based on water availability and agricultural water demand according to the real needs of crops and in agreement with their phenological development. This necessitates the Moroccan government to actively stimulate farmers about converting their irrigation systems from surface irrigation (furrow) to drip irrigation and subsidize the investment costs by 80%–100%. Farmers owning more than 5 ha can apply for a subsidy of 80%, while those with 5 ha or less can apply for subsidies of 100%. These subsidies are part of the National Irrigation Water Saving Plan of 2007, which was summarized in the Green Morocco Plan in 2008. The National Irrigation Water Saving Plan aims to counterbalance the water deficits that the country faces. According to the plan, stimulating the conversion of 550,000 ha (of these, 217,940 ha will be through collective conversion and 332,060 ha through individual conversion (Belghiti, 2009)).

The Irrigation Management Transfer (IMT) of the 1970s attempted to establish the water user’s association (WUA) after government-built irrigation facilities and transferred management to the WUA. Also, in participatory irrigation management (PIM) proposed by the World Bank since the 1990s, beneficiary farmers' participation in all irrigation development processes (construction, operation, management, and maintenance) has been required (Samad and Vermillion, 1999). Many researchers have proposed ways to manage and regulate the allocation and distribution of commonly held resources by human communities. Elinor Ostrom's framework has inspired a robust commons literature that investigates how human communities manage and regulate the allocation and distribution of commonly held resources. The earliest, and perhaps most well-known, strand in this common’s literature deals with the distribution of natural resources, with an emphasis on the use or consumption of these resources (Azergun, 2020). Eight frameworks were designated by Ostrom for equitable and effective management of the commons (the commons are those things or resources that people own together), which requires both effective institutional arrangements and shared social capital among system participants (Ostrom, 2009; Ostrom et al., 2003).

OBJECTIVE

A brief survey was conducted to clarify the impact of drip irrigation on the planning and management of water delivery after the conversion program from surface to drip irrigation at the Beni Amir irrigation scheme in the Tadla region. The data collected and the results analyzed can be used as preliminary findings to guide future research.

METHODOLOGY

Study Area

The Beni Amir irrigation district is located on the right side of the irrigated perimeter of the Tadla region in the southwest of Morocco and has a total irrigated area of 34,000 ha. The outline of the Beni Amir irrigation district is shown in Fig. 1. The study area is in the arid and semi-arid regions, receiving about 300 mm of rainfall per year, most of which is received during the rainy season from November to March. The main crops are alfalfa, olives, maize, fruits (citrus), sugar beets, wheat, and vegetables. The irrigation water source is the Ahmed El Hansali Dam reservoir. Water released from the dam is distributed to the fields via the main, lateral (14 canals), and tertiary canals. Surface irrigation has been commonly practiced, and drip irrigation has been recently introduced under the Green Morocco Plan.

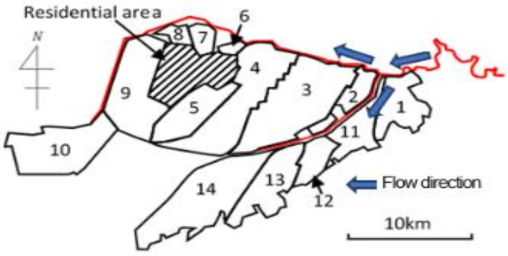

Fig. 1 The outline of the study area

The red line is the main canal, and the numbers represent farm blocks served by 14 lateral canals.

Data Collection and Analysis Methods

Data were gathered through discussions and interviews with officials and members of the irrigation scheme's management team. The layout of the irrigation system of the Beni Amir irrigation district was collected from the Regional Office on Agriculture Enhancement, Tadla (ORMVAT). Regarding the management and operation of the irrigation organization, a guided discussion was held with the responsible management team, which is Watershed Management Agency (ABHOER). An open questionnaire survey with 13 farmers (4 farmers at upstream, 5 farmers at midstream, and 4 at downstream locations) was conducted. The information gathered consists of farmers' socioeconomic conditions, farming methods, satisfaction levels for water sufficiency and equity, and some of their challenges regarding the newly introduced drip irrigation methods. The questions were asked individually through a face-to-face interview with farmers in the study of irrigation scheme. The field survey was conducted in September 2022, and it was an extreme drought year when compared with the last 20 years' record of rainfall data. Also, Farmers were unable to obtain water from the dam due to the drought, so they dug deeper wells up to 500 meters to get water. This eventually led to an overuse of groundwater, which has resulted in decreased quality and quantity for many farmers. The water management structure and distribution systems of the Beni Amir irrigation scheme were investigated before the conversion.

The irrigation scheme has established water management organizations in which government agencies control, plan, and decide on water distribution methods for beneficial farmers. This is a rare case in the management of public irrigation schemes. Although there is WUA, it does not function regarding PIM. In an ideal situation, WUA, which is composed of beneficiary farmers, takes on the responsibilities of operation, management, and maintenance of the irrigation systems after their development through the PIM concept. Hence, it may be required to investigate how equitable water distribution was accomplished without the PIM concept of water management. Elinor Ostrom suggests 8 frameworks to initiate sound collective action for equitable and sustainable commons management, which it seeks to employ in various scales and configurations. Therefore, Ostrom's frameworks were used to diagnose the current water management system of the Beni Amir irrigation scheme.

Water Management System and Planning

In each irrigation season, the water delivery plan from the dam to the Beni Amir irrigation district is decided in consultation with ABHOER, which is responsible for water resources management in the Tadla region, and ORMVAT, which is responsible for water distribution planning and management in the irrigation districts of the Tadla region. The amount of water to be distributed is communicated to the Agriculture Development Center (CDA), which is responsible for managing the distribution of water to the tertiary canals. The CDA coordinates the farmers' requests for water distribution, determines the date, time, and volume of water to be distributed to each field, and distributes water to the tertiary canals. The responsibility of water distribution in the field canals is left to each farmer during his scheduled irrigation period, which is decided by the ORMVAT and ABHOER (Katsuyuki et al., 2022). The schematic diagram of water supply and management responsibilities is shown in Fig. 2.

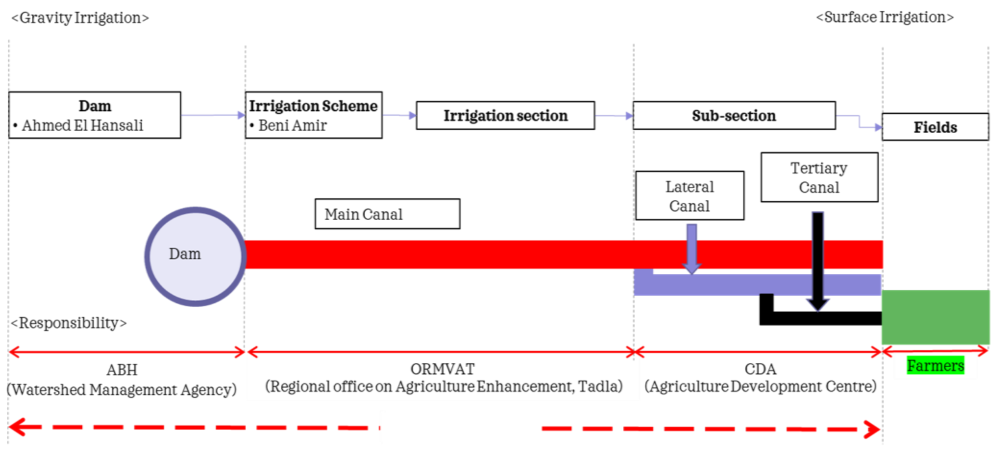

Fig. 2 The schematic diagram of water supply and responsibilities for management

RESULTS AND DISCUSSIONS

General Evaluation of Water Management Concerning Ostrom's 8 Frameworks for Managing the Commons

The survey result in Fig. 3 revealed that even though the study irrigation scheme is run by government organizations, the majority of farmers who were surveyed expressed satisfaction with how fairly water is distributed and managed. As a result, it is necessary to examine how equitable water distribution was accomplished without the PIM concept of the water management system.

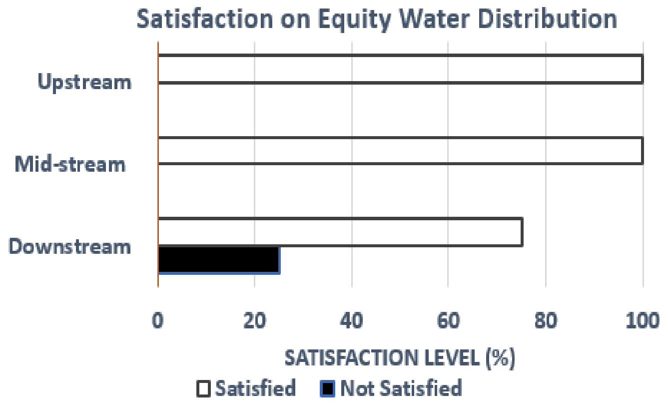

Fig. 3 Survey result of farmer's satisfaction with equity water distribution

The Beni Amir irrigation scheme's adherence to the eight frameworks for managing the commons with the rules employed in water management and planning will help explain how it was able to sustain itself without using the PIM concept while still providing fair water distribution to farmers.

Table 1 demonstrated that the 8 management frameworks proposed by Elinor Ostrom had been adhered to. This supported the irrigation system's successful management and equitable water distribution to farmers.

Table 1 Eight frameworks of managing the common by Elinor Ostrom

Nos.	8 Frameworks of managing the common by Elinor Ostrom	Result
1	Commons need to have clearly defined boundaries	Yes
2	Rules should fit local circumstances	Yes
3	Participatory decision-making is vital	Yes (by Govt)
4	Commons must be monitored	Yes
5	Sanctions for those who abuse the commons should be graduated	Yes (by Govt)
6	Conflict resolution should be easily accessible	Yes
7	Commons need the right to organize	Yes (by Govt)
8	Commons work best when nested within larger networks	Yes (by Govt)

Effect of Change to Drip Irrigation on Water Management

The conversion is done in such a way that farmers utilize the tertiary canals to get and store water in the newly constructed small pond for drip irrigation purposes. The storage capacity of the pond for farmers with less than 5 ha is 3,200 m^3 (20 m x 20 m x 8 m) and is connected to the tertiary canal as the main water source. Water is temporarily stored before being pumped to the overhead tank and used for drip irrigation. Therefore, farmers can store water during their scheduled rotation time and use it for drip irrigation as needed.

The findings of this study indicated that the conversion project may cause certain changes to the water management system, which could have an impact on the CDA's and farmers' long-term monitoring and planning of water use. The changes are highlighted below.

Storing More Water in the Newly Constructed Small Ponds for Drip Irrigation

Farmers have a chance to store enough water more than is required during their existing scheduled rotation time. If before the conversion, 3 hours were scheduled for each farmer, now that farmers can store water, they may need at most 24 hours (30 l/s X 3600 X 24 = 2,592 m^3) to be able to have enough water to pump to their overhead tank. Therefore, the average water rotation time will increase, making it difficult to adjust with non-converted farmers to achieve equity in water distribution during times of scarcity.

The ability of farmers to divert and store adequate water during their unscheduled rotation phase may lead to an increase in water theft. Therefore, CDA will increase the level of supervision and monitoring. Consequently, the CDA's labor and water management costs will rise as well. However, when there is enough water in their ponds, farmers can schedule their irrigation period as desired. Farmers will then spend less time managing their water resources.

Change in the Cropping Pattern

According to the survey, most of the farmers’ cropping patterns changed after the conversion to drip irrigation. Before the conversion, farmers usually plant cereal and forage crops such as maize, alfalfa, etc. to provide food for their livestock. After the conversion, farmers are now planting fruit trees, particularly citrus and olive trees, as they are high-value crops and to compensate for the running expenses of drip irrigation. The non-converted farmers may require more water to irrigate their cereal and forage crops through surface irrigation. Since the CDA allocates an equivalent amount of water to farmers before the conversion, the water allocation plan will change with the conversion. This will also affect the water scheduling plans of both the CDA and the farmers to suit each farmer’s irrigation method.

Farmers’ Low Capacity for Using Drip Irrigation

The survey showed that many farmers have limited knowledge about the operation and maintenance of drip irrigation. This makes them reluctant to introduce the conversion project. The partial conversion of some farms may require regular monitoring and supervision to ensure proper scheduling is followed. This will increase the CDA's water management labor and costs.

Increase in Groundwater Use

Farmers are now able to pump water from wells and store it in their small ponds. This will increase groundwater withdrawal and may lead to groundwater overexploitation. The impact of the overexploitation of groundwater resources on their quantity and quality can be witnessed by many farmers, as discussed during the survey. Also, farmers increased the frequency and duration of their irrigation after the conversion project. Due to the extreme drought of the year 2022, farmers cannot get water from the canals. Therefore, most farmers try to deepen their wells to about 500 m to get adequate water to store in their small ponds.

CONCLUSION

The impact of the drip irrigation system on water delivery planning and management following the conversion of surface (furrow) irrigation to drip irrigation was studied. Based on the findings, the following were concluded.

(1) Farmers had equitable water distribution, as most farmers interviewed expressed satisfaction with equitable water distribution. Compliance with Ostrom's eight frameworks may aid in the successful management of the irrigation system and equitable water distribution to farmers.

(2) Some changes occur as a result of the conversion project, which may have an impact on the CDA's and farmers' overall water management monitoring and planning. These include as follows;

(i) Storing more water in the newly constructed small ponds for drip irrigation

(ii) Change in the cropping pattern

(iii) Farmers' low capacity for using drip irrigation

(iv) Increase in groundwater use

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Research article

Conditions of Bio-Slurry Application in Crop Production in Kampong Cham Province, Cambodia

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Abstract Bio-slurry is an organic fertilizer produced from the decomposition of organic waste or residues in anaerobic digestion. It is applicable for improving vegetable production as it contains necessary nutrients such as nitrogen (N), phosphorus (P), and potassium (K) for plant growth and organic matter that improves soil structure and water-holding capacity. About 29,000 biodigesters have been installed across Cambodia using animal waste to produce biogas, so huge quantities of bio-slurry are produced. Therefore, this study aimed (1) to assess the conditions of bio-slurry application in crop production in rural areas, (2) to determine NPK content in the bio-slurry, and (3) to estimate annual bio-slurry production and NPK production from biodigesters. The research was conducted between April and September 2022 by selecting 30 farming households that have biodigesters and use bio-slurry for crop cultivation in Prey Chhor District, Kampong Cham Province. It was found that 70% of the farmers used bio-slurry for rice cultivation and 16.7% for backyard vegetables, basically before planting. The nutrient content of slurry produced from cow manure consists of 0.20% N, 0.22% P, and 0.44% K. Most farmers preferred to use solid slurry for rice cultivation and liquid slurry for vegetables such as chili peppers, sweet peppers, eggplant, spinach, mustard greens, and cucumbers. However, bio-slurry was commonly mixed with chemical fertilizer in the crop growth stage. Farmers are willing to use both slurry and chemical fertilizers as this helps the plants to grow well and have higher yields.

Keywords bio-slurry, biodigesters, crop production, vegetables, chemical fertilizer

INTRODUCTION

The installation of biodigesters has increased in rural Cambodia due to the need to help small-holder farmers manage animal waste and convert it into energy for cooking and other applications in their livelihoods. They also utilize bio-slurry, a by-product produced from biogas production, as organic fertilizer for crops. According to a 2019 assessment report released by the National Biodigester Program (NBP), almost 29,000 digesters have been constructed across Cambodia in the period 2006-2012. Farmers normally raise cattle and use animal manure as a substrate for the biodigesters, and apply slurry, sometimes mixed with compost or other organic fertilizer, to their backyard vegetable garden and rice cultivation (Hyman and Bailis, 2018). In 2020 alone, of the planned 1,500 biodigesters, 703 were constructed, which was equivalent to 47% (NBP, 2019). Among all the installed biodigesters, it is reported that there are approx. 2,353 digesters used by small-holder farmers in Kampong Cham Province, which is well-known for agricultural production on a large landscape. Among all the districts in this province, Prey Chhor, Choeung Prey, and Kong Meas had the highest number of biodigester installations compared to others (PDAFF, 2021).

In Cambodia, vegetable production was reported to be approx. 716,000 tones in 2020, even though this country experienced covid-19 pandemic and strict lockdowns. Yet, it was seen as a great opportunity for the agricultural sector to increase local production by reducing dependency on agricultural imports from the neighboring countries. Until now, it is also noticed that chemical fertilizer has still been in high demand, as farmers consume it in their crop production when compared to organic fertilizer in the form of compost or bio-slurry (Phnom Penh Post News, 2021). Technically, bio-slurry is considered one of the most efficient organic fertilizers, when applied to crops, since it is produced through anaerobic digestion. Therefore, it can be used instead of chemical fertilizer in every stage of crop growth. Furthermore, slurry also helps increase crop yield by 30%, when compared to chemical fertilizer, which leads to a reduction in production costs of 50% (Hyman and Bailis, 2018). One study showed that a 25 m^3 digester can produce 9,780 kg of bio-slurry annually, consisting of 76 kg of nitrogen (N), 107 kg of phosphorus (P), and 107 kg of potassium (K), respectively (Kissan, 2019). That finding also indicated that bio-slurry contains 93 % water and 7% dry matter of which 4.7% was organic matter and 2.5% was inorganic matter (Kumar et al., 2015). In addition, the utilization of bio-slurry was efficient in accelerating crop growth and increasing vegetable yield in both seasons. Aina (2018) illustrated that 50% bio-slurry mixed with 50% chemical fertilizer was more efficient than 100% of chemical fertilizer in promoting crop growth and yield because the bio-slurry had only high N content, whereas other nutrients were obtained from chemical fertilizer.

Bio-slurry can be a major solution for farmers who intend to use organic fertilizer to improve their crop production, and this comes at the right time due to the increase of biodigesters in rural areas.

OBJECTIVE

This study aimed to (1) to assess the conditions of bio-slurry application in crop production in rural areas, (2) to determine NPK content in the bio-slurry, and (3) to estimate annual bio-slurry production and NPK production from biodigesters.

METHODOLOGY

The study was conducted between April and September 2022 by starting with collecting basic information and designing a questionnaire for a survey. The study employed purposive sampling as a case study by selecting 30 households with biodigesters in Svay Prey commune, Prey Chhor District, Kampong Cham Province (Fig. 1) due to high household biodigester consumption. To obtain sufficient information, data such as type of bio-slurry application, size of the biodigester, type of substrates used for biodigesters, and crop type were collected.

To determine the NPK content in bio-slurry, samples were collected from 3 different household digesters in the studied area, packed, and stored at 5 ^{0}C for laboratory analysis. For the lab's activities, these three samples were mixed then using reagents (TN, TP, TK diluting with a sample with a mass of 100 g for each parameter to determine NPK content following ISO 11261, 11263, and 17319 respectively whereas, total organic carbon (TC) also measured by Walkley and Black method.

Estimation of daily and annual bio-slurry production from biodigester using cow dung as a substrate can be calculated based on the following Eq. (1). This estimation is based on the research by Kumar et al. (2015), who found that 1 kg of cow dung produces 0.3 kg of bio-slurry, or 30%, daily. Technically, daily manure fed into biodigesters sized 4, 6, and 8 m^3 is equal to 30, 50, and 70 kg/day, respectively (Hyman and Bailis, 2018).

$$Q_{slurry}\left(\frac{tons}{year}\right) = Daily\ manure\ (\frac{kg}{day}) \times percent\ of\ bio - slurry\ x\ 365\ days \quad (1)$$

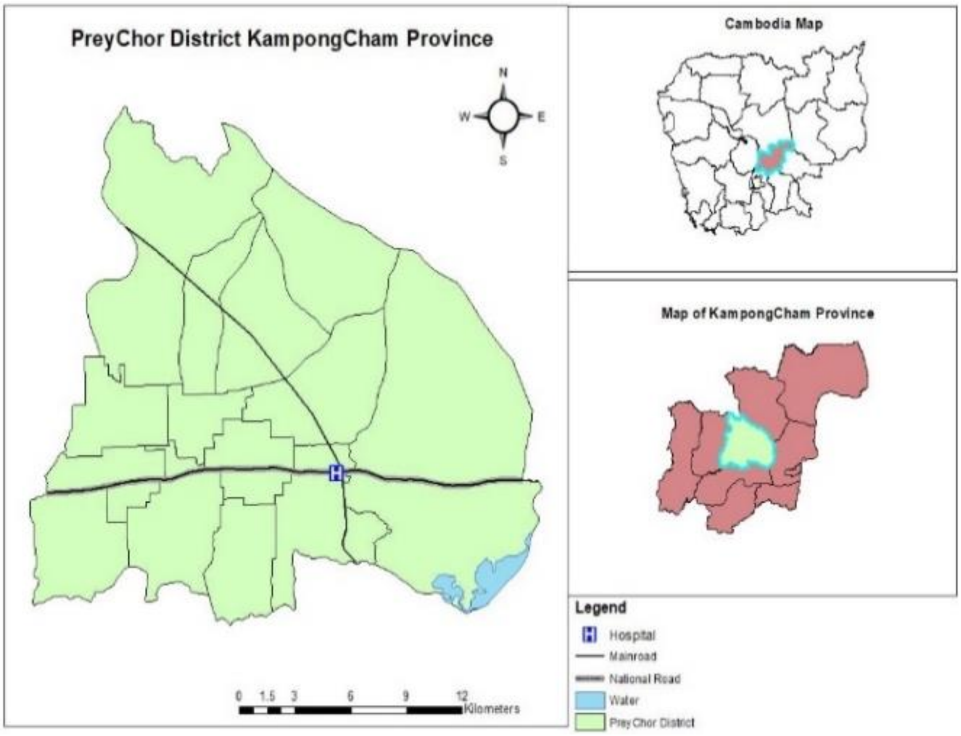

Fig. 1 A map of Prey Chhor District, Kampong Cham Province

Data Analysis and Interpretation

Descriptive statistics were employed to analyze quantitative data collected in the survey, and frequency tests were also used in the hypothesis to examine the relationship between two variables to determine the significant difference in data. Besides this, data was also organized in tables and graphs based on the types of questions and responses in Microsoft Excel.

RESULTS AND DISCUSSION

General Characteristics of Farm Households

Among 30 households, there are 50% of female farmers and 50% of male farmers whose age was 57±12.17 years (Table 1). The average household size was 4 ± 1.35. For the education status, 56.7% of farmers were at the primary school level, whereas only 26.6 % went to high school, and 16.7 % were illiterate. Regarding biogas installation, 100% of biodigesters are concrete fixed-dome digesters, of the sizes 3, 4, 6, and 8 m^3, 53% of biodigesters had a volume of 6 m^3, while 20% were 4 m^3 biodigesters. The farmers mostly raised cows, so that cow manure could be used as a main substrate for biogas production. Of all the interviewees, 97% used cow manure as a substrate.

Nutrients in Bio-Slurry / Substrate Source (Cow)

Table 2 shows that bio-slurry contained 0.2% total nitrogen (TN), 0.22% total phosphorus (TP), 0.44% total potassium (TK), and 2.77% total organic carbon (TOC). With this result, the C/N ratio was calculated to be 13.9, while the pH was 7.11. In contrast, based on the study of (Kumar et al., 2015), the nutrient content of bio-slurry from cattle was between 1.4% and 1.8% of TN, 1.1-2% of TP, and 0.89-1.2% of TK. The result of low NPK content in this study might be due to different cow species and feed types used for cows in Cambodia, whereas they raised the local breed of cattle and mostly fed their local grass and brewery waste with a high protein content.

Moreover, the nutrient content of compost consisted of 0.5-1.5% TN, 0.4-0.8% TP, and 0.5-1.9% TK, while the nutrient content of fresh cattle manure contained 0.5-1% TN, 0.5-0.8% TP, and 0.5-0.8% TK in the same study. Additionally, Bonten et al. (2014) indicated that cattle slurry consists of 1.3-1.5% of N, 0.3-2.8% of P, and 0.3-1.4% of K, whereas swine slurry consists of 1.8-2.7% of N, 0.8-3.3% of P, 0.5-0.8% of K, respectively.

Table 1 General characteristics of the farmers

Variables	Mean ± SD	Number of interviewees	
		Person	Percentage (%)
Sex	-	-	-
Male	-	15	50.00
Female	-	15	50.00
Age (year)	57 ± 12.17	-	-
Household size (person)	4 ±1.35	-	-
Education	-	-	-
Illiteracy	-	5	-
Primary school	-	17	56.70
Secondary school	-	0	0.00
High school	-	8	26.66
Type of biodigester	-	-	-
Concrete fixed dome	-	30	100.00
Other types	-	0	0.00
Digester size (m^3)	-	-	-
3	-	1	3.00
4	-	6	20.00
6	-	16	53.00
8	-	3	10.00
Type of substrate	-	-	-
Cow manure	-	29	97.00
Others	-	1	3.00

Table 2 Nutrient content in bio-slurry freshly produced from cow manure

No.	Parameters	Unit	Testing result (%)
1	Total nitrogen (TN)	g/100g	0.20
2	Total phosphorus (TP)	g/100g	0.22
3	Total potassium (TK)	g/100g	0.44
4	Total organic carbon (TOC)	g/100g	2.77
5	C: N Ratio	g/g	13.90
6	pH	-	7.11

Estimation of Daily Bio-slurry Production

Table 3 compares the annual bio-slurry production by three sizes of biodigesters. Generally, the 8 m^3 digester requires 70 kg/day of cow manure and can produce 21 kg of bio-slurry daily or 8 tons/a. For a 6-m^3 sized digester, the daily and annual bio-slurry production would be 15 kg and 5 tons/year respectively for the 4-m^3 digester, about 9 kg of bio-slurry is produced per day, or 3 tons/year. In comparison with Kumar et al. (2015), animal manure generated 256.2 Mt each year, and total annual biogas slurry was 76.8 Mt/year which was a huge amount of bio-slurry produced from biodigesters and they were recoverable approx. 60% of total produced dung (resourced from cattle+ buffalo) while the total estimated potential of biogas plants was in total 12 million plants for generating biogas and bio-slurry daily in India.

Table 3 Estimation of daily and annual bio-slurry production

Digester volume (m^3)	Daily slurry production (kg/day)	Annual slurry (ton/year)
4	9	3
6	15	5
8	21	8

Figure 2 shows the comparison of NPK content in bio-slurry annually produced in the three sizes of biodigesters. It is seen that the annual TK yield in bio-slurry was higher than the others. Starting with annual TK production in bio-slurry, it varied from 1.45 to 3.37 tons/year of P produced from an 8 m^3 sized digester, while TN of 0.66 tons/year was obtained from one unit of a 4 m^3 sized digester, 1.1 tons/year for a 6 m^3 sized digester, and 1.53 tons/year for an 8 m^3. However, the finding was relatively low when compared to Kumar (2015) who found that nitrogen content was 1.15 Mt in 76.8 Mt slurry produced annually. Additionally, Martinez-Suller et al. (2010) found that the average TN, TP, and TK yields from cattle slurry were 3.43 kg/m^3, 0.56 kg/m^3, and 4.41 kg/m^3 respectively.

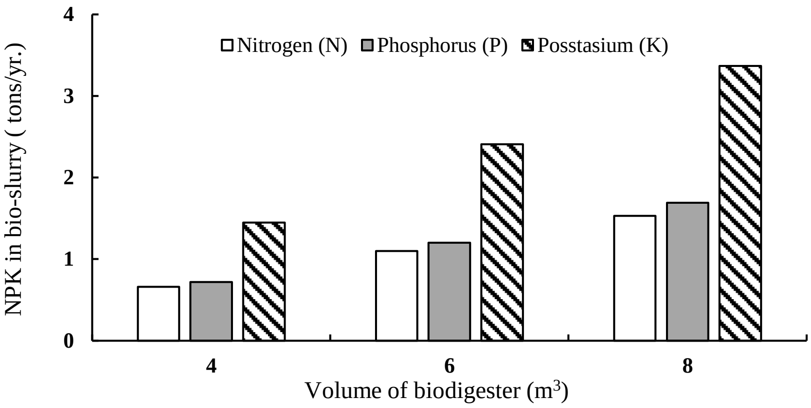

Fig. 2 Comparison NPK content in bio-slurry annually produced in different sizes of digester

Proportion of the Farmers Applying Bio-Slurry for Crop Production

It is observed that most of the farmers applied the slurry in solid state (Fig. 3). About 63.3 % of the farmers applied solid slurry for their crop production, whereas only 13.3% consumed liquid bio-slurry, and around 23% (Table 4) used both solid and liquid bio-slurry in their crop production.

Table 4 Type of slurry application

Type of slurry application	Numbers	Percentage (%)
Wet	4	13.33
Dry	19	63.33
Both	7	23.33

Nevertheless, all the interviewees were willing to utilize dry or solid slurry for their rice production, and they all also applied liquid slurry for leafy vegetables such as water morning glory, lettuce, onion leaf, mustard greens, and spinach. Additionally, 70% of the farmers utilized solid slurry for fruity vegetables like eggplants, cucumbers, sweet peppers, and chili peppers, whereas 30% preferred liquid slurry. On the other hand, it is observed that before having biodigesters, the respondents used chemical fertilizer only, for both rice and vegetables. After the installation of bio-digesters, the consumption of chemical fertilizer for rice production was reduced by 39% and by 35%

for vegetable production. Concerning the liquid slurry application, one study (Musse et al., 2020) reiterated that a mixture of bio-slurry in liquid state and N-inorganic fertilizer applications provided a high yield of green bean (fruity vegetable) and improve both soil physio-chemical properties.

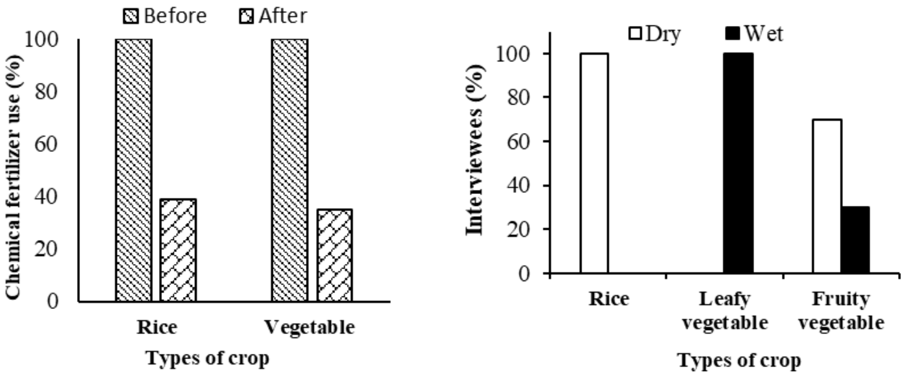

Fig. 3 Types of slurry application and percentage of chemical fertilizer use in different crops

CONCLUSION

In conclusion, bio-slurry production varies based on the amount of cow dung fed into biodigesters daily. In the meantime, the nutrient content of bio-slurry had higher potassium (K) than other sub-nutrients such as nitrogen (N) and phosphorus (P). For bio-slurry application, most farmers always applied solid bio-slurry for crops, and all farmers prefer to use solid slurry for rice and liquid forms for vegetables. Furthermore, the use of slurry can replace and reduce chemical fertilizers in crop production. Finally, the farmers still mix chemical fertilizer with bio-slurry because they think it is key to obtaining good quality and high-yield crops. Therefore, further research should be performed to identify the impacts of bio-slurry on crop growth and yield for better documentation and wider adoption.

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Research article

Determination of Histamine Level and Its Correlation with Viable Bacterial Count in Cambodian Fermented Fish

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Abstract Nem trey (NT), Sangvak (SV) (minced fish), and Nem sbek chrouk (NC) (minced fish mixed with pork skin) are fermented fish products popular in Cambodia; NC and NT are ready for direct consumption after two or three days of fermentation, while SV must be additionally grilled before consuming. However, food safety standards for these products including control of biogenic amines such as histamine are neglected, which could pose a health problem. Biogenic amines are nitrogenous organic chemical compounds mainly produced from the decarboxylation of amino acid, histidine, by the activity of certain bacteria associated with fish products processed under poor hygiene and unstable temperature control. This study aimed to determine the histamine level in NT, SV, and NC products and studied its correlation with the viable bacterial count (BVC). Twenty-six samples, NT (n=12), SV (n=5), and NC (n=9), were collected from different producers from Battambang (BB) and Kratie (KT) provinces. A histamine test kit utilizing a colorimetric enzymatic assay, was used to determine histamine level. The BVC was done using the spread plate technique on Luria Bertani agar media incubated at 37ºC for 24h. For KT province, NT and NC contained BVC ($\log_{10}$ CFU/g) in the range of 5.74±0.02 to 6.57±0.01 and 5.52±0.01 to 5.98±0.01, while histamine (mg/kg) ranged from 0 to 156.43±0.13 and 28.76±0.71 to 73.87±0.13, respectively. SV, NT, and NC from BB province contained the BVC ($\log_{10}$ CFU/g) ranging from 6.02±0.16 to 6.56±0.15, 5.97±0.15 to 6.04±0.15, and 5.69±1.18 to 6.12±0.11, while histamine (mg/kg) ranging from 6.10±0.44 to 54.52±0.00, 0 to 10.90±0.14, and 0 to 38.54±0.00, respectively. The BVC and histamine showed a significant correlation, with a value of 0.448 (p-value < 0.05). Therefore, raw materials, processing, and storage conditions along the production chain should be evaluated in further studies to ensure safety of the fermented fish products.

Keywords biogenic amine, viable bacterial count, fermented fish, food safety

INTRODUCTION

Fish and fishery products have long been associated with people's socioeconomic lives. To preserve fish, fermentation is one of the oldest and most cost-effective methods (Uochoi, 2019). Fish fermentation is practiced in many parts of the world, but the most popular practice is found in Southeast Asia, including Cambodia. Generally, the common fermented fish product in Cambodia includes prahok (fish paste), teuk trey (fish sauce), trey praherm; trey proma (salted fish), and mam trey, paork, and nem (other fermented fish) that have played an essential part of the typical diet in Cambodia involved to fermented fish (Ly et al., 2018, 2020). Among these types of Cambodian fermented fish products, Nem such as Nem trey (NT), Sangvak (SV) (minced fish), and Nem sbek chrouk (NC) (minced fish mixed with pork skin) are the fermented fish products that usually take two to three days for fermentation. These ready-to-eat appetizers, except for Sangvak, which needs to be grilled before consumption, are popular among Cambodians.

Potentially pathogenic bacteria such as *Bacillus*, *Clostridium*, and *Staphylococcus* were found in traditional Cambodian fermented fish products (Chuon et al., 2014; Ly et al., 2018). So, fermented fish products can contain microorganisms that affect human health. Chemical compounds and microbiological contamination can cause acute poisoning or long-term disorders such as cancer (Ruiz-Capillas and Herrero, 2019). Another study reported that many bacterial isolates from Cambodian fermented fish products were from the non-lactic acid bacteria (LAB) genera, including *Staphylococcus, Bacillus*, *Clostridium, Virgibacillus, Kocuria*, *Clostridium, Lisinibacillus, Psychrobacter, Lantibacillus,* and *Micrococcus* (Chuon et al., 2014).

Next to microorganisms, a toxic chemical substance such as biogenic amines (BAs) is the most common compound associated with fermented fish (Visciano et al., 2012). Biogenic amines are basic nitrogenous chemicals with various structures that may be found in various foods, including fish and fishery products, meat and animal products, cheeses, wine, beer, and other fermented meals and beverages (Durak-Dados et al., 2020). Histamine, tyramine, putrescine, cadaverine, and b-phenylethylamine are the most significant BAs in foods and drinks, both qualitatively and quantitatively, as a result of the decarboxylation of histidine, tyrosine, ornithine, lysine, and phenylalanine, respectively (Spano et al., 2010). Fish and fish products show the highest levels of BAs in previous studies (Linares et al., 2011; Durak-Dados et al., 2020). Among all types of biogenic amines, histamine (HIS) is the most concern BAs related to food safety (EFSA, 2011) as histamine has been shown to cause severe symptomatology such as skin rashes, headache, nausea, diarrhea, and variations in blood pressure (Botello-Morte et al., 2022). The synthesis of histamine in mackerel and other marine fish carrying high levels of endogenous histidine is linked to the action of microflora rather than the activity of a decarboxylase found natively in fish (Durak-Dados et al., 2020). Histamine consumption of 8-40 mg, 40-100 mg, and more than 100 mg may generate mild, moderate, and severe poisoning, respectively (Sahu et al., 2016). European Union limited the histamine level in food products by 100 mg/kg on average, no one sample exceeds 200 mg/kg, and no more than two samples may each have a value of more than 100 ppm, but less than 200 ppm for nine samples tested (EFSA, 2007).

Microorganisms, known as factors, that affect the formation of biogenic amines and histamine formation, have been reported. The genus *Photobacterium*, *Aeromonas hydrophila*, and Enterobacteria such as *Morganella morganii*, *Enterobacter aerogenes*, *Raoultella planticola*, and *Klebsiella oxytoca* are involved in the accumulation of histamine in fish and seafood products (Fernández-No et al., 2010; Küley et al., 2013). Some fungi (yeast and molds) are implicated in BAs formation, although their significance is debatable in several ways (Tristezza et al., 2013). Poor raw material quality and improper handling are two reasons for including BAs in fermented fish (Ruiz-Capillas and Herrero, 2019).

OBJECTIVE

According to the relation between histamine level and microorganisms, this study aimed to determine the histamine level and identify the correlation between histamine level and viable bacterial count in Cambodian fermented fish, Nem, collected from two provinces, including Battambang and Kratie. This study provides insight into predicting the safety of the fermented fish product and can be a supporting document for standard quality development for the fermented fish product in Cambodia.

METHODOLOGY

Samples Collection

Twenty-six samples were collected from local producers in two provinces in Cambodia, Kratie (KT) and Battambang (BB) provinces. From KT, there were 11 samples collected, and separated into three types of samples such as fermented fish packaged by banana leaves, Nem Trey (KTNTB) three samples; fermented fish packaged by plastic, Nem Trey (KTNTP) four samples; and fermented fish mixed with pork skin, Nem Sbek Chrouk (KTNCB) four samples were collected. Whereas for BB province, 15 Nem samples were collected including Songvak (BTBSV) five samples, Nem Trey (BTBNT) five samples and fermented fish with pork skin, Nem Sbek Chrouk (BTBNC) five samples.

Table 1 Description of collected samples

Province	Type and number of samples	Sample code	Main ingredient
Battambang	Nem trey (fermented fish) (n=5)	BTBNT	Fish
	Nem sbek chrouk (fermented fish mixed with pork skin) (n=5)	BTBNC	Fish and pork skin
	Songvak (fermented fish) (n=5)	BTBSV	Fish
Kratie	Nem trey (packaged by banana leave) (n=3)	KTNTB	Fish
	Nem trey (packaged in plastic) (n=4)	KTNTP	Fish
	Nem sbek chrouk (packaged by banana leave) (n=4)	KTNCB	Fish and pork skin

Viable Bacterial Count Analysis

The enumeration of viable bacterial count (BVC) was done using the spread plate technique. For each Nem product, a homogenized sample of 10g was diluted with 90 mL of phosphate-buffered saline (PBS). Appropriate dilutions of the samples were prepared using the same diluent. Then 0.1mL aliquots of each dilution were applied to Luria Bertani agar media and spread on its surface until completely absorbed. Plates were then incubated at 37℃ for 24 hours. The colonies counting of BVC were presented as logarithms colony-forming units per gram ($\log_{10}$ CFU/g).

Histamine Concentration Analysis

The sample preparation and extraction followed the manufacturer's instructions for the extraction kit (Kikkoman Biochemifa, Tokyo, Japan). 10 g of each Nem sample was first homogenized, and 1 g of the homogenized sample was diluted with 24 ml of sample treatment buffer (EDTA) in a centrifuged tube. The tube was vortexed for 30 mins and then boiled for 20 mins. The tube was cold by placing it on an ice box (until < 20°C). The tube was vortexed again and put in an ice box to separate the phase. The tube was centrifuged 10 000 x g for 5 min; then the supernatant was collected. 11 ml of deionized water was added to the colorimetric reagent vial. 6 ml of buffer vial was added to the enzyme reagent vial. The concentration of histamine (mg/kg or ppm) (HIS) was calculated by Eq. (1).

$$HIS = (Es - Eb) \div (Estd - Ec) \times 100 \quad (1)$$

The absorbance of the sample, Es, was measured by mixing extracted sample solution, colorimetric reagent, and enzyme solution. Eb stands for absorbance of sample blank obtained by mixing extracted sample solution, colorimetric reagent, and buffer. The absorbance of standard solution, Estd, by mixing standard histamine solution, colorimetric reagent, and enzyme solution. The last absorbance of reagent blank, Ec, got by mixing Distilled water, colorimetric reagent, and buffer. Absorbance was measured using a spectrophotometer (UV-1280, Shimadzu, Japan) with a 1 cm optical wavelength of 470 nm.

Statistical Analysis

Results units of the quantitative bacterial viable count were log_{10} CFU/g. The histamine content and viable bacterial count were analyzed with statistical analyses using the Statistical Package for the Social Sciences (SPSS, Version 20.0.0 for Windows, 2018; IBM Co., Somers, NY, USA). Data were analyzed for the degree of variation by calculating the result's mean and standard deviations (SDs). The significance of differences was evaluated using analysis of variance (ANOVA). A *p*-value of less than 0.05 was considered statistically significant. The correlation value was determined using the Pearson Correlation coefficient.

RESULT AND DISCUSSION

Evaluation of Viable Bacterial Count and Histamine Level

Figures 1 and 2 described the result of HIS and BVC, respectively. For KT province, Nem trey packaged by banana leaves and plastic (KTNTB and KTNTP) contained HIS (mg/kg) in the range from 6.35±0.48 to 156.43±0.13, while BVC (log_{10} CFU/g) showed a range from 5.74±0.02 to 6.57±0.01. However, Nem sbak chrouk described the HIS (mg/kg) in the range 228.76±0.71 to 73.87±0.13. At the same time, BVC (log_{10} CFU/g) presented from 5.52±0.01 to 5.98±0.10. On the other hand, from BB province, NT showed the range of HIS (mg/kg) from 0 to 10.90±0.14, while BVC (log10 CFU/g) represented from 5.97±0.15 to 6.04±0.15. NC showed a range of HIS (mg/kg) and BVC (log_{10} CFU/g) from 0 to 38.54±0.00 and 5.69±1.18 to 6.12±0.11, respectively. For Songvak, the data represented 6.10±0.44 to 54.52±0.00 and 6.02±0.16 to 6.56±0.15 for HIS (mg/kg) and BVC (log_{10} CFU/g), separately.

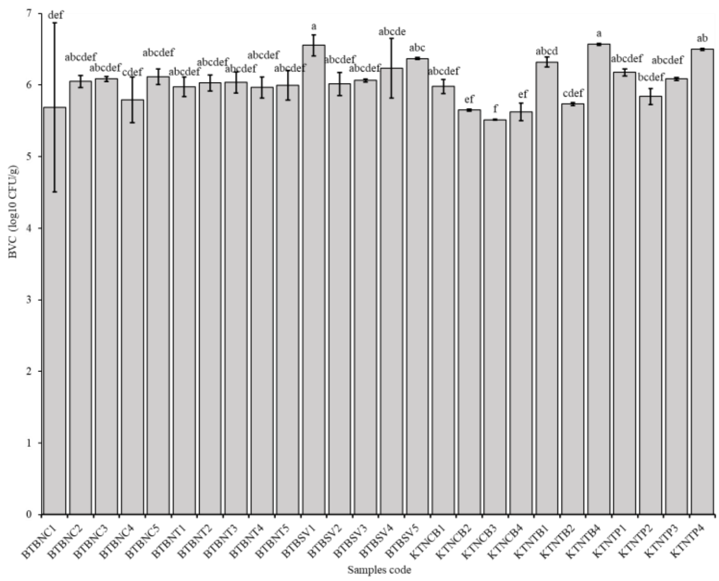

Fig. 1 Viable bacterial count in all samples

The result of all samples was compared with maximum limits. The US Food and Drug Administration (FDA) set the maximum of histamine in fish and fish products at 50 mg/kg (Ly et al., 2020), while European Food Safety Authority set the limit of histamine in fishery products at 200 mg/kg (EFSA, 2007). Seven in twenty-six samples exceed 50 ppm, and no one above 200 mg/kg. The safety of these fermented products should be slightly concerning. Previous studies on Cambodian fermented fish showed that the histamine concentration loaded in products ranged from 32 to 840 mg/kg (Ly et al., 2020). This result showed higher histamine levels, but it might be comparable with a concentration of histamine studied in this paper as the Nem products required only a few days to consume, while other fermented fish mentioned in that previous study were other types of fermented products that require a longer time to consume (Paork Chav, Paork Chau, and Mam Trey). The Malaysian fermented fish, *Budu*, detected 187 mg/kg of histamine concentration (Saaid et al., 2009). Histamine was found at a high concentration in *Feseekh*, Egyptian fermented fish (521 mg/kg) (Rabie et al., 2011).

The microbial ranged from 5.52 to 6.32 $\log_{10}$ CFU/g. The total cell counts identified on other Cambodian fish products were 5 to 7 $\log_{10}$ CFU/g for Prahok (fermented fish paste), 5 to 8 $\log_{10}$ CFU/g for Kapi (fermented fish), and 2 to 6 for Toeuk Trey (fermented fish sauce) (Chuon et al., 2014). The viable plate count found 6 $\log_{10}$ CFU/g in the Indonesian salt-fermented fish product (Kusmarwati et al., 2020). This information may be compared with each other for the same type of products (fermented fish products).

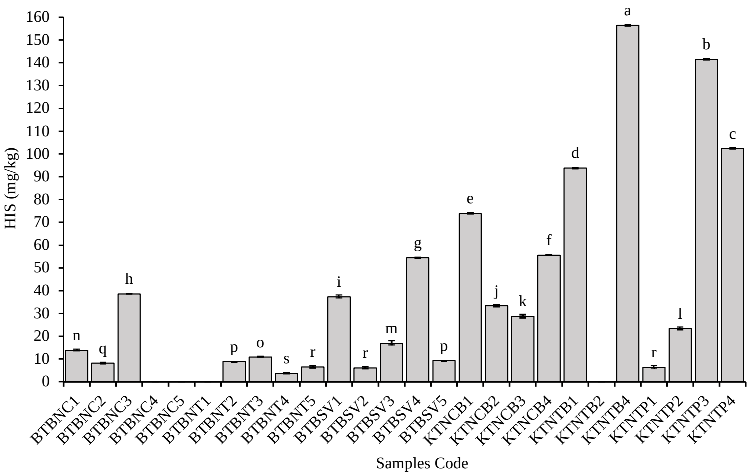

Fig. 2 Histamine content in all samples

As determined by One-way ANOVA and LSD tests in SPSS 2018. The significant differences of all samples are shown in script on the bar chart in Fig 1 and 2 for BVC and HIS, respectively. Statistically significant differences (p<0.05) were found among the defined concentration of histamine, except BTBSV2, KTNTP1, and BTBNT5 showed non-significant differences (p>0.05) and pair of BTBNT2 and BTBSV5 found that non-significant differences also (p>0.05). However, for the viable bacterial count, statistically significant differences (p<0.05) were found, but some of the group samples were described that they are non-significant differences (p>0.05). Moreover, comparing histamine levels with 50 ppm showed non-significant differences (p>0.05). In contrast, the significance differences (p<0.05) were found in analyzing 200 mg/kg histamine levels using the One Sample T-test. Table 2 showed the significant moderate correlation between histamine concentration and bacterial viable count value r=0.448, p<0.05, n=26 was found using Pearson Correlation. Sample form Kratie showed a non-significant different (p>0.05) between banana leave packaging and plastic packaging through Paired Samples T-test.

Table 2 Correlation between BVC and HIS by Pearson Correlation

		Viable bacterial count
Histamine content	Pearson Correlation	0.448
	Significant	0.022
	Number of samples	26

The histamine concentration and microbial loaded in these Nem samples were correlated. Therefore, to prevent the increase of histamine levels in Nem products, the elimination of microbial through applied raw material quality, good hygiene production, and cold processing line play an important factor in reducing histamine in food.

CONCLUSION

The histamine level, a formation chemical concerning food safety, in Cambodian fermented fish products, was studied on 26 samples collected from 2 different provinces in Cambodia. The range of histamine concentration was detected from 0 to 156.43 ± 0.13 mg/kg, with seven samples exceeding the maximum limit of 50 mg/kg set by the FDA. Microbial loads of each product were also determined, and the results ranged from 5.52 ± 0.01 to 6.32 ± 0.07 $\log_{10}$ CFU/g. The correlation between histamine and bacterial concentration was significantly correlated with a moderate correlation on the positive side (r=0.48). This result is important for setting limits of food safety criteria for local fermented products. It is important to note that to reduce the risk of the formation of histamine concentration of the Nem product, reduction or elimination of certain bacteria species through the hygienic practice through food supply chains such as raw material, operating, and temperature controlling shall be applied.

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Research article

Evaluation of Soil Erosion Risk from Weathering Effects on K Factor of RUSLE in Cobija, Bolivian Amazonia

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Abstract Soil erosion by water is a serious problem in the Amazonia region of Bolivia. In the area of Cobija, Bolivia, around 8 Mg ha^{-1} of Amazon soil is lost to the nearby watershed annually. The physical weathering of soils under natural conditions is one of the key processes for understanding structural changes in the soil. The soil erodibility (*K*) factor in RUSLE represents the susceptibility of soils to erosion, which can be measured with the standard unit plot experiment or through calculation with particle sizes and organic matter. Soil weathering affects soil particle distribution that is closely related to the *K* factor. Therefore, the purpose of this research is to evaluate and determine the change in the distribution of soil particles as well as the *K* value. The experiment was conducted in a laboratory setting. A total of 120 cans containing 1 g of soil each were used and treated with different periods and volumes of water added to represent weathering. The simulated weather conditions were set in line with conditions observed in Bolivian Amazonia. The pipette method was used to determine the distribution of soil particles. The results indicated slight changes in the distribution of the soil particles, reducing the percentage of fine sand and increasing the silt content, which affected the *K* factor as well as the estimate of soil losses based on RUSLE.

Keywords soil erosion, weathering, RUSLE, soil particle, Amazonia, Bolivia

INTRODUCTION

Weathering soils under natural conditions is a pivotal process to quantify sustainability assessments of forestry and land use, as well as to evaluate the rate of soil losses in the field. Accelerated weathering occurs as a consequence of deforestation and the loss of plant cover, which exposes the soil to the direct impact of temperature and wet-drying processes. The impact of raindrops on the soil causes changes in the percentage distribution of soil particles, ultimately altering the values in the *K* factor of the Revised Universal Soil Loss Equation (RUSLE) and influencing the results of soil loss calculations. For this study, a total of 120 containers filled with the soil from the Bolivian Amazon were subjected to weathering conditions identical to the study area, maintaining the same temperature and applying water for various periods. The objective was to determine if the changes observed in the percentage distribution of soil particles. After a 100-days experimental period, the pipette method was used to assess particle distribution in the soil, followed by the calculation of the *K* factor as well as other factors in the RUSLE. Accordingly, this study aimed to discuss the weathering effects on the *K* factor and the amounts of soil loss.

OBJECTIVE

The objective of this study was to assess soil erosion risk, focusing on the weathering effects on the *K* factor and the amounts of soil loss in Cobija, Bolivian Amazonia, using the Revised Universal Soil Loss Equation (RUSLE).

METHODOLOGY

Site Description

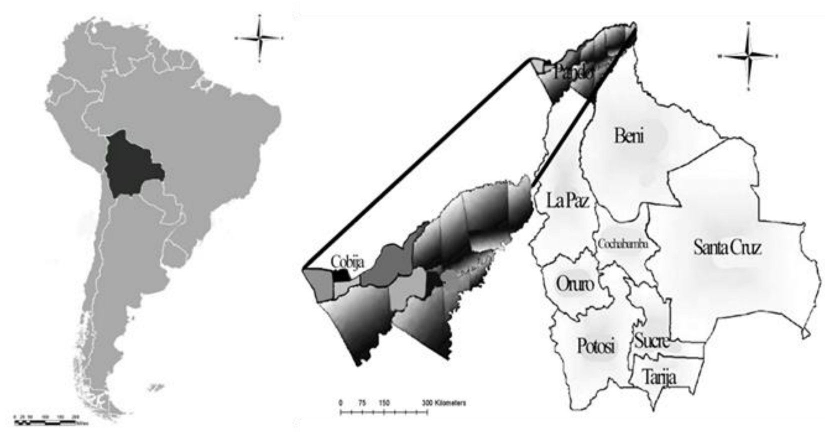

Fig. 1 Location of the soil sample collection in the city of Cobija, Bolivian Amazonia

Cobija is a Bolivian city, 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 Institute, 2015). This process was greatly influenced by the regional development strategy initiated by the Bolivian Government in 2015. Local farmers gradually transformed the forested landscape into an urban city. 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 2016 mm (Mayoralty of Cobija, 2020). The research area spans 14 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.

Soil Sample Source and Preparation

Twenty soil samples were collected from an area of 60 ha in the Bolivian Amazonia that was recently deforested. And after mixing to give a homogenous sample the soil was air-dried. A quantity of 5.4 kg of each soil sample was transported from Bolivia to Japan for physical experiments conducted in the Land and water laboratory using engineering equipment at the Tokyo University of Agriculture, Tokyo, Japan.

Weathering Experiment

A weathering experiment was undertaken to replicate the climatic conditions prevalent in the Bolivian Amazon. A total of 120 soil containers were meticulously prepared, with each container containing 1 g of soil. These cans were then subjected to a controlled environment in an incubator, simulating the temperature conditions found in the Bolivian Amazon.

To mimic the effects of rainfall, 0.4 ml of water was carefully added to each soil can at specific intervals of 2, 4, and 12 hrs. This process was repeated 100 times for each treatment, ensuring sufficient replication for reliable analysis and accurate data collection.

Determination of Soil Particle Distribution Experiment using the pipette method

To determine the percentage distribution of particles in the soil samples before and after the treatment, the pipette method was employed for each treatment and repetition. This method allows for the determination of the percentage of coarse sand, fine sand, silt, and clay. The experiment involved using 10 g of dry soil, with the organic matter content initially removed with a previous treatment using H_2O_2. A 20 ml solution of sodium hexametaphosphate at a concentration of 6% was prepared for each analysis. The gravel and sand content were collected by filtering the soil through sieves with a mesh size of 2.0 and 0.2 mm, respectively. The remaining silt and clay contents were placed in 500 ml measuring bottles, and 20 ml of the 6% sodium hexametaphosphate solution was added. Subsequently, 10 ml of the solution was collected at different time intervals based on Stokes' law to determine the content of clay, silt, and fine sand.

Brief Description of the RUSLE

The RUSLE represents how climate, soil, topography, and land use affect rill and inter-rill soil erosion caused by raindrop impact and surface runoff (Renard et al., 1997). It has been extensively used to estimate soil erosion loss, assess soil erosion risk, and guide development and conservation plans in order to control erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands (Millward and Mersey, 1999; Boggs et al., 2001) The RUSLE is expressed by Eq. (1) as follows.

$$A = R \times K \times LS \times C \times P \tag{1}$$

Table 1 summarizes the terms for estimating the factors using Eq. (1), where A is the average annual soil loss in t/ha; R is the rainfall-runoff erosivity factor; K is the soil erodibility factor; L is the slope length factor; S is the slope steepness factor; C is the cover-management factor; and P is the support practice factor. Table 1 summarizes the methods for estimating these factors.

Table 1 Summary of methods for developing RUSLE used in this research

Term	Methods	References
R	A regression model based on the measurement of annual precipitation uses averages monthly precipitation and average annual precipitation	Renard and Fremund, 1994
K	Experimental models based on soil properties (composition of coarse sand, fine sand, silt, clay, percentages.	El-Swaify and Dangler, 1976
LS	Estimated from actual field measurements of length and steepness calculated from DEM data with various approaches	Hickey, 2000; Van Remortel et al., 2001
C	Land use comparison table	Silva et al., 2007
P	Table of P values for different conservation practices	Bertoni and Lombardi Neto, 1985

RESULTS AND DISCUSSION

Soil Erodibility *K* Factor

Soil Erodibility K Factor was calculated using inherent soil properties following the procedure for tropical soils and determined using inherent soil properties, following the El-Swaify and Dangler (1976) procedure for tropical soils, which uses the percent-modified silt (0.002-0.2 mm), percent modified sand (0.1-2.0 mm), base saturation, percent unstable aggregates, and percent very fine sand. The values for the measured soil properties were used to calculate K Factor using Eq. (2).

$$K = -0.03970 + 0.00311X_1 + 0.00043X_2 + 0.00185X_3 + 0.00258X_4 - 0.00823X_5 \tag{2}$$

Where X_1 is the percent unstable aggregates < 2.0mm, X_2 is the product of the percent of modified silt (0.002-0.01 mm) by the percent of modified sand (0.1-2.0 mm) present in the sample, X_3 is the percent base saturation of the soil, X_4 is the percent silt present (0.002-0.05 mm), and X_5 is the percent of modified sand in the soil (0.1-2.0 mm). The calculated results of K factor were summarized in Table 2.

Table 2 Changes in soil properties for calculating the RUSLE *K*-factor with weathering

Fraction	Control T0 (0 h)	Treatment T1 (2 h)	Treatment T2 (4 h)	Treatment T3 (12 h)
Silt (0.002-0.05 mm)	29.05%	30.85%	31.88%	33.48%
Modified silt (0.002-0.01 mm)	29.60%	31.50%	32.50%	33.60%
Fine sand (0.02-0.2 mm)	28.68%	27.89%	26.84%	24.70%
Modified sand (0.1-2.0 mm)	7.24%	5.89%	5.78%	5.56%
Aggregates (< 2.0 mm)	0.78%	0.52%	0.29%	0.25%
Base saturation (%)	25.56%	25.56%	25.56%	25.56%

As shown in Table 2, the results were used to calculate the K factor and also indicated a rise in the percentage of soil clay and silt particles following the treatment. These notable increases served as an indication that the soil was exposed under the harsh climatic conditions prevalent in the Bolivian Amazon region, where has a discernible impact on the changes in soil particle distribution. The climate in the study area plays a pivotal role in enhancing the weathering effects, leading to changes in the soil composition and structure. The heightened exposure to the Amazonian climate accelerates the breakdown of soil particles, making them more vulnerable to weathering processes. Thus, the relationship between climate and the weathering effect is crucial in understanding the alterations in soil particle distribution and their implications for soil erosion.

Table 3 Changes in particle size-dependent variations in RUSLE *K*-factor with weathering

Value	Control T0	Treatment T1	Treatment T2	Treatment T3
X_1	0.78	0.52	0.29	0.25
X_2	214.30	185.53	187.85	186.82
X_3	25.56	25.56	25.56	25.56
X_4	29.05	30.85	31.88	33.48
X_5	7.24	5.86	5.78	5.56
K values (hundreds of acre ft ton in.)	0.1175	0.1203	0.1239	0.1293
K values (Mg h $MJ^{-1}mm^{-1}$)	0.0154	0.0158	0.0163	0.0170

In Table 3, the impact of varying K values in the Revised Universal Soil Loss Equation (RUSLE) is elucidated concerning alterations in particle size distribution. These modifications are intricately linked to shifts in the soil particle distribution following the weathering experimental treatment. The data presented therein offers a comprehensive insight into the progressive changes in K values, thereby providing valuable information about the soil erosion susceptibility resulting from shifts in particle size distribution due to the experimental weathering treatment.

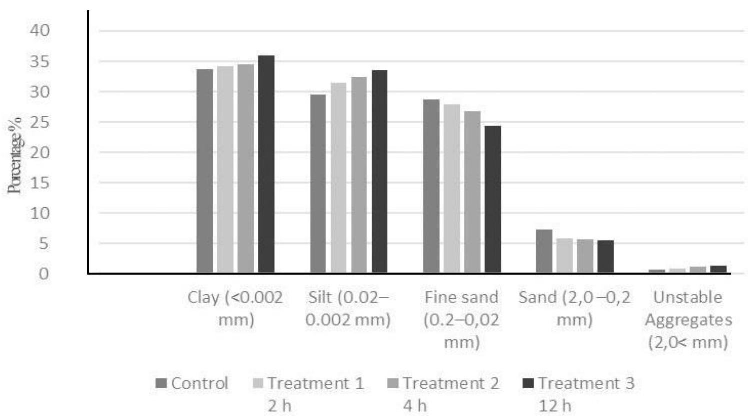

Fig. 2 Changes in soil particle distribution with weathering

As shown in Fig. 2, the changes in the percentage distribution of soil particles in the soil revealed an interesting trend; there is a tendency for the proportion of fine sand to decrease while the silt content experiences a slight increase. This suggests that the weathering processes and exposure to the climatic conditions in the study area contribute to the transformation of soil particle composition. Specifically, the finer sand particles exhibit a decreasing presence, potentially due to their susceptibility to weathering and erosion. On the other hand, the slight increase in silt content could be attributed to the redistribution of soil particles caused by weathering processes. Overall, these observations highlight the intricate relationship between weathering, soil particle distribution, and the impact of climatic conditions in shaping the composition of soil samples.

Table 4 Annual soil losses in the city of Cobija

Year	A0 (t/ha year)	A1 (t/ha year)	A2 (t/ha year)	A3 (t/ha year)
2017	9.36	9.81	10.03	10.15
2018	8.41	8.82	9.02	9.12
2019	10.36	10.86	11.10	11.23
2020	8.48	8.89	9.09	9.20
2021	11.11	11.65	11.91	12.05
Average	9.54	10.01	10.23	10.35

Average Annual Soil Loss in the City of Cobija

The results applied all the factors of the RUSLE on the different treatments to obtain the annual soil loss per unit area are summarized in Table 4. The average annual soil losses were in the range of 10 < t/ha/year before the effects of weathering, but the values were beyond 10 < t/ha/year after affecting weathering. Also, there was a tendency that the values of Treatment 3 affected higher weathering were higher than those of other treatments affected lower weathering. Figure 3 showed the increasing trends in the average annual soil losses, *A* value, in the City of Cobija, based on the changes in soil particle distribution due to weathering processes.

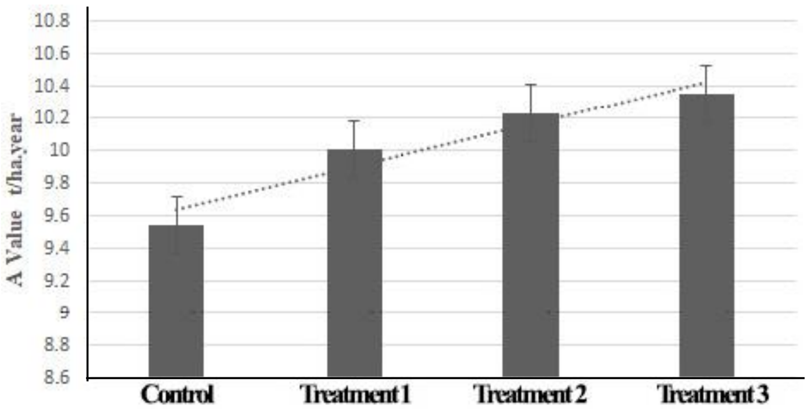

Fig. 3 Increase in *A* values (annual soil loss) with weathering

CONCLUSION

Soil erosion by water remains a big concern in the Amazonia region. This study aimed to assess the weathering effects on the *K* factor of the Revised Universal Soil Loss Equation (RUSLE) in Cobija, Bolivian Amazonia. The experiments utilized Bolivian Amazon soil were conducted to replicate the meteorological conditions prevalent in the study area. The pipette method was employed to measure the distribution of soil particles in a sample. The experimental results indicated remarkable changes in soil particle distribution with weathering, and the changes affected *K* value as well. This trend influences the final results of RUSLE, the average annual soil losses, A value.

In conclusion, this study highlights the significant impact of weathering on the *K* factor of the Revised Universal Soil Loss Equation (RUSLE) in the Cobija region of Bolivian Amazonia. The experimental investigation involving Bolivian Amazon soil, conducted to mimic the local meteorological conditions, revealed alterations in soil particle distribution due to weathering. While the specific changes in *K* values were not presented in this manuscript, the observed trend of weathering-induced shifts in soil particle distribution undoubtedly plays a crucial role in influencing the accuracy of the RUSLE model's predictions, particularly in terms of average annual soil losses.

On the basis of this research outcomes, it is suggested that the soils should not be exposed for long period after deforestation. Soils should be covered by some sheets or residues as mulching for decrease weathering effects on soil structure.

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Research article

Assessment of Antibacterial Activity of Lactic Acid Bacteria Isolated from Fermented Foods against *Escherichia coli* O157:H7 and *Proteus penneri* and Their Potential as Starter Cultures

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Abstract Fermented fish and vegetables produced by spontaneous fermentation are the most well-known traditional foods in Cambodia. Even though fermented foods provide health benefits related to nutrition, probiotics, and postbiotics, some of them are not safe due to the survival of bacteria harmful to humans. The purpose of this research is to examine *in vitro* the antibacterial activity of lactic acid bacteria (LAB) isolated from fermented fish and vegetables against *E. coli* O157:H7 and *Proteus penneri*, histamine forming LAB, and the survival of LAB in low pH levels and high salt concentration using pH and salt tolerance tests. LAB was isolated from 134 naturally fermented fish and vegetables from four different provinces and identified using the Biolog GEN III MicroStation semi-automated system. The antagonistic properties of these isolates against *E. coli* O157:H7, and *Proteus penneri* were examined using a co-culture method at 24, 48, and 72 hours of incubation times. As a result, 36 strains of LAB were identified from a total of 134 samples. Seven LAB species out of 36 strains can survive at pH 3 for 6 hours, while four of these seven LAB can tolerate pH 2. *Lactobacillus plantarum, Lactococcus lactis, Lactobacillus gasseri, Leuconostoc lactis,* and *Leuconostoc gilidum* have a significant capacity to inhibit *E. coli* O157:H7 and *Proteus penneri* growth when compared to control. These five LAB do not produce histamine and can tolerate up to a 10% salt concentration. All the results demonstrate that *Lactobacillus plantarum, Lactobacillus lactis, Lactobacillus gasseri, Leuconostoc lactis,* and *Leuconostoc gilidum* have great potential for use as starter cultures for suppressing pathogenic bacteria growth in fermented fish and vegetables.

Keywords fermented fish and vegetables, *E. coli* 0157:H7, lactic acid bacteria, antimicrobial activity, pH and NaCl tolerance

INTRODUCTION

The nutritional balance and food security of traditional fermented foods have made them popular throughout Asia. Across several Asian nations, methods for preserving crops, vegetables, meat, and fishery products seem to be well-developed. Moreover, Food preservation was the prime purpose of fermentation, which was achieved by the synthesis of inhibitory metabolites including organic acid, ethanol, and antimicrobials combined with decreased water activity (Anal, 2019).

Cambodia is a kingdom in Southeast Asia that borders Vietnam, Laos, and Thailand. There are many varieties of fresh fish and vegetables caused by the Tonle Sap Lake in the north of Cambodia is recognized for its extensive river system and favorable climate for agriculture(LeGrand et al., 2020). Mostly in the traditional Cambodian diet, fermented foods play a significant role. There are different fermented foods ready to eat (Chrun et al., 2017). It is well known that five groups of fermented fish and vegetables including *Pra hok* (Fish paste), *Pha'ork* (Fermented fish), *Trey proheum* (Salt Fish), *Mam* (Fermented Fish), and *Chruk* (Fermented vegetable) (LeGrand et al., 2020) and have their benefit in term nutritional function such as vitamins, proteins, essential fatty acids, and amino acids (Nuraida, 2015). In addition, at the same time add value to agricultural products (Chrun et al., 2017).

Microbiological research on Asian fermented foods reveals that the identification of 68 samples of fermented vegetables from a local market in Cambodia contained *Enterobacter spp*. in 24% of the samples (Chrun et al., 2017). Another study that examined 13 samples of fermented fish in Cambodia discovered that the majority of the microbial communities were gram-positive cocci and rods such as Bacillus, Clostridium, Staphylococcus, and Tetragenococcus (Chuon et al., 2014). In the case of Vietnam was found that unprocessed fish and poultry are likely to be contaminated with *Salmonella* and in the absence of proper kitchen hygiene and may contaminate processed foods. Raw poultry samples were found high levels of contamination with *E. coli* (45%), *Campylobacter jejuni* (28.3%), and *Salmonella* (8.3%) and high-risk food classification. Additionally, raw fish, meat, and vegetables all contained *E. coli* at rates of 21.3%, 6.6%, and 18.5%, respectively. This article confirmed the importance of hygienic working practices when preparing food. (Thi et al., 2006). The purpose of this research is to examine in vitro the antibacterial activity of lactic acid bacteria (LAB) isolated from fermented fish and vegetables against *E. coli* O157:H7 and Proteus penneri, histamine forming LAB and and the survival of LAB in low pH level and high salt concentration using pH and salt tolerance tests.

OBJECTIVE

The objective of this research is to examine in vitro the antibacterial activity of lactic acid bacteria (LAB) isolated from fermented fish and vegetables against *E. coli* O157:H7 and *Proteus penneri*, histamine forming LAB and the survival of LAB in low pH levels and high salt concentration using pH and salt tolerance tests.

METHODOLOGY

Sample Collection Methods

Fermented fish and vegetable samples are divided into five groups such as *Pra hok* (Fish paste), *Pha'ork* (Fermented fish), *Mam* (Fermented fish), Salted fish (*trey proheum*) and *Chruk* (Fermented vegetable). All samples were collected from 4 provinces such as Kompong Thom, Siem Reap, Kandal, and Kompong Cham province. All samples are purchased from small-scale producers and local markets. There are 134 samples in total. For fish paste (*Pra hok*, n=17), Fermented fish (*Pha'ork,* n=30), Fermented fish (*Mam*, n=11), and Fermented vegetables (*Chruk*, n=76). All samples were sealed in plastic sample bags and stored in cool boxes during transportation to the laboratory which was less than 24 hours. After the arrival, all samples were immediately studied for their identification.

Sample Identification

Pure colonies were conducted with several tests before using Biolog System (Semi-Auto Microstation) for identification. These tests helped to avoid misidentification and save a lot of money since the Biolog System is costly. Most important tests such as Gram staining, Catalase, and Oxidase are alternatives yet also help to give information on bacterial characteristics. The suspected pure LAB were sub-cultured two times to ensure the purification of the colony on MRS agar before culture on BUG Agar before identification with the Biolog system. By using GENIII-Microplate (BIOLOG) within protocol-C, inoculate pure colony from BUG Agar into Inoculating Fluid-C (IF-C) (provided by BIOLOG) within 92 to 95% Turbidity by using a Turbidity Meter (BIOLOG). Using an electric multi-dispense micropipette (SARTORIOUS), dispense 100 microliters in each microplate well then incubate the plate at 30ºc for 20 to 24 hours and using Microstation (BIOLOG) accompany with Microlog Software (BIOLOG) for interpreting the ID result of identification(Al-Dhabaan & Bakhali, 2017).

Antimicrobial Activities by Co-culture Method

10% of LAB suspension (9 Log CFU/ml) was inoculated with 6 Log CFU/ml of indicator *E. col*i 0157:H7 and *Proteus penneri* in each tube of MRS broth. This experiment was performed under aerobic conditions at 30 ^{0}C in the water bath for 72 hours. Every 24 hours, the presence of indicators was determined by streaking on selective Agar and incubating at 35^{0}C (Balouiri et al., 2016).

pH and Sodium Chloride Tolerance

LAB against *E. coli* 0157:H7 and *Proteus penneri* by co-culture method have been conducted with pH and sodium chloride tolerance. Selected LAB isolates were grown in MRS broth at 30°C overnight before being sub-cultured in new MRS broth by using HCl (0.1M) adjusted pH to 2 and 3 and used to adjust the salt content in MRS broth (5%, 6%, 7%, 8%, 9%, and 10%). Following an incubation period of 24 hours at 30°C (Dimic et al., 2015). After this, Streak Method on MRS Agar was used to confirm the tolerance of each LAB (Balouiri et al., 2016).

Determine the Concentration of Histamine Produced by Lactic Acid Bacteria

LAB was refreshed on MRS Agar at 30 ^{0}C for 24 hours. Inoculate one loop full colony of both Lactic acid bacteria in TSB broth with histidine and incubate at 30 ℃ for 24 hours centrifuge 6000 rpm/min for 15 min. Suspend 1 ml of supernatant in 9 ml of sterile saline for dilution 10-fold. After dilution that supernatant was used in the enzymatic histamine assay (Leszczyocha and Pytasz, 2018). Histamine concentration was calculated as follows.

$$\text{Histamine concentration (mg/L = ppm)} = (Es - Eb) \div (Estd - Ec) \times 4 \times 25 \times \text{dilution factor}$$

RESULTS AND DISCUSSION

The LAB species isolates were examined based on selective agar media called MRS and sub-cultured for few times until obtained a pure culture. The later suspected colony was Gram-positive, clustered cocci or bacilli, catalase-positive, and oxidase positive. LAB was later identified by using Biolog semi-auto system as shown in Fig. 1. Of 134 samples, 98 samples were rejected due to the absence of a suspected colony. group of *Mam* (n=11) isolated as *L. lactis* and *P. parvulus* (27%). There are 12% of group *Prahok* (n=17) isolated as *P. parvulus* and *P. pentosacues*. Other groups of *Pha'ork* (n=30) detected 10% were *L. garvieae, P. parvulus,* and *P. pentosaceus*. And 37% of group *Chruk* (n=76) isolated as *Lactobacillus, P. parvulus, P. pentosaceus, L. alimentarius, L. mali, L. gasseri, P. acidilactici, L. acidophilusBGA, L. lactis, P. sanguinis, Leu. gelidum, Tetra. solitarius, L. garvieae, L. reuteris, L. plantarum, Leu. citrem, L. bifermentans,* and *L. salivarius.* We found the relevance of the identification LAB by the API 50 CHL system from fermented food in Cambodia, thus three species of lactic acid bacteria were found, including *Lactobacillus acidophilus* and *Lactobacillus plantarum*. strains Y'11b,2, Y'11e,2, and Y'85,1. (Sophakphokea1 et al., 2021). According to (Ly et al., 2022) to study dentification, Classification and Screening for γ-Amino-butyric Acid Production in Lactic Acid Bacteria from Cambodian Fermented Foods by using Matrix-assisted laser desorption/ionizing time-of-flight mass spectrometry (MALDI-TOF MS) and partial 16S rDNA sequencing were used to identify 68 LAB. And the result shows as one *Lactobacillus futsaii*, two *Lactobacillus namurensis*, and *three Lactobacillus plantarum* strains were found in fermented food in Cambodia.

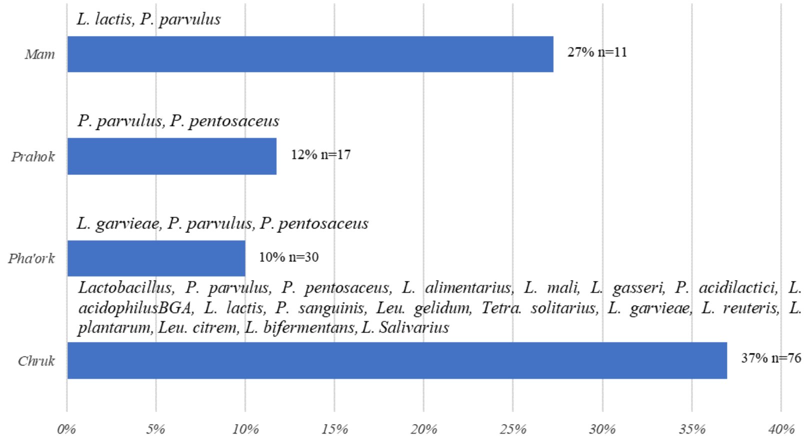

Fig. 1 Isolated LAB from fermented fish and vegetables in Cambodia

Table 1 Result of antimicrobial activities by co-culture method

Species	n	Time	*E. coli* 0157:H7	*Proteus penneri*
Leuconostoc lactis	3	24 h	+++	+++
		48 h	++	+
		72 h	+	-
Lactobacillus gasseri	3	24 h	++	+++
		48 h	-	+
		72 h	-	-
Lactobacillus plantarum	3	24 h	+++	++
		48 h	++	+
		72 h	+	-
Lactococcus lactis	3	24 h	++	+
		48 h	-	-
		72 h	-	-
Leuconostoc gelidum	3	24 h	+++	+++
		48 h	+	++
		72 h	+	-
Lactococcus garvieae	3	24 h	++	++
		48 h	+	+
		72 h	+	-
Lactobacillus mali	3	24 h	+++	+++
		48 h	++	+
		72 h	++	-

"+" represent to positive or resistance and "-" represent to negative or susceptible

According to the results shown in Table 1. Lactic acid bacteria are able to against *E. coli* 0157:H7 such as *Lactobacillus gasseri* and *Lactococcus lactis*. Moreover, Lactic acid bacteria able to against *Proteus penneri* were *Lactobacillus mali*, *Lactococcus garvieae*, *Leuconostoc gelidum*, *Lactococcus lactis*, *Lactobacillus plantarum*, and *Leuconostoc lactis*. Hassanzadazar et al. (2012) studied about antibacterial activity of Lactic Acid Bacteria against *Escherichia coli*, *Listeria monocytogenesis*, *Bacillus cereus*, and *Salmonella enteritidis*, and reported that lactic acid showed the strongest inhibitory activity against gram-positive bacteria than gram-negative bacteria. Similarly, Muzikowski (2009) also reported some species of *Lactobacilli* against different gram-positive and gram-negative bacteria were determined by agar-well diffusion assay. It also shows the antagonistic effect of the antibacterial agent on the growth of other gram-positive and gram-negative pathogenic microorganisms which *E. coli*, *Listeria monocytogenes*, *Salmonella enterica*, *Staphylococcus aureus* and *Bacillus cereus*.

The pH tolerance is an important characteristic of species that hoped to affect the gastrointestinal tract. Moreover, tolerance to salt was an important cause of cell membrane structure can become damaged by salt. A study by Azam et al. (2017) focused on the isolation and characterization of *Lactobacillus spp*. from kefir samples in Malaysia mentions that *Lactobacillus spp.* isolated from kefir E was unable to survive in all pH conditions (pH 2, 3, and 4). All isolates tested did not survive pH 2.0, most of the isolated *Lactobacillus spp.* from kefir samples were able to tolerate the moderate pH levels of pH 3.0, pH 4.0, and all the isolated *Lactobacillus spp*. from kefir samples survived at 0.3-0.5% bile concentration after incubation. The *Lactobacillus spp*. from kefir H conferred the highest survival rate at 0.3% and 0.5% bile concentration, with a survival rate of 96.89 ± 0.02% and 96.84 ± 0.02%, respectively. Subsequently, the survival rate in bile salt condition was followed by isolated *Lactobacillus spp*. from kefir G and kefir C. (Hassanzadazar et al., 2012) research was done into the Investigation of antibacterial, acid, and bile tolerance properties of lactobacilli isolated from Koozeh cheese. The screening process involved 28 different *Lactobacillus* species that were obtained from Koozeh cheese, a typical cheese. A control pH of 7.5 was used while the acid tolerance test was investigated at pH 2.0 and 3.0 with 5 N HCl. Results showed that only one out of twenty-eight isolates have the ability to tolerate acid and bile salts. The ability to produce histamine of LAB was acceptable due to the concentration of histamine higher than 200 ppm will cause the disease in a human (Leszczyocha and Pytasz, 2018, Food Safety Authority of Ireland, 2005).

Table 2 Result of salt, pH tolerance test, and Histamine of identified bacteria from fermented samples

Bacteria species	pH and salt tolerance								Histamine concentration
	Salt (%)						pH		
	5	6	7	8	9	10	2	3	ppm
Lactococcus garvieae	+	+	+	+	+	+	0%	14%	2.35
Lactobacillus mali	+	+	+	+	+	+	21%	50%	4.70
Leuconostoc lactis	+	+	+	+	+	+	10%	13%	6.79
Lactobacillus gasseri	+	+	+	+	+	+	12%	18%	7.05
Lactobacillus plantarum	+	+	+	+	+	+	32%	52%	7.8
Lactococcus lactis	+	+	+	+	+	+	26%	44%	10.1
Leuconostoc gelidum	+	+	+	+	+	+	0%	20%	3.9

"+" represent to positive or resistance and "-" represent to negative or susceptible

CONCLUSION

Seven Lactic acid bacteria out of 36 species, such as *Lactobacillus mali, Lactococcus garvieae, Leuconostoc gelidum, Lactococcus lactis*, *Lactobacillus plantarum,* and *Leuconostoc lactis* were isolated and identification by using Biolog System (Semi-Auto Microstation) were found from fermented fish and vegetables. according to this study two species of LAB inhibition against *E. coli* 0157:H7 and all these seven species inhibitions against Proteus *penneri*. The identified bacteria isolated were subjected to different salt concentrations (5%, 6%, 7%, 8%, 9%, and 10%). Bacteria species *Lactococcus garvieae*, *Lactobacillus mali*, *Leuconostoc lactis*, *Lactobacillus plantarum, Lactococcus lactis, Leuconostoc gelidum* can tolerate with salt up to 10% and tolerate either pH3 in rate (14%, 50%, 13%, 18%, 52%, 44%, and 20%) nor pH2 in rate (21%, 10%, 12%, 32%, and 26%). In contrast, *Lactococcus garvieae* and *Leuconostoc gelidum* weren't tolerated with pH2. On the other hand, these seven species LAB were not histamine-producing bacteria due to the level of histamine concentration lower than 10 ppm. All the results demonstrate that *Lactobacillus plantarum*, *Lactococus lactis*, *Lactobacillus gasseri*, *Leuconostoc lactis*, and *Leuconostoc gelidum* have a great potential for use as starter cultures for suppressing pathogenic bacteria growth in fermented food.

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Research article

Nitrogen Removal from Mining Dewatering and the Fate of Water Release to a River

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Abstract Seepage water in underground mining voids arises from interception with aquifers that may become contaminated with nitrogen (N)-based explosive during underground blasting operations. The nitrogen-contaminated water may be pumped from underground mining voids and stored at the surface or discharged to a nearby river without treatment if sufficient dilution is achieved to minimize effects on the aquatic environment and pastoral activities. Maximum N concentration in dewatering water was observed to be 200 times the receiving water of the nearby river when compared against ANZECC/ARMCANZ (2000) water quality guidelines. This study sought to identify sources of N contamination of underground seepage water, pumped to the surface for discharge to the nearby river. The level of protection (for an aquatic ecosystem) specified the water quality objectives to be achieved following water release. The ANZECC/ARMCANZ (2000) has three levels of aquatic ecosystem protection, and 'Level 2 Aquatic Ecosystem' was selected being described as applying to slightly–moderately disturbed systems including rural streams receiving runoff from land disturbed to varying degrees by grazing or pastoralism, nearby or adjacent to urban areas. The study considered river flow data, underground dewatering production, discharge rates, and river water quality for upstream and downstream of the discharge point, as well as quantities of explosives used underground at specified % N in explosives estimated to remain following blasting. The most important nitrogen form present in the mine discharge wastewater was found to be oxidized-N (>93%). Only 0.54 % of end-of-pipe discharge was measurable in the downstream river and indicated that rapid dilution and removal of oxidized-N (nitrate/nitrite) by biota could be achieved. The level of oxidized-N expressed as load discharged to the river showed that the quantity of N discharged was similar in magnitude to the spillage of 4% explosive.

Keywords nitrogen, explosive, mining, dewatering, discharge, cattle, aquatic species

INTRODUCTION

Seepage water in underground mining voids arises from interception with aquifers that may become contaminated with nitrogen-based explosives during underground blasting operations. Ammonium nitrate used commonly as an explosive is the same as the common fertilizer. Nitrogen (N)-contaminated water may be pumped from underground mining voids and stored at the surface for treatment or discharged to a nearby river without treatment if sufficient dilution is achieved to minimize effects to the aquatic environment and pastoral activities and can be demonstrated and approved by Government regulators. Existing nitrogen (N)-contaminated water added upstream arises from local agricultural and urban activities and may affect the aquatic ecosystem. This study sought to identify sources of nitrogen contamination of underground mining seepage water, pumped to the surface for discharge to the nearby river and if additional nitrogen (N)-contaminated water pumped to the river gives further effects on the aquatic ecosystem. The level of protection (for an aquatic ecosystem) specified the water quality objectives to be achieved following water release follows the ANZECC/ARMCANZ (2000) levels of aquatic ecosystem protection.

OBJECTIVE

The objective of this study is to identify sources of N contamination of underground seepage water from a mining operation that is pumped to the surface for discharge to a nearby river and to identify if the level of protection (for an aquatic ecosystem) of the specified water quality criteria can be achieved following water release.

METHODOLOGY

The study is based on a site in Queensland, Australia, and considered river flow data, underground dewatering production from mining, discharge rates, and river water quality upstream and downstream of the discharge point (Noller, 2006).

The level of protection (for an aquatic ecosystem Environmental Value - EV) is the level of aquatic ecosystem condition specified by water quality objectives (WQOs) to be achieved for the intended water. The Queensland Water Quality Guidelines (QWQG, 2006) were developed concurrently with the EVs and water quality objectives (WQOs) and release process. These are technical guidelines for deriving WQOs for rivers in Queensland and include locally and regionally relevant water quality data for fresh, estuarine, and marine waters.

The ANZECC/ARMCANZ (2000) established three levels of aquatic ecosystem protection that are applied by QWQG (2006). The levels of aquatic ecosystem protection are: (i) Level 1: High ecological/conservation value ecosystems - effectively unmodified or other highly valued systems; (ii) Level 2: Slightly–moderately disturbed ecosystems - ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity; and (iii) Level 3: Highly disturbed ecosystems - measurably degraded ecosystems of lower ecological value. The EVs and WQOs identified that the study river is: A level 2 Aquatic Ecosystem. This is described by ANZECC/ARMCANZ (2000) as an 'Ecosystem in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity'. The biological communities remain in a healthy condition and ecosystem integrity is largely retained. Typically, such systems have slightly to moderately cleared catchments and/or reasonably intact riparian vegetation. Slightly–moderately disturbed systems could include rural streams receiving runoff from land disturbed to varying degrees by grazing or pastoralism. This description fits the surrounding area of the study mine and river.

Ammonium nitrate is the key explosive used in the underground workings at the study mine. The quantities of ammonium nitrate explosives with specified % N used at the underground mine gave an estimate of remaining explosives following blasting. As a general rule, 1 tonne of rock uses 1 kg of explosive. Some ammonium nitrate may be spilt during charging and was estimated to be 4% based on collecting residues and weighing them (Noller, 2006).

Water quality was collected and analyzed for dewatering from an underground source, to the discharge point, following discharge to a local river, upstream and downstream at the following sites: (i) Dewatering from underground; (ii) Dewatering storage tank at exit to discharge pipe before discharge to the local river; (iii) Downstream local river beyond mixing zone; and (iv) Upstream of the local river, including an historical gauging site of 40 years operation. Water samples were collected by mine staff and water quality data was measured by the mine laboratory for pH, total dissolved solids (TDS), suspended solids (SS), N forms as total unfiltered nitrogen, total filtered N, nitrite and nitrate (oxidized-filtered), particulate N (>0.45 µm), organic-N (total - oxidized-N) and ammonium ion (filtered). Filtration for N was conducted on-site using 0.45 µm cartridge membrane filters with a plastic syringe.

The site water budget included water quality of water consumed on site, water discharged quantities, and surface runoff from sub-catchments on site. The Queensland regulator has a large number of monitoring sites and gauging stations on the study site river (N and M, 2006). An upstream gauging station with 40 years of records was selected as having the most complete and relevant set to the discharge of the study mine (Noller, 2006).

RESULTS AND DISCUSSION

Table 1 gives the average monthly river flow (ML) for September to February at the main upstream gauging station which corresponds to the release of water from the mine. January and February and the annual summer rains (see Table 1 for rainfall during the study period). The data record for monthly flow at the upstream gauging station over 40 years had the corresponding average monthly flow for the period ending 2,400 hrs. and was 68,970 ±178,630 ML. According to the Queensland Environmental Authority water from the mine must not be discharged to the river when the flow rate at the main upstream gauging station is less than 20 ML (Noller, 2006). For the period November–December (Table 1) the total underground transfer from the discharge tank to the river was 11,222 kL/month, based on a rate of 362 kL/day. The accumulated groundwater from the mine that was discharged to the river contained a consistently high total N level that was primarily oxidized-N.

Table 1 Monthly River flow (ML) at the main upstream gauging station over 40-years period

Month	Mean[a]	Standard deviation[a]	Percent (%)	Monthly rainfall (mm) at mine[b]
September	14,575	23,850	44.41	
October	17,384	27,491	1.34	134
November	31,678	47,532	15.17	216
December	50,762	11,106	16.52	141
January	115,284	319,054	15.64	-
February	210,310	379,291	8.79	-

Source and explanation: a. NR&M (2006); b. Noller (2006)

Table 2 gives a summary of ammonium nitrate used by the mine during the period from September to February. It is noted that all explosives were consumed in the explosion, apart from spillage (Noller, 2006). Assuming that spillage was 4%, 2,009 kg ammonium nitrate was dissolved in the underground water system from September to February. The established guide of 4,000 kg/month was equivalent to 1,400 kg-N/month and the loss of 160 kg is 56 kg-N. The calculated load of N released from the rising water main, discharge tank, and via the pipe was compared with the total ammonium nitrate used and spillage at the mine (Table 2). Percent N in explosives gave a total N budget, together with an estimate of how much remains following blasting.

Table 2 Total ammonium nitrate (as % of explosive use) consumption over a 6-month period

Explosive Accounting period (% Explosive use)[a]	Total ammonium nitrate (kg)[a]	Spillage ammonium nitrate estimated at 4% (kg)[a]	Total ammonium nitrate-N (kg)[b]	Spillage-N estimated at 4% (kg)[b]
May	7,467.4	299	2,614	104.5
October	11,778.9	471	4,122	164.9
November	4,099.1	164	1,435	57.4
December	6,435.7	257	2,253	90.1
January	10,714.8	426	3,750	150.0
February	11,784.2	471	4,124	165.0
Total	52,280.0	2091	18,298	731.85

Source and explanation: a. Noller (2006); b. Factor for ammonium nitrate - N = Total x 0.35; molecular weight = 80

Table 3 gives the calculated and measured loads of N from underground dewatering and discharged to the river, including a summary of the oxidized-N discharged from the mine to the river, showing that the quantity of N discharged was similar in magnitude to the spillage of 4% explosive. Table 4 gives the predicted and measured oxidized–N concentration in the river based on end-of-pipe discharge and river mean flow. The difference between measured and calculated concentrations indicates lower recent flow in the river compared with the historical record. Some particulate forms of N arose from the mine dewatering, but most N present was filterable, as expected from explosive residues. Some particulate N (100 µg/L) was also present in river water (Noller, 2006), but data was not included in Tables 3-5.

Table 3 Calculated and measured loads of nitrogen from underground dewatering

Month	End of pipe discharge (kL)[a]	Measured nitrite-nitrate-N end of pipe (µg/L)[a]	Nitrogen discharged end of pipe (kg-N)[a]	Spillage of 4% explosive as -N (kg)[a]
October	5,260	21,800	114.7	269.4
November	11,222	19,800	222.2	297.5
December	7,157	17,600	126.0	(Nov-Jan)
January	9,030	18,900	170.7	165.0
Sum	-	-	633.6	731.85

Source and explanation: a. Noller (2006)

Table 4 Predicted and measured nitrate and nitrate – N concentration in river

Month	River mean monthly flow (ML)[a]	End of pipe discharge (kL)[b]	Measured Oxidized -N end of pipe (µg/L)[b]	Dilution ratio[b]	Predicted Oxidized -N river (µg/L)[b]	Measured Oxidized-N river (µg/L)[b]
October	17,384	5,260	21,800	3,305	6.6	997
November	31,678	11,222	19,800	2,823	7.0	254
December	50,762	7,157	17,600	7,093	2.5	166
January	115,284	9,030	18,900	12,767	1.5	12
Range					1.5-7.0	997-12

Source and explanation: a. NR&M (2006); b Noller (2006)

Table 5 Nitrogen in underground seepage water and following discharge to river

Site	Total N[a]	Total N (filtered <0.45µm)[a]	Oxidized-N[a]	Ammonia-N[a]
Rising water main (µg/L)	20,900	19,200	20,000	270
Discharge Tank (µg/L)	19,900	20,500	31,300	0.10
End of pipe discharge (µg/L)	20,200	18,700	18,700	130
River upstream 10m (µg/L)	500	400	50	60
River downstream 10m (µg/L)	1,100	0.50	0.17	70
River main upstream gauging station 40 years (µg/L)	750	-	0.29	21
Queensland water quality guideline (µg/L)[b,c]	<250	-	<10	<10

Source and explanation: a. Noller (2006); b. QWQG (2006) annual median; c. QWQG (2006) guideline for Organic-N <200µg/L =total-N – oxidized-N

Table 5 gives N in underground seepage water and following its discharge to the river. The most important N form present in the mine discharge wastewater was found to be oxidized-N (>93%). Only 0.54 % of end-of-pipe discharge was measurable in the downstream river and indicated that rapid dilution and removal of oxidized-N by biota could be achieved. The level of oxidized-N expressed as load discharged to the river showed that the quantity of N discharged was similar in magnitude to the spillage of 4% explosive. The accumulated groundwater from the mine that is discharged to the river contains a consistently high total N level that is primarily oxidized-N.

The historical upstream gauging station data for the river (Table 5) shows that total N has been consistently higher than the Queensland water quality guideline Level 2 water quality guideline, including upstream of the mine, for a long period of time. The results in Tables 5 and 6 show that the river has had a consistently high nitrogen load that exceeds the current guideline. An additional load to the river was added by the mine discharge. Table 6 gives water quality in underground seepage water and following discharge to the river for pH, total dissolved solids, and suspended solids. pH was marginally lower than the mine dewatering which also contributed to salinity. Suspended solids remained at or lower than the guideline.

Table 6 Water quality in underground seepage water and following discharge to the river

Site	pH[a]	Total dissolved solids (mg/L)[a]	Suspended solids (mg/L)[a]
Rising water main	8.18	2,280	6
Discharge Tank	8.18	2,280	6
End of pipe discharge	8.16	913	2
River upstream 10m	7.90	247	4
River downstream 10m	7.8	260	5
River main upstream gauging station 40 years	7.7	-	-
Queensland water quality guidelines	6.5-8.2	-	<6

Source and explanation: a. Noller (2006); b. QWQG (2006) annual median.

Total N in river upstream water was 500 µg/L which exceeded the Queensland water quality guideline (Table 5). The river 10m below discharge was 1,100 µg/L Total N which also exceeded the guideline (QWQG, 2006). Some particulate N (100 µg/L) arose from the mine dewatering but most N present was filterable (Noller, 2006).

Ammonia in the river upstream (60 µg/L) and downstream river (70 µg/L) both exceeded the Queensland water quality guideline level of 10 µg/L (Table 5). The addition of ammonia from the mine to the river was therefore 10 µg/L and the level at the river downstream exceeded the QWQG (2006) guideline. The discharge of any ammonia from the mine dewatering was compromised by the existing river load.

Oxidized-N in the river upstream was 50 µg/L which exceeded the guideline (<40 µg/L). The river downstream level was 170 µg/L and indicated an addition of 120 µg/L oxidized-N to the river from mine dewatering. However, comparison with the end of pipe discharge and river downstream oxidized-N indicated efficient removal of oxidized-N. The oxidized-N discharged from the end of the pipe was in the key form of oxidized-N i.e., 18,700/20,200 X 100 = 92.6 % of Total-N. However, the discharge of any oxidized-N like ammonia from mine dewatering was compromised by the existing river load. Although the oxidized-N at the end of the pipe was 18,700 µg/L, the difference between the river upstream and river downstream was only 120 µg/L.

Organic-N concentration, calculated as the difference between total and oxidized-N, was very low. The upstream river level was <100 µg/L compared with the river downstream level of 330 µg/L, the latter exceeding the QWQG (2006) guideline figure of 200 µg/L. This may be due to the presence of urea or a similar soluble organic form of nitrogen from pastoral and crop activities.

The most important N form present in the mine discharge was therefore the oxidized-N (>93%) and organic-N was less important. Some particulate-N was also present. The fact that only 0.54 % of end-of-pipe discharge remained measurable in the river downstream indicated that rapid dilution and removal of oxidized-N by biota was occurring. Maximum N concentration in dewatering water for this study was observed to be 200 times the receiving water of the nearby river when compared against ANZECC/ARMCANZ (2000) water quality guidelines and 'Level 2 Aquatic Ecosystem' that was selected for this river receiving runoff from land disturbed to varying degrees by grazing or pastoralism, nearby or adjacent to urban areas.

CONCLUSION

The study showed that accumulated underground groundwater from the mine dewatering being discharged to the river had a consistently high total N level that was primarily oxidized-N (>93%) and was derived from 4% ammonium nitrate spillage from blasting. Although only 0.54 % of end-of-pipe mine discharge was measurable in the downstream river and indicated that rapid dilution and removal of oxidized-N by biota could be achieved, the Total N in river upstream water was 500 µg/L which exceeded the QWQG (2006) water quality guideline (Table 5). The river 10m below discharge was 1,100 µg/L Total N which also exceeded the guideline (QWQG, 2006), but most N present was filterable (Noller, 2006). Ammonia in river upstream (60 µg/L) and downstream river (70 µg/L) both exceeded the QWQG (2006) water quality guideline level of 10 µg/L (Table 5).

The selected 'Level 2 Aquatic Ecosystem' Slightly–moderately disturbed ecosystems-ecosystems in which aquatic biological diversity may have been adversely affected to a relatively small but measurable degree by human activity for the receiving water of the nearby river when compared against ANZECC/ARMCANZ (2000) water quality guidelines for this river receiving runoff from land disturbed to varying degrees by grazing or pastoralism, nearby or adjacent to urban areas. However, the presence of excess Total N in the river water from upstream agricultural and urban activities compromised the mine water discharge. The discharge of any ammonia from the mine dewatering was also compromised by the existing river load.

Thus, treatment options for the mine-discharged water were required and focused on the removal of oxidized N. Ammonia was effectively removed by a shift in the equilibrium of its dissolved form prior to its transfer to the surface, i.e., the ammonia was either removed as nitrogen gas or converted to nitrate. The co-cations in the solution are alkaline and alkaline earth metals and not hydrogen ions as the pH are relatively high.

ACKNOWLEDGEMENTS

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Research article

Development of Erosion Protection Zones in the Catchment of the Kalimanci Reservoir, North Macedonia

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Abstract Construction of reservoirs is a priority for ensuring sustainability of water resources. In the Republic of North Macedonia, there are 23 big and over 120 small water reservoirs. On the other hand, erosion and the filling of reservoirs with sediment is one of the main problems in reducing the lifespan of the reservoir. The total annual accumulated sediment in all the reservoirs in the Republic of Macedonia is 3,000,000 m^3 (Erosion map of RM, 1993). The selected study area for the current research is the Kalimanci reservoir in the frames of the catchment of the Bregalnica River, North Macedonia. The main method used to estimate the sediment transport on catchment level is the Erosion Potential Method (EPM; Gavrilovic method), and the validity is assessed on the basis of accumulated sediment in the reservoirs. The EPM method only estimates the total transported sediment at one point. To estimate how the sediment is transported, re-transported, and accumulated in the river bed, a hydraulic sediment transport model (HEC RAS) was used. Then the critical sub-catchments from an erosion point of view are delineated. Most of the critical sub-catchments are situated around the Kalimanci reservoir, while the middle of the catchment experiences erosion of medium severity, and the highest parts of the Bregalnica River are the least critical. The largest part of the sediment transported by the Bregalnica River (nearly 75%) is deposited in the valleys. With the aggregation of the previous steps, the erosion zones of the Kalimanci reservoir were identified.

Keywords erosion, bathymetry, GIS, zoning, erosive sediment material

INTRODUCTION

The soil and the water are two out of three components of the natural environment. Water is a renewable resource, but the soil genesis on the other hand is a long-term process. So, in other words the soil is not a renewable resource (Blinkov et al, 2003). Soil erosion is deemed as the most important, most dangerous, and most spread type of soil degradation and it is the limiting factor of the sustainable use of the land and development of the areas, states, and regions.

The construction of reservoirs is a priority for providing sustainability of the water resources. In the Republic of North Macedonia, there are 23 big and over 120 small water reservoirs. On the other hand, erosion and filling the reservoirs with sediment are one of the main problems in reducing the lifespan of the reservoir. The total annual accumulated sediment in all the reservoirs in the Republic of Macedonia is 3,000,000 m^3 (Erosion map of RM, 1993). It is estimated that worldwide, annually, from 0.5% to 1% of the total storage of reservoirs is lost because of filling up the reservoirs with sediment (White, 2001).

Soil erosion is the main cause of filling up the water reservoirs with sediment. The intensity of the erosive processes in the catchment is the main driver for sedimentation but on the other hand, it is very important where those processes occur. If the erosion hotspots are in the vicinity of the reservoir or on the main waterway it can be assumed that the produced sediment will be mostly transported into the reservoir. In this manner, it is very important to perform zoning of the reservoir catchment to prioritize anti-erosive activities and do appropriate land management.

OBJECTIVE

The main objective of this study was to develop a methodology for erosion protection zones in the catchment of a water reservoir. The case study for the development of this model is the Kalimanci water reservoir.

METHODOLOGY

The study area is situated in the North-East part of North Macedonia, and it is encompassing the middle and the upper catchment of the Bregalnica River. The catchment of the Kalimanci reservoir is taken as a case study (Fig. 1). The area of the catchment of the reservoir is 1,135.3 km^2, and the length of the longest Bregalnica River is 94 km. The dam was built in 1969 and the total reservoir storage was $127x10^6$ m^3.

The catchment of the Kalimanci reservoir mainly consisted of natural-rural elements: forests 46.1%, arable land 19.1% meadows 18.2%, and shrubs 12.7%. The geology consists of granites and granite porphyry 20.3%, marl clay, sands, and gravel 16.6%, and also more than 20% consists of not stable schist formations. The main soil type is cambisol and cambisol with regosol 29% and also ranker 37%. The annual total rainfall in the catchment is from 591 mm, on the lower slopes, to 1114 mm on the highest peaks or the mean value is 748 mm.

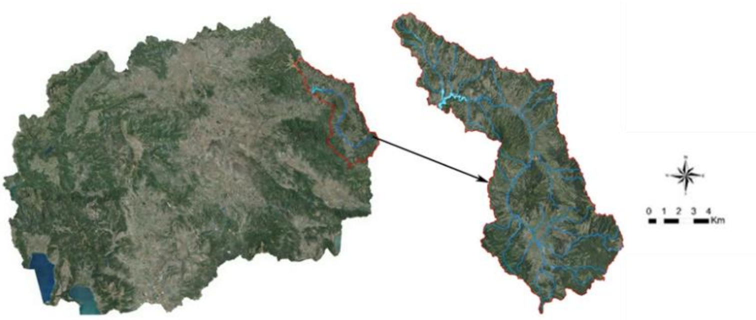

Fig. 1 Study area showing catchment of the Kalimanci reservoir in North Macedonia

The main method used to estimate sediment transport on the catchment level is the Erosion potential method (EPM) developed by Professor Gavrilovic (1972). At the moment, there are several methods used for estimating erosion on-site and on the catchment level. Blinkov and Kostadinov (2010) in their paper stress the good and bad sides of several models for the estimation of erosion: EUROSEM, USLE, PESERA, KINEROS, WEP, WEPP, and EPM. Several of these methods can model erosion from different points of view. Only a few deals with the transport and deposition of the sediment: EUROSEM, WEPP, and EPM. EPM was chosen to be used in the study because it has the unique trait that was developed in the Balkan region, south Serbia, which is very similar in climatic conditions to North Macedonia, secondly, the ability to predict sediment transport and deposition was developed with calibration of deposited sediment in the existing reservoirs and also the data produced about the erosion potential in North Macedonia was developed with the EPM, so the results would be comparable and the methodology would be transferable (Mincev, 2018).

The validity of the model is assessed with the accumulated sediment in the reservoirs. The Kalimanci reservoir was measured for deposed sediment 12 times, between 1969 and 1997. The measuring was done on already established profiles. To estimate the current situation, in 2013, the accumulated sediment was measured directly through bathymetric measurements using eco-sounding equipment on the established transect profiles in the reservoir.

RESULTS AND DISCUSSION

From the measurements can be distinguished two separate periods 1969-1985 and 1985-2013 according to the rate of sedimentation. In the first period, the annual sedimentation of the reservoir is 467,686 m^3/year and in the second the sedimentation decreased to 214,325 m^3/year. The sedimentation in the first period is more than double. According to Mincev (2015), this can be accounted to different factors: climate change, migratory processes, changes in land use and animal husbandry, the effects of implemented erosive measures and works, and consolidation of the sediment. The annual sedimentation of 214,325 m^3/year will be taken as the true sedimentation of the recent period and will be compared with the modeled values of the transported sediment.

The EPM method only estimates the total transported sediment at one point. To estimate how the sediment is transported, re-transported, and accumulated in the river bed, a hydraulic sediment transport model HEC-RAS was used. The hydraulic calculations were done in the HEC-RAS on transect profiles. The output of the software was the total load of transported sediment of the Bregalnica River in the reservoir and zones of sedimentation in the river bed based on cumulative input and output of sediment.

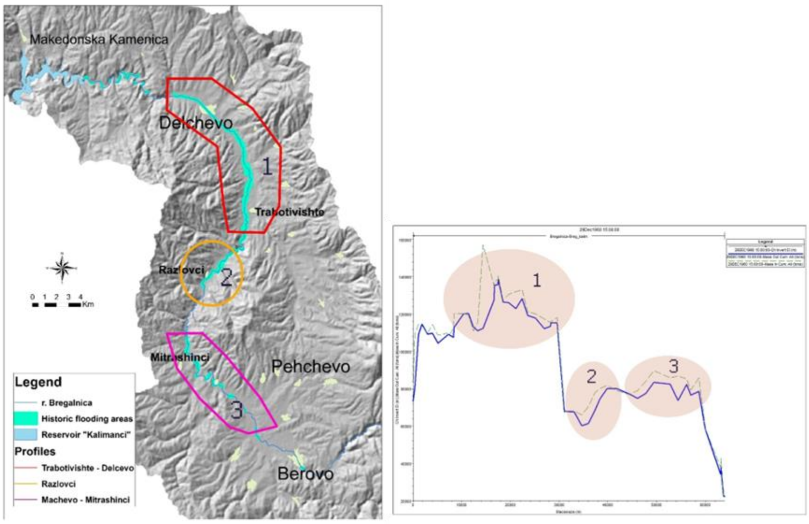

Fig. 2 Zones of sedimentation in the main Bregalnica River, Position of the historic flooding areas (left); sedimentation output of the HEC-RAS software (right)

From the HEC-RAS model, there can be distinguished three general zones of accumulation of sediment (Fig. 2). If the profiles of accumulation are spatially transferred on the map it can be seen that accumulation of the sediment is in the larger valleys: Machevo – Mitrashinci, Razlovci and Trabotivishte - Delchevo. Almost 75% of the input sediment in the Bregalnica River is deposited in the valleys. So, it can be concluded that all of the erosive hot spots upstream of the Bregalnica River are with lower erosion risk because a large portion of the sediment is deposited in the geomorphological expansions, flattened areas, or small valleys along the Bregalnica River. After considering this, there can be distinguished two zones of sedimentation, before and after the geomorphological expansions (Fig. 3). So, in this sense, the first zone is the immediate zone around the reservoir which encompasses catchments that have short transport distances and most of the sediment is deposited in the reservoir. The second zone is before the geomorphological expansions and in this case, 75% of the sediment is left behind and a small amount of the produced sediment is transported in the reservoir.

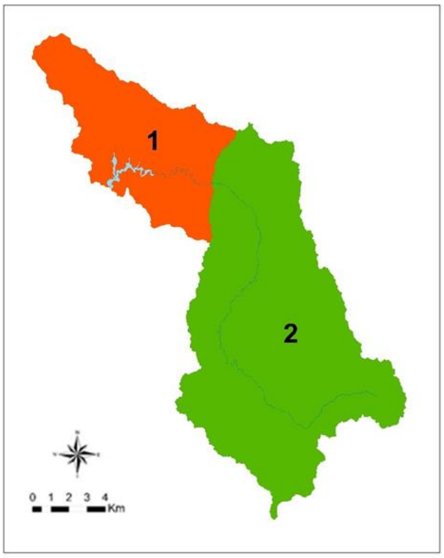

Fig. 3 Zones of sedimentation in the catchment of the Kalimanci reservoir

The EPM model produced quantities of transported sediment on the sub-catchment level in $m^3/km^2/ann$. These quantities were transformed into 4 categories according to the severity of the erosive processes in the sub-catchment (I – High risk > 300 $m^3/km^2/ann.$; II – Medium risk 201-300 $m^3/km^2/ann.$; III – Low risk 71-200 $m^3/km^2/ann.$ and Very low risk <70 $m^3/km^2/ann.$) (Fig. 4a).

The next step is a combination of the severity of the erosive processes with the sedimentation zones. The rule imposed here is: if the sub-catchment is in the second sedimentation zone, then the severity of the erosion of the highest class is lowered by one category; if the sub-catchment is in the first sedimentation zone, then the severity of the erosion classes remains the same class (Fig. 4). The final step is defining a buffer zone around the reservoir with a distance of 100 m in which the land management practices are reduced to a minimum.

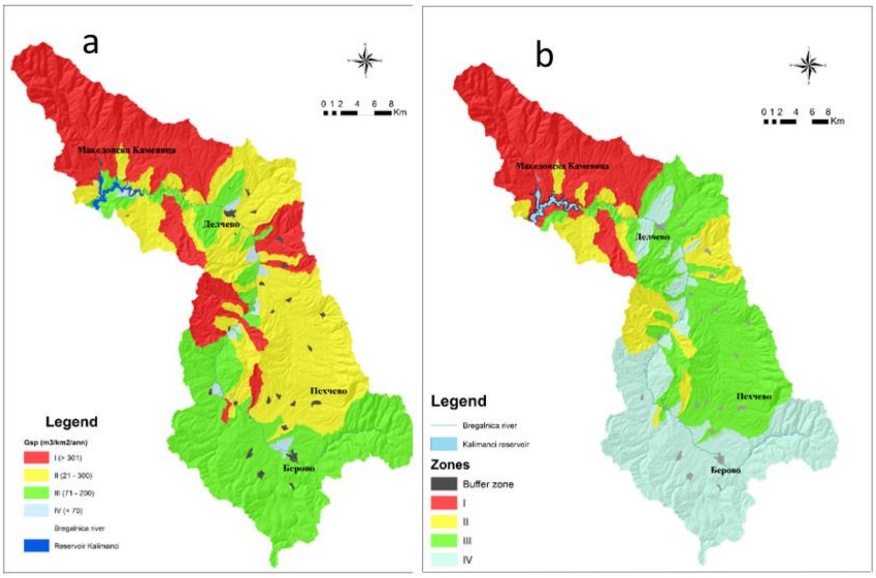

Fig. 4 Erosion severity on sub-catchment level (a), erosion protection zones in the catchment of the Kalimanci reservoir (b)

Figure 4b below shows the proposed zones around the Kalimanci reservoir in terms of erosion, where zone I represents the most critical zone, and accordingly, the catchments in zone IV are the least critical in terms of erosion.

The buffer zone is out of category and in this zone, there should not be any activities that would disturb the natural regime: conservation of agricultural practices, forests with a protective character without any invasive interventions, and construction activities that should be aimed at protecting the land from erosion, without major disturbances of the land.

In Zone I, activities should be aimed at soil conservation and forest practices that promote sustainability. Forestry activities should protect both the quantity and quality of forest resources in the medium and long term by balancing cuts/removals and yields, preferring techniques that minimize direct or indirect damage to forests, soil, and water resources. Appropriate practices should be undertaken to increase the increment in the direction of economic, environmental, and social benefits. It should also be considered the conversion of abandoned agricultural land into forest land if it contributes to the acquisition of economic, ecological, social, and cultural values.

CONCLUSION

The main motive for the preparation of this paper was to prepare a methodology for zoning the reservoirs in terms of erosion. There are examples of making such zones, but they are based on expert judgment. The goal, in this case, was to make an exact and applicable procedure, which will be reproducible on another case study and further the obtained results will be comparable.

The development of the methodology for the zoning of the reservoir catchment in terms of erosion should be understood as a basis for future considerations on the approach to its improvement. The research was done with an empirical model using measured bathymetric measurements of the reservoirs, to confirm the reliability of the results. The methodology is aligned to be able to use standardized spatial databases, which with standard reclassification fit easily into the model. From previous research, EPM methodology has been implemented in part because existing databases are taken as a finished product and directly reclassified, without any corrections.

The zoning of the reservoir catchment is a prerequisite for integrated catchment management. The approach of forming zones in the catchment areas of the reservoirs with spatial (GIS) support and cartographic display will facilitate the work of future spatial planners from several areas: urbanism, forestry, agriculture, pasture management, etc.

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Research article

On-farm Effects of Subsurface Drainage System on Chinese Cabbage (*Brassica pekinensis* L. Rupr.) Production in Rainy Season at Svay Rieng Province, Cambodia

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Abstract Vegetable production in Cambodia is unstable during the rainy season due to saturated soil conditions, leaving the comparative market advantage to neighboring Vietnam and Thailand. One potential solution that has been proposed is the introduction of a Subsurface Drainage (SD) system, as elucidated in our previous studies. In the current study, SD systems was installed on plots of Chinese cabbage in Svay Chrum District, Svay Rieng Province, to determine their potential in increasing the production period and productivity during the rainy season. The treatments consisted of three SD systems within three growing conditions (GC) including open-field, plastic house, and net house including five replications with a total of 45 plots. The results of the experiment showed positive improvement in terms of growth and yield of Chinese cabbage at a rate of 15% and 22% for SD2 and SD3 systems respectively; and 58% and 66% for net house and plastic house conditions, respectively. The extension of the production period from intermittent to year-round is of great benefit to vegetable producers, and will lead to improved market connections and better production margins, stabilizing income generation. However, the analysis still excluded the cost-effectiveness and efficiency of the experiment due to the absence of detailed data on expenditures, including the cost of drainage pipes, construction of the net and plastic houses, and water consumption.

Keywords on-farm, subsurface drainage (SD), Chinese cabbage, rainy season

INTRODUCTION

Agriculture is an important mainstay of the Cambodian economy to lift many people out of poverty. In 2021, the share of agriculture in Cambodia's gross domestic product (GDP) was 22.85%, including the contributions of fishery at approximately 5.5%, livestock at 2.6%, forestry at 1.6%, and crops at about 13% (MAFF, 2021). Although the major occupation of the Cambodians is agriculture, the country is a net agricultural importer, giving vegetable imports worth approximately USD 200 million annually (Thira et al., 2020). The heavy reliance of the country on neighboring countries' vegetables is associated with the highly seasonal productions of Cambodian producers lasting for around only three months from late December to late March. The period is appropriate for vegetable production as the weather is relatively mild and dry (Wandschneider et al., 2019). Moreover, rice farmers are free from rice production and some of them opt to produce vegetables for additional income, causing the volume of vegetables to reach a peak while the price falls to the lowest one (IRL, 2007). After the period, water becomes scarce and the soil becomes too dry whereas the wet season faces the problem of too much rainfall, causing waterlogging, high pests, and diseases (Wandschneider et al., 2019). The discontinuous supply of vegetables at stable volume has caused the vegetable value chain to break and loss of competitiveness to the neighboring countries, namely Vietnam and Thailand. It is reported that local capacity for vegetable production could supply approximately 45% of the market demand and 70% is in the peak period of the production in dry season (CPS, 2019). A wide variety of vegetables was cultivated across the country, including leafy, stem, and fruit-bearing, root, bulb, tuberous, leguminous green vegetables, etc. Fruit-bearing vegetables were planted on 35,000 ha; leafy and stem vegetables on almost 6,000 ha. Vegetables are increasingly recognized as essential for food and nutritional security. Vegetable production is a key component of farm diversification strategies to provide a promising economic opportunity for reducing rural poverty and unemployment in developing countries (Pepijn et al., 2018). Chinese cabbage (*Brassica pekinensis* L. Rupr.) is annually grown as a salad crop. It is indigenous to China and eastern Asia, where it has been in cultivation since the fifth century. Two more or less distinct species of Chinese cabbage are grown. The leaves are long, dark green, and oblong or oval, and they do not form a solid head. It is also called Chinese mustard (Kalloo et al., 1993). Chinese cabbage (*Brassica pekinensis* L. Rupr.) is a popular leafy vegetable of Cambodian farmers and consumers among many kinds of vegetables for their daily food security and income generation (Um Raingsey, 2015). The drainage system provides substantial benefits to agricultural production which could contribute to (i) increasing farm income, (ii) intensification and diversification of cropping; and (iii) generation of employment (Datta et al., 2004). Proper management of irrigation practices could provide various benefits to crop production such as extended crop season, increased yield, and improved aeration of the root zone. However, the development of drainage systems has been lagging far behind the development of irrigation, leaving agriculture at a high risk of losing productive lands due to waterlogging and salinization (Abdel, 2000). There is no exception for Cambodia where the introduction of Subsurface irrigation systems has been very limited and hardly found at any Cambodian farm. Unstable quantity on the supply side has been one of the reasons behind the loss of production competitiveness to the neighboring countries including Vietnam and Thailand. The experience from the collaboration between Svay Rieng University with Svay Rieng Agricultural Cooperatives shows that vegetable producers are facing severe issues of waterlogging during the wet season causing their production to be least productive and delayed (Hong et al., 2021). Therefore, the introduction of the SD system is essential to study in determining its potential contribution to vegetable production during the rainy season which could also be essential for other vegetable producers across the country. The on-farm experiment was conducted with farmers in Svay Chrum District, Svay Rieng Province to solve the problem of unproductive soil due to high water content (saturation) by the installation of a subsurface drainage with plastic house and net house. Draining water from the production area under plastic houses and net houses would help farmers solve the problem of highly saturated soil and continue their production during the wet season. The system will be of great benefit to vegetable producers in terms of a production period that can be extended from intermittent to year-round. This will lead to a better market connection and production margin which is stable in income generation.

OBJECTIVE

The overall objective of the research is to determine the appropriateness, potential, and suitability of the subsurface drainage under different growing conditions with Chinese cabbage as per field application of vegetable producers in increasing the period and productivity during the rainy season.

MATERIALS AND METHODS

Experimental Site

The experiment was conducted in Svay Chrum District, Svay Rieng Province, Cambodia (Fig. 1) with fifteen farmers' fields of vegetable producers who are members of Svay Rieng Agricultural Cooperatives (SAC). The experiment was carried out from August to November 2022. The soil characteristics of the experimental fields are located on the saturated soil of abandoned paddy fields with soil pH of around 5.5 of the loamy soil (averagely, clay: 17.5%, silt: 39.4%, and sand: 41.4%). The rainy seasonal precipitation ranges from 142.4 mm to 248.9 mm, while the temperature ranges from 27.9°C to 29.8°C, and the humidity ranges from 80% to 92.5% (Table 1).

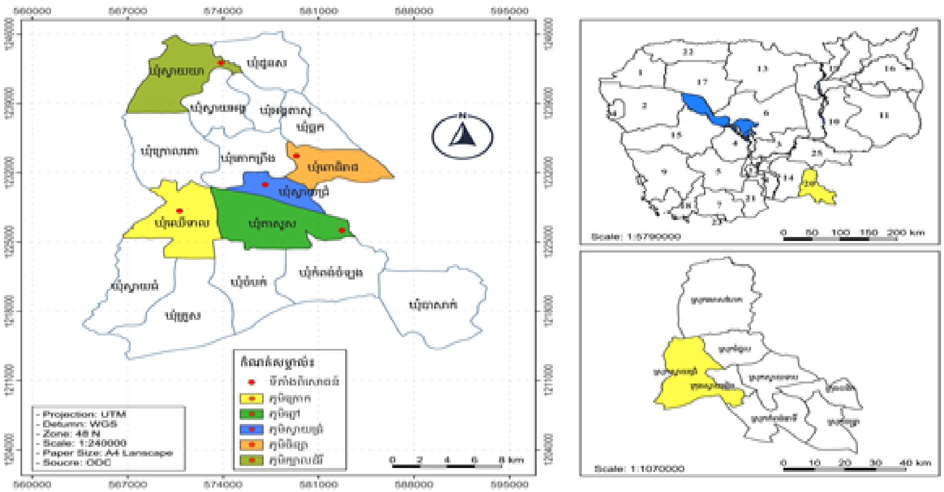

Fig. 1 The experimental location in Svay Chrum District, Svay Rieng, Cambodia

Table 1 Monthly rainfall, temperature and humidity during growing season in 2021-2022

Month	Rainfall (mm)		Temperature (°C)		Humidity (%)	
	2021	2022	2021	2022	2021	2022
Aug	218.8	174.3	30.0	29.4	91.0	87.5
Sept	255.5	238.5	29.3	29.8	96.0	85.0
Oct	254.2	248.9	28.8	27.9	92.5	92.5
Nov	248.4	142.4	29.0	29.0	86.0	85.0
Total	976.9	804.1	117.0	116.0	365.5	350.0

Experimental Design

The factorial design is used, containing fifteen farmers' fields with five replications and nine combined treatments including three SD systems and three GCs. The same design of the Subsurface drainage (SD) systems (SD1 = No Subsurface drainage pipe, SD2 = 2 rows Subsurface drainage pipe per bed, SD3 = 3 rows Subsurface drainage pipe per bed) were applied under the different Growing Conditions (GC) of open field (OP), net house (NH), and plastic house (PH). One farmer's field was used as one GC, and three SD systems were allocated. The pipes were sawed in a row at every 2 cm with 1/3 dept of pipe size to make holes for water inlets to drain through outlets to the nearby canal. The total land area for each farmer's field was 5 m x 15 m =75 m^2. The net house was fully covered by a 150-mesh net, and the plastic house was surrounded covered by a 150-mesh net with 300 UV plastic covering on top of the roof.

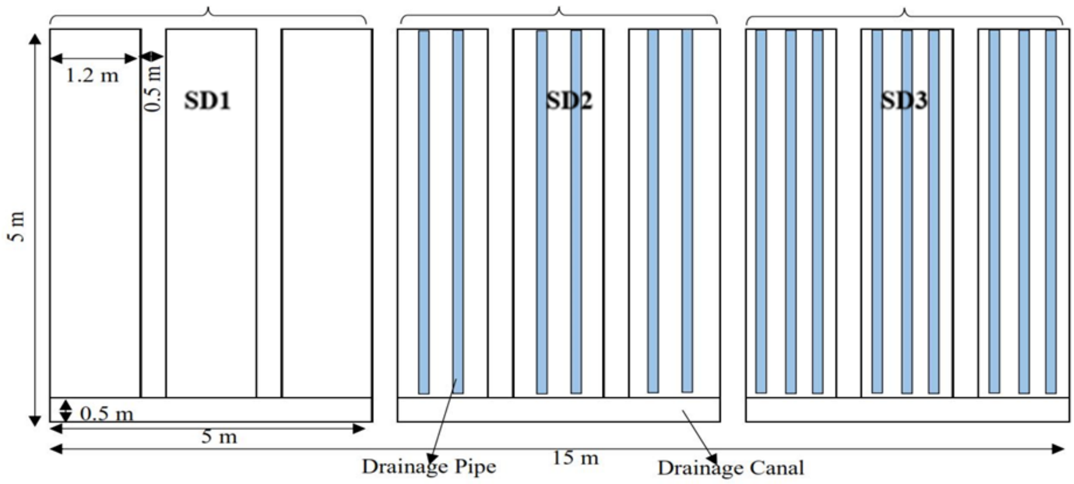

Fig. 2 Illustration of the experimental design for each farmer's field

Agronomic Practices

The Chinese cabbage seedlings were grown on the raised bed with the PVC pipe being buried underneath (sawed side goes to the ground) at a depth of 20 cm under the root zone. Mechanical methods were used for pest management. The weeding was controlled every week till the harvesting by hand. During the experiment, the diseases were not observed. The insects were normally bothered during the experiment, even in the net house or plastic house condition. The chemical methods of crop protection were used by spraying natural pesticides and by hand picking. For the irrigation, the plants were irrigated from pumped water sources by hand spraying with 20 liter-bucket. In case there was not enough or no rain, the water was applied at field capacity. Some agronomic traits such as root length, stem height, leaf area, and stem density (survived stem: is the total stem which is still alive both useful and useless stems at the harvesting date, useful stem: is the good stem which can be consumed, loss stem: is the died stem which cannot be survived at the harvesting day, damage stem: is the total of useless stems and died stems), and weight (estimated max yield: is the average weight of complete useful stems with 100% density at the harvesting date, useful yield: is the weight of good or consumable stems, loss yield: is the estimated weight of died stems which cannot be survived at the harvesting day, damage yield: is the estimated weight of useless and died stems) of the cabbages were collected. The collected data was analyzed as a factorial design using Statistix 8 program for the analysis of variance (ANOVA) and Minitab 20.4 for LSD mean comparison at p-value $p<0.01$, $p<0.05$. Before the analysis, the data were normalized to exclude the covariance being observed from the differentiation among farmer's plots.

RESULTS AND DISCUSSION

Effects on Agronomic Traits

To compare vegetative effects on the Chinese cabbage growth, the four key parameters were measured from the experiment including root length, stem height, leaf area, and leaf number. The result of the experiment is summarized in Tables 2-5.

Table 2 A root length change of Chinese cabbage

Treatment (Tr)	Root length (cm)		
	At planting day	At harvesting day	Increase
Growing condition (GC)			
Open field (OF)	2.43	9.39c	6.97c
Net house (NH)	2.51	10.14b	7.62b
Plastic house (PH)	2.42	11.30a	8.88a
Subsurface drainage (SD)			
SD1	2.47	8.99c	6.52c
SD2	2.45	10.21b	7.76b
SD3	2.43	11.63a	9.19a
CV (%)	6	18	18
Sig. (GC)	ns	**	**
Sig. (SD)	ns	**	**
Sig. (GC X SD)	ns	ns	ns

Table 3 Stem eight change of Chinese cabbage

Treatment (Tr)	Stem height (cm)				
	At planting day	At 1st week	At 2nd week	At harvesting day	Increase
Growing condition (GC)					
Open field (OF)	9.09	14.74 c	24.47c	26.44c	17.35c
Net house (NH)	9.13	14.89 bc	24.83bc	27.19b	18.07b
Plastic house (PH)	9.05	16.12 a	26.03a	30.09a	21.03a
Subsurface drainage (SD)					
SD1	9.17	13.59 c	24.00c	26.60c	17.44c
SD2	9.03	15.73 b	25.21b	27.83b	18.80b
SD3	9.07	16.41 a	26.13a	29.28a	20.21a
CV (%)	2	5	6	7	8
Sig. (GC)	ns	**	**	**	**
Sig. (SD)	ns	**	**	**	**
Sig. (GC X SD)	ns	ns	Ns	ns	ns

Table 4 Maximum leaf area change of Chinese cabbage

Treatment (Tr)	Maximum leaf area (cm^2/leaf)				
	At planting day	At 1st week	At 2nd week	At harvesting day	Increase
Growing condition (GC)					
Open field (OF)	8.90	28.54c	81.03c	187.25c	178.35c
Net house (NH)	8.98	30.10b	90.60b	196.87b	187.89b
Plastic house (PH)	9.03	34.82a	97.24a	206.43a	197.41a
Subsurface drainage (SD)					
SD1	8.88	29.03c	85.07c	189.20c	180.32c
SD2	9.04	31.81ab	90.91b	197.87b	188.84b
SD3	8.98	32.63a	92.88a	203.48a	194.50a
CV (%)	3	16	21	19	20
Sig. (GC)	ns	**	**	**	**
Sig. (SD)	ns	**	**	**	**
Sig. (GC X SD)	ns	ns	Ns	ns	ns

Tables 2 to 4 show that the level of changes for root length, stem height, and leaf area at the different growing stages of the Chinese cabbage are statistically different after the planting stages. Growing conditions and Subsurface drainage systems could make a significant impact on the growth of cabbage with a p-value less than 0.01. Overall, the level of increase of growing condition in Plastic House (PH) is observed to be better than Net House (NH) and Open Field (OF), while the level of increase of SD3 is observed to be better than SD2 and SD1. Plastic House (PH) performed the best as well as SD3, but the interaction of GC x SD was not significantly detected for root length, stem height, and leaf area of the cabbage in all growth stages.

Table 5 Leaf number change of Chinese cabbage

Growing conditions (GC)	Subsurface drainage (SD)	Number of leaves (leaf/stem)				
		At planting day	At 1st week	At 2nd week	At harvesting day	Increase
Open Field (OF)	SD1	2.99	3.63h	7.45e	10.06i	7.07i
	SD2	2.97	3.88g	8.59d	10.54h	7.57h
	SD3	2.97	3.91fg	8.40d	10.80g	7.83g
Net House (NH)	SD1	2.98	3.96ef	8.75d	11.25f	8.26f
	SD2	2.99	4.03cd	9.22c	12.55d	9.55d
	SD3	2.99	4.11ab	9.77ab	12.75c	9.77c
Plastic House (PH)	SD1	2.98	3.98de	9.16c	12.15e	9.18e
	SD2	2.97	4.10bc	9.69ab	12.96b	9.99b
	SD3	2.99	4.18a	10.07a	13.27a	10.28a
CV (%)		1	2	9	5	5
Sig. (GC)		ns	**	**	**	**
Sig. (SD)		ns	**	**	**	**
Sig. (GC X SD)		ns	**	*	**	**

The finding (Table 5) shows that leaf numbers were not significant at planting. At the later stage, the level of changes for the number of leaves at the different growing stages of the Chinese cabbage were statistically different. All parameters of growing conditions (GC) and Subsurface drainage (SD) systems could make a significant impact on the growth of cabbage with a p-value less than 0.01. In addition, the interaction of GC x SD was significant. Overall, the best performance of crop growth was observed under plastic house conditions with Subsurface drainage systems type 2 (SD2) and 3 (SD3).

Effects on Productivity

The Stem density, stem weight, and yield per hectare were measured and calculated from the experiment to compare productivity effects. The results from the experiment are provided in Tables 6 and 7.

Table 6 Stem density on the harvesting day of Chinese cabbage

Growing conditions (GC)	Subsurface drainage (SD)	Stem Density (stem/m^2)			
		Survived stem	Useful stem	Loss stem	Damage stem
Open field (OF)	SD1	9.57h	7.44g	15.43a	17.56a
	SD2	13.92g	8.16fg	11.08b	16.84ab
	SD3	14.92f	8.80f	10.08c	16.20b
Net house (NH)	SD1	17.78e	16.16e	7.22d	8.84c
	SD2	19.68d	17.86d	5.32e	7.14d
	SD3	20.68c	19.23c	4.32f	5.77e
Plastic house (PH)	SD1	20.09cd	18.29cd	4.91ef	6.71de
	SD2	22.00b	21.09b	3.00g	3.91f
	SD3	23.32a	22.36a	1.68h	2.64g
CV (%)		4	4	4	4
Sig. (GC)		ns	**	**	**
Sig. (SD)		ns	**	**	**
Sig. (GC X SD)		**	**	**	**

The result (Table 6) shows that the level of changes for the density of survived stem, useful stem, loss stem, and damaged stem on the harvesting day of the Chinese cabbage are statistically different. All parameters under growing conditions and Subsurface drainage systems could make a significant impact on the productivity of cabbage with a p-value less than 0.01. The interaction of GC x SD was significant. In overall, the plastic house condition with Subsurface drainage system type 3 was observed to be the best performance for survived stem and useful stem, while under plastic house condition with Subsurface drainage system type 2 and net house condition with Subsurface drainage system type 3 were observed to be better performance compared to Subsurface drainage system type 1 in all growing conditions. In addition, open field condition with Subsurface drainage system type 1 was observed to be the worst performance for loss stem and damage stem.

Table 7 Yield of Chinese cabbage

Growing conditions (GC)	Subsurface drainage (SD)	Total yield (ton/ha)			
		Estimated max yield	Useful yield	Loss yield	Damage yield
Open field (OF)	SD1	32.03i	9.53g	19.77a	22.50a
	SD2	32.42h	10.58fg	14.37b	21.84a
	SD3	32.90g	11.58f	13.27b	21.32a
Net house (NH)	SD1	33.36f	21.57e	9.63c	11.79b
	SD2	35.90e	25.65d	7.64d	10.25c
	SD3	36.92d	28.40c	6.38d	8.52d
Plastic house (PH)	SD1	36.49c	26.70d	7.17d	9.79cd
	SD2	37.90b	31.97b	4.55e	5.92e
	SD3	38.58a	34.51a	2.59f	4.07f
CV (%)		1	3	3	3
Sig. (GC)		**	**	**	**
Sig. (SD)		**	**	**	**
Sig. (GC X SD)		**	**	**	**

The result (Table 7) shows that the level of changes for the estimated maximum yield, useful yield, loss yield, and damage yield of the Chinese cabbage are statistically different. All parameters under growing conditions and Subsurface drainage systems could make a significant impact on the productivity of cabbage with a p-value less than 0.01. The interaction of GC x SD gradually developed and became significant. In overall, the plastic house condition with Subsurface drainage system type 3 was observed to be the best performance for estimated maximum yield and useful yield, while under plastic house condition with Subsurface drainage system type 2 and net house condition with Subsurface drainage system type 3 were observed to be better performance compared to Subsurface drainage system type 1 in all growing conditions. In addition, open field condition with Subsurface drainage system type 1 was observed to be the worst performance for loss yield and damage yield.

Discussion

The result of the experiment indicated high productive benefits for the Chinese cabbage in terms of yield at a rate of 15% and 22% for SD2 and SD3 systems respectively; and 58% and 66% for net house and plastic house conditions respectively. In comparison to the previous assignment conducted at the same location during the dry season, the increase is 26% to 34%, respectively (Hong et al., 2021). The yield from the experiment was slightly better than the one being conducted during the dry season at the Royal University of Agriculture with a yield of 28 tons/ha (Teb Kimheng, 2015). This would be more precise with the full-control condition of experimentation which would be possible in generalizing the actual condition of the country. In addition, a field experiment was conducted in paddy fields during the rainy seasons (October to May) from 2011 to 2015 to evaluate a suitable drainage system for improving the grain yield of lowland paddy soil. The saturated hydraulic conductivity of the soil in all treatments increased, which resulted in improved soil properties, water movement, and drain discharge rates (Mehdi et al., 2016). The results of the experiment were quite better in comparison to the installation of a subsurface drainage system resulting in an improvement of paddy yield by 13.27% and an increase in soil organic carbon content. However, it was the first year after the installation of the subsurface drainage; the yield could be expected to improve considerably during the succeeding seasons with appropriate and better cropping and irrigation management practices (Sahana et al., 2023). The increase was due to improvement in soil physical properties viz., infiltration rate, porosity, and chemical properties (low pH, EC, ESP) and improved nutrient availability in the drained field. Similarly, Abdel-Dayem, and Ritzema (1990) reported an increased yield of many crops to a tune of 10% for rice, 48% for berseem, 75% for maize, and more than 130% for wheat under a subsurface drainage system. The increase was because of decreased soil salinity, and improved air and water condition in crop root zones. The poor yield of maize in the undrained field due to poor soil physicochemical properties viz., shallow water table depth, high pH, EC, and ESP (Stieger and Feller, 1994; Samad et al., 2001 and Zhang et al., 2015), which limits the growth and development of crops in waterlogged saline-alkali soil (Arumugam et al., 2019). In addition, the enormous increase would result in reducing of water stress and strong drops of rain under the plastic house protection during the rainy season. This would bring enormous economic benefits for farmers. It is reported that the consumption of vegetables in Cambodia is approximately 1,062 million tons per year (SAAMBAT Project, 2020). This would translate into approximately contribution of 79,650-116,820 tons with the application of Subsurface drainage and approximately contribution of 307,980-350,460 tons with the application of growing condition (Net house and Plastic House) for the wet season production (June to December) for Cambodia with the application of the drainage under the net house or plastic house condition at the maximum scenario. There is still another concern regarding the cost of the drainage pipe and growing structures, which was included in the production. A more detailed analysis of the cost and benefit of the product will be included in future research assignments to make the drainage system and net or plastic house growing condition more determined and applicable for the rainy season.

CONCLUSION

The growth of the Chinese cabbage within the Subsurface drainage (SD2 and SD3) systems and growing conditions (NH and PH) performed better under both saturated and drought conditions. At the time of rain, the cabbage could continue its growth with less effect, while during the time of drought, cabbage could maintain its yield, possibly because of good aeration of the soil and less soil compaction after a strong drop of rain. The analysis still excluded the cost-effectiveness and efficiency of the experiment due to the absence of detailed expenditures on drainage pipe, construction of the net and plastic house, and water consumption is also excluded. Anyway, future research should be conducting a detailed analysis of the loss of other nutrients in soils, water consumption, and possible economic loss as a result of drainage systems and conduct a detailed analysis of the economic benefits of drainage systems with actual price estimation.

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Research article

Prediction of Land Use Change through the Cellular Automata-Markov Model: A Case Study of the Upper Sangkae River Basin in Cambodia

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Abstract The expansion of agricultural land and the diminishment of forest cover in Battambang Province (Cambodia) has been recently reported. At the same time, while forest cover has decreased, the amount of water resources in the river basin has been variable. The aim of the current study was to forecast land use change in the upper Sangkae River basin of Battambang Province by 2030. For this purpose, remote sensing and geographic information systems (GIS) methods were used to analyze satellite data from 2014 to 2018, using the generated maps as data input in the cellular automata (CA)-Markov model. We also integrated the CA-Markov model and GIS spatial analyst tools to assess what will most likely occur in the presence of policy intervention from land use development planning by 2030. Additionally, the model simulated actual and predicted land use in 2022 for accuracy assessment, using the Kappa Index of Agreement for confirmation. Based on the findings, the modeled scenario predicted the increase in built-up land and the decrease in the natural forest cover by 2030 in the absence of a land use policy. Additionally, the findings suggested that in the absence of a land use policy, forest cover will suffer from continued deforestation until forest loss reaches the protected area boundary. Conversely, in the presence of a land use policy, the model shows an increase in forest cover by 2030, even though some areas would be allocated under economic land concessions for industrial agriculture. Moreover, non-forest cover, such as farmlands and paddy fields, is not expected to decline, whereas built-up land is forecast to dramatically increase, with or without policy intervention. This study sheds light on the use of practical evaluation tools for governmental land use policies and development planning.

Keywords CA-Markov model, land use change, government land use planning, prediction

INTRODUCTION

Land use/land cover has been considered the main factor in changing the hydrological cycle since it directly influences evapotranspiration and soil moisture contents (Gupta et al., 2015). In this regard, significant land use changes in Battambang Province (Cambodia) have been recently reported. For example, previous research (Sourn et al., 2021) found a considerable increase in agricultural land, with a dramatic decrease in forest cover between 1998 and 2018. These changes were driven by population growth, economic growth, landmine clearance projects, and social and economic land concessions (SLCs and ELCs, respectively). Based on the Cambodia Land Law of 2001 (Open Development Cambodia), the term SLC refers to the social purpose of allowing beneficiaries to build residential constructions and/or cultivate land belonging to the state for their subsistence. The term ELC refers to the economic purpose of allowing beneficiaries to clear the land for industrial and agricultural exploitation.

Understanding land use change has become an increasing matter of interest and concern among landscape planners and environmentalists because it influenced the global environment (Subedi et al., 2013). Land use/land cover mapping derived from remotely sensed data has long been an area of focus for many researchers (Civco et al., 2002; Araya and Cabral, 2010). Meanwhile, recent advancements in geographic information systems (GIS) and remote sensing tools/methods have enabled researchers to effectively model land use change (Araya and Cabral, 2010).

In general, modeling land use dynamics is a complex process (Subedi et al., 2013), due to factors such as natural settings, society, economics, culture, politics, and legal aspects (Lambin, 1997). Various models for land use simulation and prediction have been used in GIS such as statistic, dynamic, and machine learning modeling (Aburas et al., 2019). Based on historical spatio-temporal data, the cellular automata (CA)-Markov module in IDIRISI software was first used in this study to simulate and predict future land use change, due to its widespread use by scholars to understand landscape change at the global level (Wang et al., 2021). It was also used to analyze the related effects and natural resource management strategies (Brown et al., 2000). However, this model did not consider land use policies and socio-economic factors (Subedi et al., 2013).

OBJECTIVE

Therefore, the present study examines the SLCs, ELCs, and potential areas for forest communities according to the local government's 2030 master plan (Open Development Cambodia). The primary objective is to integrate the CA-Markov model and GIS-based spatial analyst tools to enhance the predictive land-use change map.

METHODOLOGY

Study Area

The study focused on the upper Sangkae River basin, situated in Battambang Province (the largest agricultural area in Cambodia), with a total drainage area of 3,062 km^2 (Vanna et al., 2020) (Fig. 1). The elevation ranges from 13 to 1,400 meters above sea level. Based on Mekong River Commission (MRC) land use data in 2010, 53.13% of land use within this basin was covered by forest, followed by agriculture at 44.41%, built-up land at 2.03%, and water bodies at 0.44%. More than one million people live in this province, with an annual population growth rate of 2.28% (Hagenlocher et al., 2016). Meanwhile, human activities have been affected in this watershed by landmine clearance and explosive remnants of war projects, and land concessions (Sourn et al., 2021).

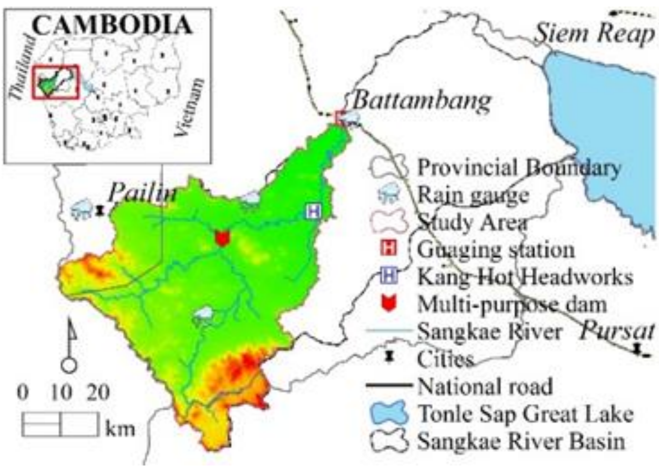

Fig. 1 Map of the study area

Data Input and Image Classification

Freely available Landsat 8 (Path 127-128, Row 51) images in 2014, 2018, and 2022 were acquired from the U.S. Geological Survey (https://earthexplorer.usgs.gov/). The images were mosaicked and composited using Bands 1-7 and projected in UTM 48N using ArcGIS 10.5. Due to prior knowledge of the Sangkae River basin, the images were classified by hard supervised classification, a popular algorithm of maximum likelihood based on signature files (Rawat and Kumar, 2015). According to the user's knowledge, a signature was processed by using the on-screen digitizing feature to create 5–12 vector files of the training site for each class. Land cover was identified, following MRC land use-2010 and satellite imagery, while land use was aggregated into five major classes: forest cover, farmlands, paddy fields, water bodies, and built-up areas. The stratified randoms of more than 500 points were created for each image using the Create Accuracy Assessment Points tool in ArcGIS. They were then manually checked and compared by using existing land use and the Google Earth Engine, as reference data. The overall accuracy and Kappa coefficient (Table 1) of the classified images were larger than 95% and 0.90, respectively.

Table 1 Accuracy assessment of image classification

Year	Overall accuracy	Kappa coefficient
LULC2022	95.06	0.92
LULC2018	95.40	0.94
LULC2014	96.00	0.95

Land Use Change Modeling and Prediction Process

In this study, three land use maps (2014, 2018, and 2022) were converted into ASCII files and then imported into IDIRISI software for land use change simulation and prediction. First, land use predictions in 2022 and 2030 were performed with the CA-Markov model (Eastman and Toledano, 2018) by inputting suitability maps, transition areas, and a transition probability matrix, all computed from the Markov chain analysis of the 2014 and 2018 images. Second, the 2018 image was set as the base map. Third, the VALIDATE module was used to assess the model's validity, which was confirmed by the statistical Kappa Index of Agreement (KIA). Fourth, the predicted land use in 2030 was generated by using the projected transition probability matrix derived from the simple powering of the base matrix (Takada et al., 2010). Finally, according to the presence of a future land use policy, another land use map was created by overlaying the development areas onto the predicted land use map in 2030.

The Markov and CA-Markov Models

The Markov model is a convenient tool for simulating land use/land cover change when variations in the landscape are difficult to describe (Kumar et al., 2014). Specifically, it depicts land use/land cover change from one period to another and uses it as a basis for predicting future changes. Table 2 presents the conversions of land use from one class to another for the 2014–2018 study period. The CA-Markov model combines the cellular automata-Markov chain and the multi-criteria/objective procedures for land use/land cover prediction (Eastman and Toledano, 2018). In particular, it allocates land based on the suitability of the land for end covers (along with a cellular automaton rule) to promote spatial contiguity (Eastman and Toledano, 2018). In addition, by using the Markov chain analysis outputs, especially the transition area file, the CA-Markov model applies a contiguity filter to grow land use from one time to a later time.

Table 2 Transition probability matrix from 2014 to 2018

Land use classes	Forest cover	Farmlands	Built-up land	Paddy fields	Waterbody
Forest cover	0.7435	0.2510	0.0005	0.0005	0.0045
Farmlands	0.1557	0.7503	0.0162	0.0549	0.0229
Built-up land	0.0014	0.2035	0.7666	0.0251	0.0034
Paddy fields	0.0225	0.2921	0.0003	0.6851	0.0000
Waterbody	0.0710	0.1909	0.0140	0.0019	0.7222

Regarding the suitability for predictive land use, it refers to the suitability of a cell for particular land use (Eastman and Toledano, 2018). Normally, suitability images are constructed with multi-criteria evaluation, a common method for assessing/aggregating the "constraint and factor" criteria. Constraints are usually represented as a Boolean image (0 and 1), while factors define some degree of suitability for all geographic regions. In this study, the factors were empirically developed by using the underlying land use change dynamics between 2014 and 2018.

Additionally, various factors, such as proximity to roads, water, canals, and existing land use were generated and standardized on a continuous scale of 0 (least suitable) to 255 (most suitable), using a fuzzy module. The factors of each land use class were then aggregated by employing pairwise comparison associated with the analytical hierarchy process in the weighted linear combination method. For more information on the Markov and CA-Markov models, see references (Subedi et al., 2013; Wang et al., 2021; Eastman, 2012; Hamad et al., 2018).

RESULTS AND DISCUSSION

Accuracy Assessment of the CA-Markov Model

Validation of the model is an essential pre-condition for research that predicts land use/land cover changes (Wang et al., 2021). The model validation in this study was achieved by simulating actual and predicted land use images in 2022, based on known land use in 2014 and 2018, and a KIA statistics-based assessment. According to Fig. 2, the actual and predicted land uses in 2022 are similar, except for the forest cover class, due to the map accuracy during image classification. In addition, the Kappa is 1 when the observed agreement is perfect, or 0 when the observed agreement is equal to the expected agreement (Pontius, 2022). The statistics derived from the VALIDATE module in IDIRISI software show that the Kappas for no information (Kno = 0.94), for location (Klocation = 0.94), for quantity (Kquantity = 0.94), and for standard (Kstandard = 0.92) were larger at 0.90 (Wang et al., 2021). Thus, the model was deemed valid and reliable for land use change projection.

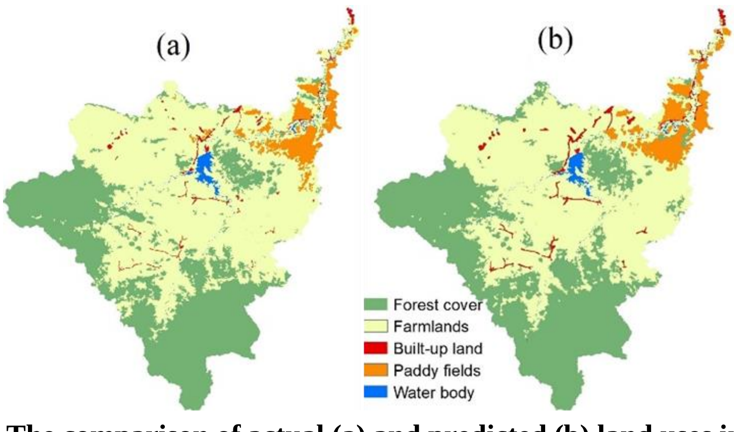

Fig. 2 The comparison of actual (a) and predicted (b) land uses in 2022

Prediction of Future Land Use

The land use prediction maps for 2030 are shown in Figs. 3(a) and 3(b). Specifically, the model scenario without a land use policy (Figure 3(a)) predicted that the farmlands will cover 52.12% of the total area of the upper Sangkae River basin, followed by forest cover (38.42%), paddy fields (6.69%), built-up land (1.82%), and water bodies (0.95%) (Table 3). Additionally, forest cover and farmlands are expected to decrease in area by 2030, compared to the predicted land use in 2022 (Table 3). However, this decrease will contribute to an increase in built-up land by 0.22%. It should be noted that the decline of forest cover in the study area has been observed over the past few decades. According to previous research (Sourn et al., 2021), deforestation was observed from 1998 to 2013. Up to 2018, forest cover was mostly stable in mountainous areas, especially naturally protected areas such as the Phnom Samkos Wildlife Sanctuary and the Samlot Multiple Use Area. The expansion of agricultural land in the upper Sangkae River basin will most likely reach these protected areas, reflecting the minor decline in forest cover predicted by the model.

With the presence of a land use development policy, the land use map in 2030 was achieved (Fig. 3(b)). If land use planning succeeds, then the positive impact on the natural forest cover in this basin can be seen in an increase in reforestation by 2030. In this case, our predicted land use shows that forest cover and built-up land of high and low population density increase by 0.78%, 0.20%, and 100%, respectively. Moreover, forest cover is predicted to increase, even though some areas at the upstream part of the river basin have been offered and allocated under ELCs. Nevertheless, the farmlands and paddy fields will decrease by 3.05% and 0.02%, respectively. Field surveys of current land use in mountain areas confirm that natural forests, even in protected areas, are being cut and burned to expand agricultural land. Therefore, it is predicted that deforestation will continue in the absence of effective land use policies. The land use policy here, however, is the planning of afforestation for forest communities by local governments. This policy is believed to help increase forest cover in the future.

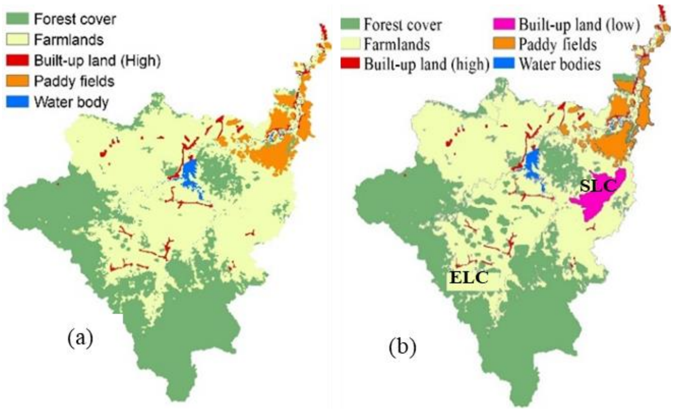

Fig. 3 The predicted land use in 2030

Overall, these decreases and increases are the result of government policies on land allocation. For instance, land use changes from farmlands to the built-up area of low population density appear as a new land use class. In this case, the land was allocated under SLCs. Meanwhile, the built-up area's expansion is expected to increase, due to the increase in the number of new marriages and residential development plans. Furthermore, there will be a slight decline in paddy fields, while water bodies will remain stable from 2018 to 2030.

Table 3 Predicted land use in 2030

Land use classes	Predicted LU2022		Without a land use policy			With a land use policy		
			Predicted LU 2030		Rate of changes	Predicted LU 2030		Rate of changes
	Area (ha)	Area (%)	Area (ha)	Area (%)	(%)	Area (ha)	Area (%)	(%)
Forest cover	118,132.18	38.61	117,678.13	38.42	−0.19	120,619.33	39.39	0.78
Farmlands	159,732.80	52.18	159,570.39	52.12	−0.06	150,436.29	49.14	−3.05
Built-up land (high density)	4,914.26	1.61	5,579.82	1.82	0.22	5,538.65	1.81	0.20
Built-up land (low-density)	-	-	-	-	-	6,386.96	2.09	100.00
Paddy fields	20,360.63	6.65	20,477.64	6.69	0.03	20,311.63	6.63	−0.02
Water bodies	2,922.47	0.95	2,909.35	0.95	0.00	2,922.47	0.95	0.00
Total	306,215.34	-	306,215.34	-	-	306,215.34	-	-

Based on the guidelines from the Ministry of Land Management, Urban Planning, and Construction, 6,386 hectares (built-up land with low population density) of state land in the Samlot district of Battambang Province and its shared border with the Koh Krala district were converted into SLCs for the poor and retired soldiers. Specifically, these individuals were legally authorized to occupy one hectare of land with one house. This project was implemented under the Battambang Provincial Administration. Conversely, according to the Sub-degree on Reclassification of State Permanent Forest Reserve and Granting of ELCs for agro-industry investment in 2009 (Open Development Cambodia), 5,200 hectares of ELCs (Fig. 3(b)) in the Samlot district were converted from forest for development purposes (e.g., rubber plantations). However, we found that this zoning area only experienced tree cutting.In this study, the objective influences on land use patterns under the local government's land use development plan were successfully predicted by using the CA-Markov model. This model was effective because the land use planning focused on built-up land with low population density and farmland zoning. However, there are still the challenges of predicting land use change when considering human activities (e.g., commercial and/or urban development) and investments in land use development policies.

CONCLUSION

This study was the first attempt to predict future land use change and the effects of governmental land use planning in the upper Sangkae River basin of Cambodia. Land use prediction has become a critical issue, due to the uncertainty of land use policies and the capacity of available models. However, spatiotemporal land use dynamics through the CA-Markov model confirmed that it is a valuable tool for simulating and predicting future changes in the landscape. Moreover, the limitations of this model were fulfilled with assistance from ArcGIS tools. It is hoped that our results will not only be used to assess the impact of future land use changes on the hydrologic environment but also be integrated with climate change prediction models to contribute to future water demand projections.

ACKNOWLEDGEMENTS

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Research article

Educational Material Research on the Color of Crayfish for Conversion to Edible Resources

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Abstract The crayfish (*Procambarus clarkii*) is an invasive alien species consumed as a food source worldwide. However, there is an extremely low demand for it as a food resource in Japan, and it is typically targeted for extermination. One reason for the lack of progress in considering crayfish a sustainable food resource is limited education on the issue during secondary education programs. It is well known that astaxanthin is the pigment responsible for the body color of common red crayfish and crustaceans such as shrimp and crabs. At the same time, while there are ample study materials on plant pigments in the science education curriculum in junior high and high schools in Japan, there are no such materials to our knowledge that focus on animal pigments. Therefore, this research sought to develop teaching materials to deepen understanding of color as a food component of crayfish through an experiment involving extracting and separating their pigments. Using pigments extracted from red crayfish exoskeletons, we developed experimental teaching materials to observe astaxanthin by employing thin-layer chromatography and high-performance liquid chromatography. In addition, an experiment was conducted to observe the effect of different foods on crayfish body color. For the experiment, food was developed to make crayfish bodies white (decolorized) and orange. When the decolorized crayfish were fed norbixin or bixin, which are components of the orange annatto pigment, norbixin tended to accumulate as orange in the exoskeleton more than bixin based on the apparent body color change, color extraction from images, and thin-layer chromatography. These findings are expected to be useful for science and nutrition education, supporting the development of the students' awareness and understanding of crayfish as a food resource.

Keywords education, teaching material, *Procambarus clarkii,* pigment, food resource, SDGs

INTRODUCTION

Crayfish (*Procambarus clarkii*), which live in rivers, ponds, rice paddies, swamps, and other bodies of water in the city, are a globally invasive alien species native to the United States (Gheradi, 2013). Although the damage they cause to ecosystems is regarded as a problem, crayfish are used as a food resource in the United States, China, and European countries (Hara, 2021). Furthermore, in the future, their excrement and shells are expected to be used as agricultural resources such as fertilizers, as raw materials for textiles, and as medical resources (Ifuku et al., 2004; Yihun et al., 2016).

Crayfish were introduced to Japan in 1927 as food for bullfrogs. Since then, the species' high fertility rate and omnivorous nature have led to substantial damage to local ecosystems and agriculture. Thus, crayfish have become a well-known representative of alien species in Japan. As part of environmental protection activities, crayfish are routinely exterminated and culled, but they are not actively used. One reason for this is the lack of opportunities for students to learn about the usefulness of crawfish as a resource in elementary and secondary education. In elementary education, crayfish are familiar observation materials because of their ease of care and management; however, in secondary education, they are only treated as an invasive alien species and representatives of crustaceans. Therefore, we thought that, in order to promote the recognition of crayfish as a food resource, experimental materials focusing on the useful food components contained in crayfish might be necessary. We focused on carotenoid pigments, which are a factor in crayfish body color that children are likely to be interested in and have functional properties such as antioxidant effects and nutrients. In Japanese secondary education, carotenoid pigments are derived only from photosynthetic organisms, and their functions are rarely discussed. Among carotenoid pigments, astaxanthin, which is found in the wild crayfish, salmon, and crustaceans (shrimp and crab) that are familiar to the Japanese people, is utilized in a variety of products because of its high functionality. Although the usefulness of astaxanthin is known commercially, it has not yet been used in Japanese secondary education. Therefore, the development of experimental teaching materials focusing on astaxanthin using crayfish will provide new science experiment teaching materials focusing on animal pigments and will enable students to learn about the usefulness of crayfish.

Astaxanthin is abundant in the exoskeletons of crayfish. The exoskeleton can easily extract pigments, and the use of molting shells obtained each time the crayfish grows is useful as a type of teaching material for collecting samples without killing the organism. Astaxanthin in the exoskeleton of crayfish exists in free and ester forms. However, the form of astaxanthin in exoskeletons derived from molted shells is unknown. Therefore, in this study, we will examine the separation conditions using thin-layer chromatography (TLC) and high-performance liquid chromatography (e-HPLC), which are treated in secondary education, as teaching materials for observing the ontogeny of astaxanthin in molting shells.

Previously, we produced crayfish that changed their body color to blue or pink by feeding astaxanthin to genetically fixed white crayfish (Takeda, 2021). We also found that feeding another carotenoid pigment, annatto pigment, to white crayfish turned their bodies orange. However, the food pigment annatto contains bixin and norbixin as components, and the difference in body color due to these components is unknown. Wild crayfish are familiar for use as general teaching material, but since they retain their original colors, they must be decolored. Therefore, in this study, as teaching material to explore the factors involved in rearing, we prepared decolorized wild crayfish diets and conducted feeding tests of diets containing mainly bixin and norbixin. Then, the experiment will compare the body color change for each color value and study the conditions to observe the substances that cause these body colors by TLC.

OBJECTIVE

This research explored the development of teaching materials focusing on pigments, which are both body color factors and nutrients in crayfish, with the aim of utilizing them in science and food education to highlight their usefulness as food resources.

METHODOLOGY

Experiment Focusing on Astaxanthin Contained in Crayfish Exoskeleton and Separation of Astaxanthin using TLC

We experimented to explore astaxanthin in crayfish exoskeletons as a body-color factor. Acetone containing 0.01% astaxanthin (Fujifilm Wako) and krill were used as controls. It has been reported that krill have astaxanthin and esters of astaxanthin (monoesters, diesters) (Takaichi et al., 2003). Since the eyes of krill contain substantial amounts of these carotenoids (Maoka et al., 1985), krill eyes were used in the experiment.

The sample for the experiment included the exoskeletons of living crayfish and molted exoskeletons. For pigment extraction, the abdominal segment of each exoskeleton was shredded to about 1 mm, and 100 µl of acetone was added to 0.01 g of the material. They were mixed lightly, allowed to stand for 15 minutes, and centrifuged for 20 seconds. Each sample was spotted on a TLC plate (TLC silica gel 60 F_{254} [4 × 8 cm], Sigma-Aldrich), and then the TLC was placed in the solvent (petroleum ether: acetone = 7:3) in the deployment tank to separate the pigments.

Isolation of Astaxanthin Using e-HPLC

"Kotori" (Uniflows, Japan) is an HPLC developed for educational purposes. It is smaller and cheaper than the general HPLC. Thus, it is used in high schools in Japan. An e-HPLC was used to detect astaxanthin contained in the molted exoskeletons of crayfish. As a control, 0.001% astaxanthin (Fujifilm Wako) was dissolved in acetone, and 100 µl of acetone was added to 0.01 g of the abdominal segment as a sample. A Cadenza CD-C18 column (Φ6 × 50 mm) (manufactured by Intact Co., Ltd.) was equilibrated with 50% methanol: THF (1:1) eluent at 600 µL/min at room temperature (25°C). Each sample of 2.7 µL was injected into the column; then, the peak of astaxanthin was detected at 405 nm.

Creation of Bait for Decolorization and Feeding Tests

Material containing no carotenoid pigments was used to create decolorization bait. Rice powder was used as a carbohydrate, soybean, pork bone, and fish powders were used as protein, and sardine oil was used as a lipid. Rice powder, soybean powder, pork bone powder, fish powder, and sardine oil were mixed at 2:3:2:2.8:0.2, and an appropriate amount of water was added. The ingredients were then molded into a round shape, steamed for 20 minutes, and then solidified and used as feed. Four crayfish aged about 8 weeks old were selected for a feeding test in which any changes to their body color after consuming the decolorization bait were observed. The crayfish were fed 0.05 g of bait once a day in the morning for 8 weeks. In addition, it was confirmed that there was no bait left over from the previous day, and any molted exoskeletons were removed, the water was changed daily before feeding. As a control experiment, commercially available crayfish bait (Kyorin) was used under the same conditions.

Pigment-containing bait was then created using the decolorization bait before it underwent steaming. The bait and pigment were mixed at a ratio of 9:1, and about 0.5 ml of water per 1 g of bait was added to assess the degree of viscosity. The pigments used were norbixin (Fujifilm Wako) and bixin (Fujifilm Wako); they are components of annatto pigment (Scooter, 2009) used for food coloring. The ingredients were then molded into a round shape, steamed for 20 minutes, then solidified. This pigment-containing bait was then used in a feeding test of crayfish decolored using decolorization bait. Any changes to the crayfish's body color were observed. Four crayfish were fed norbixin-containing bait, and four were fed bixin-containing bait. A piece of pigment-containing bait was fed at a rate of 0.03 g per 0.1 g of crayfish weight in the morning once a day for 9 days. In addition, it was confirmed that there was no bait left over from the previous day and any molted exoskeletons were removed; the water was changed daily before feeding.

Color Extraction from an Image of Body Color Change

Pictures were taken of the subject crayfish every day under the same conditions. The red, green, and blue (RGB) values of the sixth abdominal segment were measured using a color selection software called Spoitkun. The resulting data were expressed as the average value ± standard deviation.

Confirmation of Color Change Due to Boiling

It was important to confirm how the color would change after boiling as this is how crayfish are prepared as food. Therefore, we compared the color of the first pectoral leg of wild crayfish and crayfish colored using norbixin before and after boiling for 15 min.

Detection of Substances Causing Body Color Using TLC

Acetone containing 0.01% norbixin (Fujifilm Wako) and 0.01% bixin (Fujifilm Wako) was used as a control, and the tail fins of crayfish were used as a sample. For each 0.01 g of tail fin mass, 50 μl of acetone was added. The solution was lightly mixed and then centrifuged for 20 seconds to extract the pigment. After pigment extraction, each sample was quickly spotted on a TLC plate (TLC Silica gel 60 RP-18 F_{254}s [5×7.5 cm], Sigma-Aldrich). Then, the TLC was placed in the solvent (water: acetone 1:9) in the deployment tank to separate the pigments.

RESULTS AND DISCUSSION

Experiment Focusing on Astaxanthin Contained in Crayfish Exoskeleton and Separation of Astaxanthin using TLC

Astaxanthin esters were mainly present in the abdominal segment of the crayfish (lane 3) as well as the krill (lane 2), and astaxanthin was also detected (Fig. 1A). Astaxanthin was observed as a major pigment in the abdominal segment of the molted exoskeleton (lane 4) (Fig. 1A). Although it has been reported that astaxanthin esters and astaxanthin are the main pigments in the exoskeleton of wild crayfish (Nakagawa et al., 1974), no research was found describing the predominance of freeform astaxanthin in molted exoskeletons. This experiment revealed that there is a difference in the presence of astaxanthin in crayfish exoskeletons before and after molting.

Since crustacean molting is a lifelong phenomenon, molted exoskeletons can be continuously collected as samples for experiments. In addition, since the pigment contained is mainly astaxanthin in the free form, it is expected that it will be easy for children to understand. Using molted exoskeletons for experiments to observe pigments contained in the exoskeletons of crayfish is considered suitable.

Isolation of Astaxanthin Using e-HPLC

As with the control freeform astaxanthin, elution peaks were also confirmed in the molted exoskeleton at 200 s–230 s (Fig. 1B). Freeform astaxanthin was confirmed to be the main pigment contained in the molted exoskeleton using not only TLC but also e-HPLC.

"Kotori" can be used to confirm astaxanthin in a short time. Thus, it is possible to perform multiple analyses even within a typical 50-minute class period. The device and column are very small compared to general HPLC, and, since it is very portable, it is considered suitable for conducting advanced experiments aimed at separating astaxanthin in various educational settings.

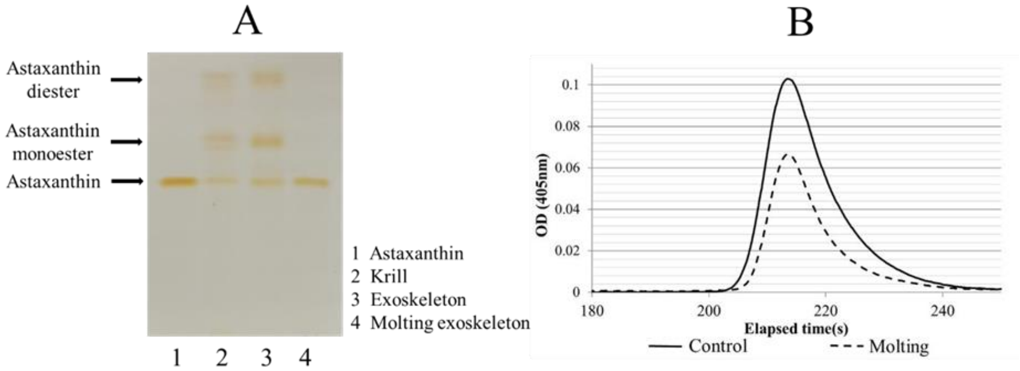

Fig. 1 Isolation of astaxanthin in wild crayfish exoskeletons A (TLC), B (e-HPLC)

Creation of Bait for Decolorization and Feeding Tests

In the feeding test using TL2-3 cm crayfish for 8 weeks, the bodies of the crayfish fed with the commercial bait turned brown (Fig. 2A-a) while the bodies of the crayfish fed with decolorized bait turned white (Fig. 2A-b). Body color changes to blue and white with each molt are known to occur by feeding horse mackerel with a low amount of carotenoid pigment. However, horse mackerel bait is likely to cause contamination and odor in the breeding water. The decolorized bait created in this experiment can also be used as an alternative bait, which is considered to have the advantage of ease of breeding.

In the feeding test with pigment-containing bait, the bodies of all four crayfish consuming the norbixin-containing bait (Fig. 2B-abc) rapidly changed to orange while those consuming the bixin-containing bait gradually changed to yellow, although there were individual differences (Fig. 2Bdef). In our previous research, genetically fixed white crayfish fed with a diet containing annatto pigment (TCI, Japan) diet turned orange. However, in that research, it was unclear whether it was norbixin or bixin that was related to the orange body color. In this study, decolored wild crayfish turned dark orange when fed with norbixin (Fig. 2B-c) and yellow when fed with bixin (Fig. 2B-f). Thus, it was apparent that norbixin is the main factor contributing to orange body color. Fig. 2 shows the change over time in the crayfish with the most colored body on day 9.

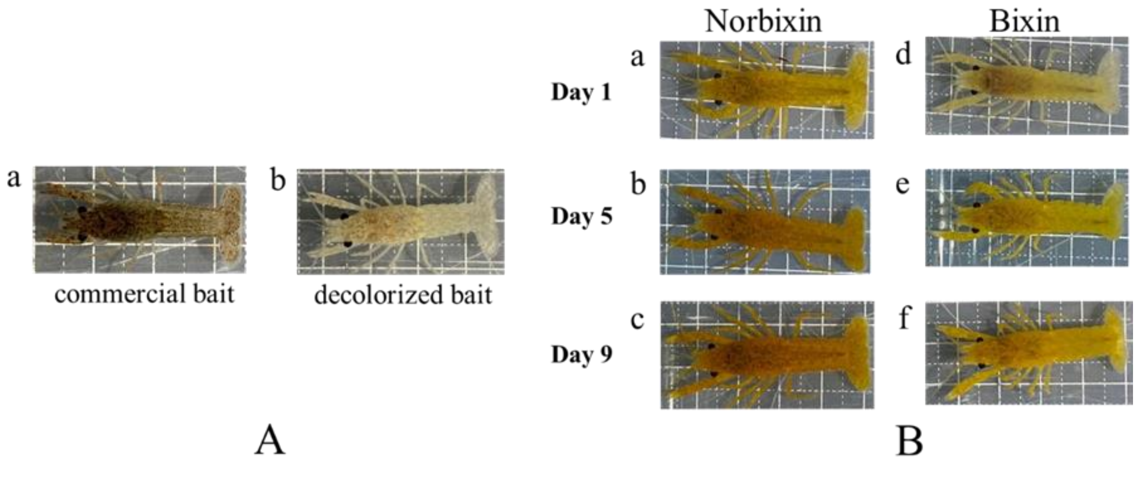

Fig. 2 Body color change by feeding test A: commercial bait (Left) and decolorized bait (Right) B: Norbixin (Left) and Bixin (Right)

Color Extraction from an Image of Body Color Change

When crayfish color is expressed as a mixture of Red (R), Green (G), and Blue (B) in 16 bits (256 steps) using color extraction of images taken over time, the R value did not change significantly for either control, bixin, or norbixin. In terms of G values, it was confirmed that the feeding period of bixin was almost constant while norbixin was gradually declining. In addition, the B value was almost zero in one day for norbixin while, for bixin, it gradually decreased (Fig. 3).

In Japan industry standard color names, yellow is R ≒ G > B (255, 212, 0), and orange is R > G > B (243, 152, 0). In addition, both orange and yellow become darker orange and yellow as the B value decreases to 0. Therefore, orange and yellow can be compared from the relative ratio of R and G. This result supports the visual color shown in Fig. 2B. Efforts to quantify changes in the color of the eyes seen using color extraction software will lead to activities to grasp observation events more scientifically and can be used for not only science but also STEAM education.

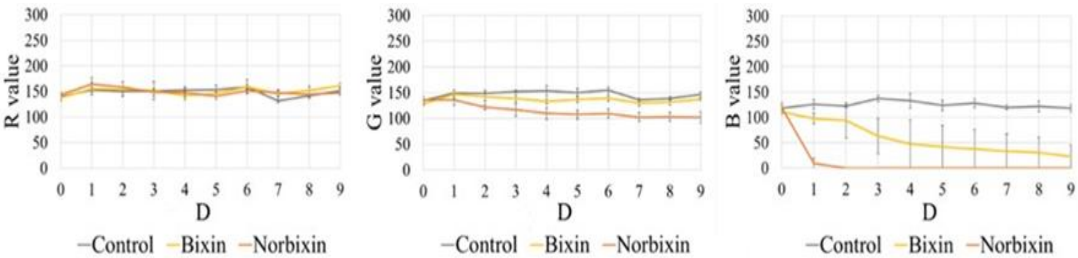

Fig. 3 Changes in RGB values of crayfish exoskeletons over time using pigment-containing baits

Confirmation of Color Change Due to Boiling

Just as many crustaceans turn red when boiled, wild crayfish are red black before boiling (Fig. 4A) but turn red when boiled (Fig. 4B). Interestingly, the first pectoral leg of a crayfish, which had turned orange with norbixin (Fig. 4C), remained orange (Fig. 4D) when boiled. Orange has the same effect on food palatability as red (Birren, 1963). Although boiled crayfish as food have typically come only in red, the above finding can be used to develop new colors of crayfish for food products. It is also hoped that crayfish will be used as a teaching material for the development of crayfish as a food source in Japan.

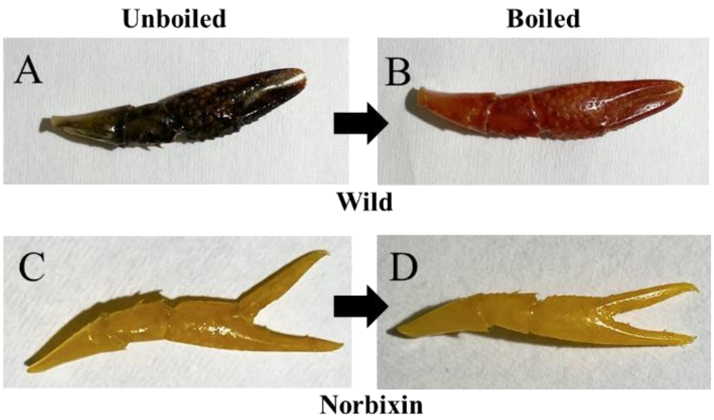

Fig. 4 Change in color of the first pectoral leg before and after boiling

Detection of Causative Substances of Body Color using TLC

TLC revealed bands at the same position in norbixin (lane 1) and the tail fans colored by norbixin (lane 2) and bixin (lane 3) and the tail fans colored by bixin (lane 4) (Fig. 5). This confirmed that the pigments contained in the bait were accumulated in the body. In this experiment, a tail fan derived from a living body was used, but the same result was obtained for the molted exoskeleton (data not shown).

By conducting this experiment in parallel with the feeding test, it is possible to use it as multiscale experimental teaching material to detect changes in body color and substances that cause body color.

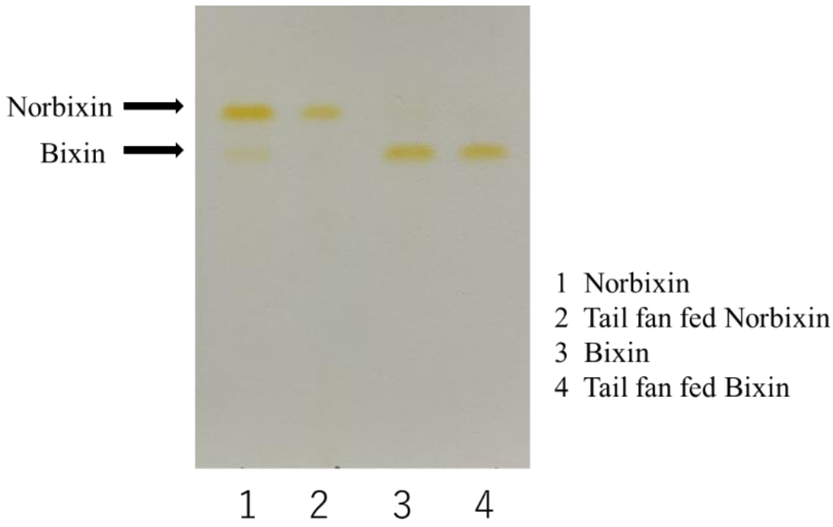

Fig. 5 Separation of norbixin and bixin in TLC

CONCLUSION

Astaxanthin is contained in red crustaceans and fish. It is a factor in body color as well as an important substance with antioxidant effects. The exoskeleton of the crayfish contains a large amount of astaxanthin and is also useful as a teaching material because crayfish is treated in educational courses and is a familiar creature. In addition, the development of experimental materials focusing on astaxanthin using crayfish will be a new scientific experimental material focusing on animal pigments and will enable students to learn about the usefulness of crayfish.

In this study, astaxanthin contained in crayfish exoskeletons was isolated using TLC and e-HPLC. TLC is an experimental technique used in secondary education for the separation of pigments derived from photosynthetic organisms. The e-HPLC is an instrument developed for educational purposes and used in secondary schools specializing in science education. In this study, we have clarified the experimental conditions under which astaxanthin can be detected in more detail and in a shorter time by using e-HPLC as well as TLC; these experimental methods can be implemented in school education. Interestingly, we found that the presence of astaxanthin in the exoskeleton of wild crayfish in living tissue differed from that derived from molting.

For wild crayfish, we developed a decolorized bait that regulated the carotenoid pigments contained in the material and succeeded in whitening it. In addition, by feeding bait containing norbixin and bixin, which are components of annatto pigment for food coloring, it was revealed that body color turned dark orange with norbixin and yellow with bixin. Furthermore, it was clarified that norbixin turns a dark orange color in a shorter period of time than bixin from changes in appearance, TLC, and color extraction.

The findings and experimental methods of this research can be implemented in schools and used as new experimental materials focusing on animal pigments. Since these are teaching materials that focus on color, it is expected they will be used in science and food education that will lead to the edible use of crayfish.

ACKNOWLEDGMENTS

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Research article

Evaluating Water Purification Capacity of *Patinopecten yessoensis* Shells Inoculated with Effective Microorganisms

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Abstract In Japan, the installation of biotopes, defined as aquatic systems aiming to recreate a natural environment, has been popular since the 20th century. Due to the closed character of many biotopes and high nutrient inputs, one of the main issues related to water quality in a biotope is the occurrence of blue-green algae. In this environment, reduction and control of the blue-green algae cannot be done by chemicals. Water quality must be maintained by other non-chemical means. Therefore, this study aims to investigate the effectiveness of *patinopecten yessoensis* shells inoculated with effective microorganisms as a method for nutrient and water quality control in a biotope environment. In Japan, huge numbers of *patinopecten yessoensis* shells are left out in the open because they cannot be properly handled. At the same time, *patinopecten yessoensis* shells are porous and have been studied for water purification. Accordingly, this research has focused on the water purification capacity of *patinopecten yessoensis* shells inoculated with effective microorganisms. In the study experiment, *patinopecten yessoensis* shells inoculated with *lactobacillus, bacillus subtilis var. natto*, and *saccharomyces cerevisiae* were used to purify water samples taken from a pond in Yatoyama Park in Kanagawa Prefecture, Japan. To compare nitrogen removal capacity, the experiments consisted of 8 treatments in total. In the first group of four treatments, *patinopecten yessoensis* shells were burned at 600 degrees to increase pore size and distribution, and were then inoculated with the aforementioned microorganisms. In the second group of four treatments, *patinopecten yessoensis* shells were not burned, and were only inoculated with the microorganisms. Uninoculated burned and unburned shells were used as control treatments. The experimental results showed total nitrogen removal rates of 42% for unburned and uninoculated shells, 0% for *lactobacillus*-inoculated unburned shells, 45% for *bacillus subtilis var. natto*-inoculated unburned shells, and 58% for *saccharomyces cerevisiae*-inoculated unburned shells. Regarding the burned shells, results showed 51% nitrogen reduction at the uninoculated shells treatment. *Lactobacillus*-inoculated burned shells reduced nitrogen by 47%, *bacillus subtilis var. natto*-inoculated burned shells reduced by 34% and *saccharomyces cerevisiae*-inoculated burned shells reduced the nitrogen in the water sample by 69%. Since this was a short-term experiment, a long-term experiment as well as field-applicable methods need to be discussed in the future.

Keywords water purification, microorganism, *patinopecten yessoensis, lactobacillus, bacillus subtilis var. natto, saccharomyces cerevisiae*

INTRODUCTION

Biotope is a term used to describe a biological space; biotopes attracted attention in Germany in the 1970s when environmental problems arose. In Japan, the expansion of urban areas due to rapid population growth since the period of high economic growth has led to a decrease in farmland and forest land. Accordingly, the habitat and growth environment for living organisms has decreased, and biodiversity has been damaged due to environmental changes, invasions, and pollution. For these reasons, biotopes have begun to be created in many places since the end of the 20th century. However, since biotopes are closed water systems with high nutrient inflow, the occurrence of blue-green algae has become one of the problems. The use of chemicals is an effective means to suppress and control the occurrence of blue-green algae. However, the use of chemicals in biotopes with biodiversity can lead to the destruction of biodiversity. Hence, it is necessary to maintain water quality by means other than chemicals.

In Japan, about 300,000 to 600,000 tons of *patinopecten yessoensis* are caught annually, and it is said that "about half of the catch is shells of *patinopecten yessoensis*" (Fishery Waste Disposal Guidelines Revised, Ministry of the Environment, 2020). The *patinopecten yessoensis* shells would normally be properly disposed of at a processing plant, but the huge number of shells is causing a shortage at the plant. As a result, many shells are left out in the open without being properly handled. However, *patinopecten yessoensis* shells are porous and have been studied for water purification. Accordingly, research attention has been focused on the water purification potential of *patinopecten yessoensis* shells inoculated with effective microorganisms.

OBJECTIVE

The purpose of this study is to investigate the effectiveness of *patinopecten yessoensis* shells inoculated with effective microorganisms as a method of nutrient removal and water quality management in a biotope environment. There has been little discussion of water purification using *patinopecten yessoensis* shells inoculated with effective microorganisms.

The objectives of this study were to investigate the water quality in the biotope, to evaluate the inoculation capacity of microorganisms in *patinopecten yessoensis* shells, and to evaluate and compare the water purification capacity of *patinopecten yessoensis* shells inoculated with effective microorganisms.

METHODOLOGY

Field Survey

This study was conducted at 3 biotopes in Yatoyama Park, Zama City, Kanagawa Prefecture, Japan (Site 1 - Site 3). Yatoyama Park has been developed as a natural ecology observation park in a place that retains a satoyama atmosphere. It is a place being rich in biodiversity with fireflies in the summer and waterflow in the fall and winter. However, according to the manager of Yatoyama Park, eutrophication of the biotope and the occurrence of blue-green algae have been confirmed. There are concerns about the impact on people who visit the park and the negative effects on the surrounding environment. Water samples were collected approximately once a month from June 2021 to February 2022, and total nitrogen (TN), total phosphorus (TP), potential hydrogen (pH), electric conductivity (EC), and suspended solid (SS) were measured. The water quality level in the biotope was determined based on the environmental standards listed by the Ministry of the Environment.

Water Purification Experiment Using *Patinopecten yessoensis* Shells Inoculated with Effective Microorganisms

In the study experiment, discarded *patinopecten yessoensis* shells from Aomori Prefecture, *lactobacillus*, *bacillus subtilis var. natto*, and *saccharomyces cerevisiae* were used. These microorganisms were used because they have been used in water purification and are relatively easy to obtain.

Discarded *patinopecten yessoensis* shells were crushed with a hammer and then divided into two groups, with one group being unburned (U) and the second group being burned at 600 degrees to increase pore size and distribution (B). In addition, the burned shells were rinsed once in water to remove the calcium hydroxide generated after burning.

The unburned and burned shells were inoculated with the above-mentioned microorganisms for 3 days. Uninoculated burned and unburned shells were used as control treatments, in total the experiments consisted of 8 treatments.

After inoculation, the shells were rinsed under running water to wash away the easily detached microorganisms. The inoculation capacity of *patinopecten yessoensis* shells was evaluated by performing a colony count using a mixed culture method for *lactobacillus* and a plate dilution method for *bacillus subtilis var. natto*, and *saccharomyces cerevisiae.*

In addition, to compare the nitrogen removal capacity, *patinopecten yessoensis* shells were immersed in 1 L of water from the biotope at Yatoyama Park for a water purification experiment for 3 days. The ultraviolet absorption spectrophotometric method was used to measure total nitrogen. The details of the 8 treatments are as follows.

Table 1 Combination of shell processing and microorganisms

Unburned and uninoculated shells	UC	Burned and uninoculated shells	BC
Lactobacillus-inoculated unburned shells	UL	*Lactobacillus*-inoculated burned shells	BL
Bacillus subtilis var. natto-inoculated unburned shells	UB	*Bacillus subtilis var. natto*-inoculated burned shells	BB
Saccharomyces cerevisiae-inoculated unburned shells	US	*Saccharomyces cerevisiae*-inoculated unburned shells	BS

RESULTS AND DISCUSSION

Water Quality In Biotope

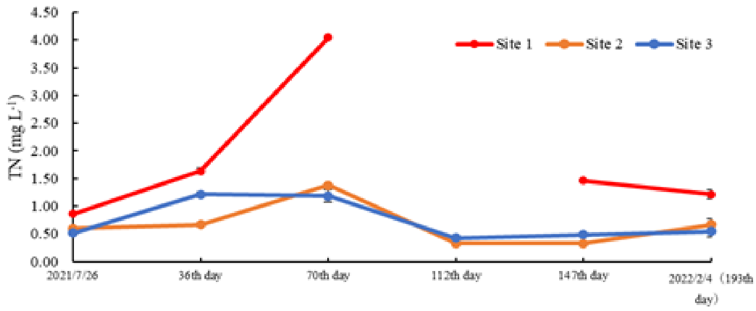

Fig. 1 Changes in total nitrogen (TN) in the biotope (26 July 2021 to 4 February 2022)

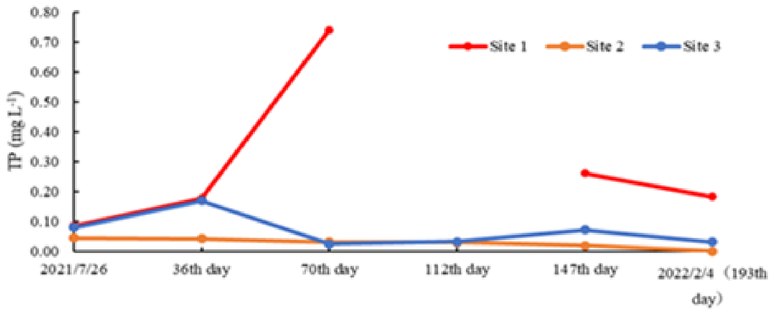

Fig. 2 Changes in total phosphrus (TP) in the biotope (26 July 2021 to 4 February 2022)

Figure 1 indicates the change in total nitrogen. The average value of total nitrogen measured at each water sampling site was 1.84 mg L^{-1} at Site 1, 0.66 mg L^{-1} at Site 2, and 0.73 mg L^{-1} at Site 3. The data tended to be higher in summer and fall, which seems to be due to precipitation, fallen leaves, and waterfowl. Figure 2 indicates the change in total phosphorus. The average total phosphorus measurement data for each water sampling site was 0.29 mg L^{-1} for Site 1, 0.03 mg L^{-1} for Site 2 and 0.07 mg L^{-1} for Site 3. As with the total nitrogen data, the data tended to be higher in the summer and fall, which seems to be due to precipitation, fallen leaves, and waterfowl. Also, the reason there is no data for Site 1 on the 112^{th} day is that the water source was buried by sediment, and water sampling was impossible.

In addition, both total nitrogen and total phosphorus tended to be higher at Site 1. This is because Site 1 is closer to the inflow point than other sampling sites, resulting in a greater inflow of sediment. The biotope at Site 1 has been found to have poor water quality compared to the environmental standards set by the Japanese Ministry of the Environment (Table 2). Therefore, there is a need for water purification. The source of nitrogen inflows and their relationship to the surrounding environment, such as waterfowl and vegetation, also need to be analyzed in detail.

Table 2 Environmental standards for total nitrogen (TN) and phosphorus (TP) in lakes

Item type	Standard value	
	Total nitrogen	Total phosphorus
I	0.1 mg/L or less	0.005 mg/L or less
II	0.2 mg/L or less	0.010 mg/L or less
III	0.4 mg/L or less	0.030 mg/L or less
IV	0.6 mg/L or less	0.050 mg/L or less
V	1.0 mg/L or less	0.100 mg/L or less

Note: Ministry of the Environment, 2022

Microorganism Inoculation Capacity of *Patinopecten yessoensis* Shells

Figure 3 shows the number of microorganisms inoculated on *patinopecten yessoensis* shells. The number of microorganisms inoculated with *lactobacillus* on unburned shells was 2.8.E+05 cfu g^{-1}, that with *bacillus subtilis var. natto* on unburned shells was 6.0.E+05 cfu g^{-1}, and that with *Saccharmyces cerevisiae* on unburned shells was 2.3.E+07 cfu g^{-1}. Also, the number of microorganisms inoculated into the burned shells with *lactobacillus* was 1.9.E+07 cfu g^{-1}, that into the burned shells with *bacillus subtilis var. natto* was 2.6.E+05 cfu g^{-1}, and that into the burned shells with *Saccharmyces cerevisiae* was 1.6.E+07 cfu g^{-1}.

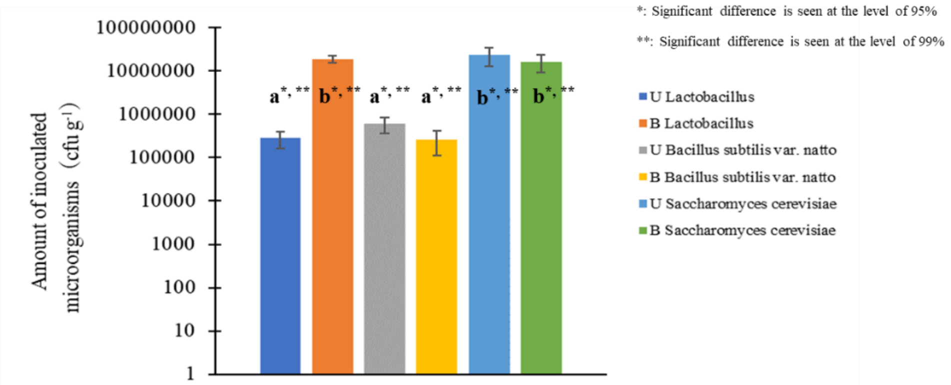

Fig. 3 Amount of microorganisms inoculated in each shell

The amount of inoculated *lactobacillus* was increased by burning the shells at 600 degrees. The amount of *bacillus subtilis var. natto* and *Saccharmyces cerevisiae* inoculated was not significantly changed by burned shells. The change in the amount of inoculum seems to be caused by changes in the pore size, specific surface area, and organic matter content of the *patinopecten yessoensis* shells. A more detailed analysis of pore size, distribution, and specific surface area will be necessary to determine the relation between the pore and the number of microorganisms inoculated.

Nitrogen Removal Capacity of *Patinopecten yessoensis* Shells Inoculated with Effective Microorganisms

The experimental result according to the Fig. 4 showed total nitrogen removal rates of 42% for unburned and uninoculated shells, 0% for *lactobacillus*-inoculated unburned shells, 45% for *bacillus subtilis var. natto*-inoculated unburned shells, 58% for *saccharomyces cerevisiae*-inoculated unburned shells. Regarding the burned shells, results showed 51% nitrogen reduction at the uninoculated shells treatment. *Lactobacillus*-inoculated burned shells reduced nitrogen by 47%, *Bacillus subtilis var. natto*-inoculated burned shells reduced by 34% and *saccharomyces cerevisiae*-inoculated burned shells reduced the nitrogen in the water sample by 69%. The highest total nitrogen removal rate was indicated by the treatment of burned shells inoculated with *saccharomyces cerevisiae*. Watabe et al. (2014) mentioned that *saccharomyces cerevisiae* is ableto incorporate nitrogen into the fungus itself. Hence, its removal capacity seems to be significantly different from that of other microorganisms. The reason that the inoculation of burned shells with *lactobacillus* did not remove total nitrogen seems to be that the rinsing process after the inoculation was not performed properly.

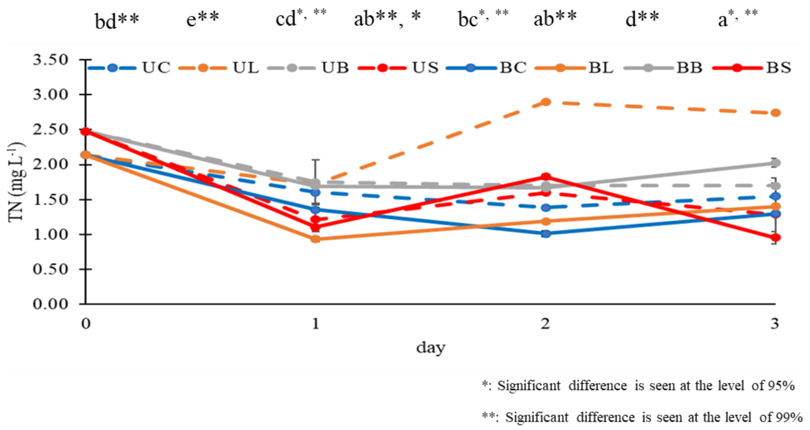

Fig. 4 Changes in total nitrogen (TN) in water purification experiments

CONCLUSION

In this study, the water quality in the biotope was determined, and at the same time, the microorganism inoculation capacity of *patinopecten yessoensis* shells and the water purification ability of *patinopecten yessoensis* shells inoculated with effective microorganisms were evaluated.

The water quality of the biotope at the subject site was found to be inadequate and in need of water purification. It is necessary to conduct a more detailed survey because of the influence of the surrounding environment, including fallen leaves, precipitation, waterfowl, and vegetation.

The microorganism inoculation capacity of *patinopecten yessoensis* shells was evaluated to a certain capacity for all microorganisms. Among them, *Saccharmyces cerevisiae* was found to have a high inoculation capacity. It is assumed that the size of the *Saccharmyces cerevisiae* was suitable with the internal pore size and specific surface area of the *patinopecten yessoensis* shells. In the future, it is necessary to study the relationship between microorganism inoculation capacity and pore size, and specific surface area.

The water purification ability of *patinopecten yessoensis* shells inoculated with effective microorganisms was evaluated for total nitrogen removal except for *lactobacillus*-inoculated unburned shells. The highest removal capacity was observed in burned shells inoculated with *Saccharmyces cerevisiae*. This was a short-term and small-scale experiment. Future experiments should be conducted to consider long-term and field applicability for the reuse of *patinopecten yessoensis* shells.

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Research article

Impact Assessment of New Dam Construction in Nam Ngum Watershed on Electric Generation at Num Ngum 1 Dam

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Abstract Lao PDR is a landlocked country and around 90% of the country is located in Mekong River Basin. Average annual rainfall is around 1,900 mm and 35% of the annual flow in the Mekong River is from Lao tributaries. Given the abundance of water resources in Laos, many hydropower dams have been constructed in the country. The generated electricity is exported to Thailand and other surrounding countries and has become an important means of earning foreign currency for Laos. In particular, the Nam Ngum 1 dam has been in operation since 1971 in the Nam Ngum watershed near Vientiane, the capital of Laos, and several additional dams have been completed in this watershed since 2010. Hydropower has great potential to boost the national income and raise living standards in Lao PDR. At the same time, hydropower reservoirs have a large number of potential cross-sector impacts, including changes in the downstream water environment. The purpose of the current study was to evaluate the impact of the construction of multiple dams in the Nam Ngum watershed on the river flow regime, as well as on the hydropower generation of the preceding Nam Ngum 1 dam. In this study, the fully distributed TOPMODEL was developed and applied to analyze the water flow in the Nam Ngum watershed with a spatial resolution of 1 km X 1 km. Simulated river discharge and dam storage were in good agreement with observed data. Subsequently, we investigated the impact of the construction of the Nam Lik 1/2, Nam Ngum 2, and Nam Ngum 5 dams, which were newly developed after 2010. Results indicated that new dam construction has positive effects in decreasing flood flow during the rainy season and increasing discharge in the dry season, while electricity generation at the Nam Ngum1 dam also increased by 6.8%.

Keywords water resource development, hydropower, multi reservoirs, Laos

INTRODUCTION

Lao PDR is a landlocked country and around 90% of the country is located in Mekong River Basin. Average annual rainfall is around 1,900 mm and 35% of annual flow in Mekong is from Lao tributaries, so many hydropower dams have been constructed against the backdrop of abundant water resources. The generated electricity was exported to Thailand or surrounding countries and has become an important means of earning foreign currency for Laos. Electricity demand in Laos has been growing at a high rate of more than 10% since 1999, both in terms of consumption and peak power and according to the national power supply development plan, demand exceeded supply until around 2014. To meet this growth in demand, the Lao government has decided to utilize its abundant hydropower resources, which are domestically produced energy, and to actively promote the development of power sources (Uematsu, 2019).

In particular, the Nam Ngum 1 Dam has been in operation since 1971 in the Nam Ngum watershed near Vientiane, the capital of Laos, and several dams have been completed in this watershed since 2010. Hydropower has great potential to boost the national income and raise living standards and create opportunities for the establishment of electricity-using industries in Lao PDR. While hydropower reservoirs also have a large number of potential cross-sector impacts, including changes in downstream flows and water quality, dam safety, and resettlement of living people (Lacombe et al., 2014). Likewise, Kudo et al. (2013) assessed how to change the flow discharge into Nam Ngum 1 reservoir due to new dam construction, however, impact on hydropower generation was not obtained.

OBJECTIVE

The purpose of this study was to evaluate the impact of the construction of multiple dams in the Nam Ngum watershed on the river flow regime, as well as on the hydropower generation of the preceding Nam Ngum 1 dam.

METHODOLOGY

Study Area

The Nam Ngum watershed in Laos is a tributary of the Mekong River. The river length is about 415 km, and the catchment area is about 17,000 km^2. The land use in the basin is paddy fields (16%), forests and bushes (72%), and residential land (only 0.2%), making the basin still rich in nature. In this watershed, several large-scale dams were constructed after 2010 to meet the increasing electric demand of domestic and surrounding countries (Fig. 1).

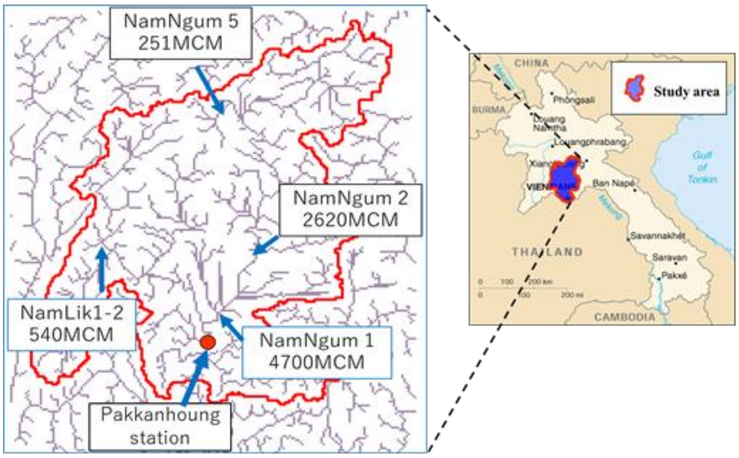


Fig. 1 Nam Ngum watershed and dams' location

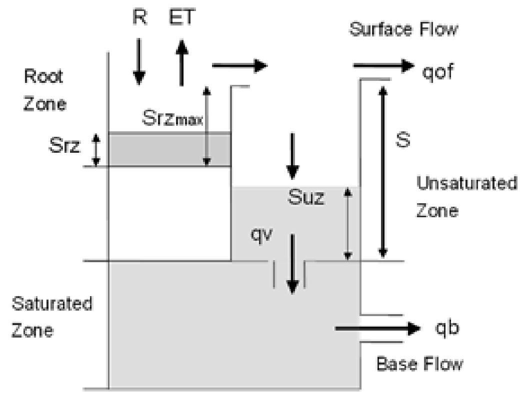
Nam Ngum 1 Hydroelectric Power Plant is located on the Nam Ngum River about 90 km north of Vientiane, the capital of Laos, and its reservoir has active storage of 4,700 MCM (million m^3), which started operation in 1971. As the main power source for the metropolitan area, its generation capacity was 155 MW until 2017. The utilization rate of the Nam Ngum 1 power plant was initially 66%, but the Nam Song and Nam Leuk power plants developed in 1995 and 2000, respectively, increased the flow rate by an average of 65 m^3/s and 15 m^3/s, respectively, and the utilization rate has increased to 74%. After 2018, the capacity was improved to 235 MW by the JICA project (Uematsu, 2019).

Nam Ngum 2 Hydroelectric Power Plant was completed in 2011, which is located about 100 km north of Vientiane, the capital of Laos, and is the second power plant on the Nam Ngum River. The Nam Ngum 2 Power Project is a concrete surface impermeable rockfill dam with a dam height of 181 m. The installed capacity is 615 MW, and 100% of the power be exported to Thailand. Its basin area accounts for 67% of the Nam Ngum 1 power plant basin area, having an effective storage capacity of 2,620 MCM. Nam Ngum 5 was completed in 2012, with a dam height of 99 m. With a catchment area of 413 km^2 and an effective storage capacity of 251 MCM, the project is smaller than the Nam Ngum 2 power project (Kudo et al., 2013).

The Nam Lik 1/2 Power Project started operation in 2011, having 100 MW power generation and 101 m height concrete surface impermeable dam in the middle reaches of the Nam Lik River, a tributary of the Nam Ngum River. With a medium-sized active storage capacity of 540 MCM, this dam is expected to smooth the flow conditions in the lower reaches of the dam throughout the year and increase the dry season flow.

Rainfall-Runoff Model

To evaluate the river water flow, a distributed water cycling model was developed and applied to analyze the water balance in the basin. TOPMODEL was employed for the rainfall-runoff analysis. Such a distributed model can include the spatial distribution of topography, land use, and soil characteristics. Therefore, TOPMODEL is widely used for hydrological characteristic analysis, water management, water quality analysis, and future forecasting. TOPMODEL was proposed by Beven and Kirkby (1979) based on the contributing area concept in hill slope hydrology. This model is based on the exponential transmissivity assumption, which leads to a topographic index ln ($a/To/\tan b$), where a is the upstream catchment area draining across a unit length, To is the lateral transmissivity under saturated conditions, and b is the local gradient of the ground surface. Figure 2 illustrates the conceptual structure of the water cycle as estimated by TOPMODEL. For details, refer to Yoshida et al. (2017).



Notes: R:precipitation, ET: evapotranspiration, Srz: storage in root zone, Srzmax: maximum storage in root zone, Suz: storage in unsaturated zone qv: discharge from unsaturated to saturate zone, S: soil water deficit until saturated condition, qof:surface flow discharge, qb: base flow discharge

Fig. 2 TOPMODEL structure

Dam Operation Model

Large scale dams having quite huge water storage capacity makes a significant effect to control river water discharge (Hanasaki et al., 2003). Normally, the dam reservoir stores water in the rainy season and releases water in the dry season so that downstream river discharge becomes stable compared to the variation of natural river flow. In the Nam Ngum watershed, several dams have more than 250 MCM capacity which is mostly used for electric generation. In this study, a simple dam storage model was applied to describe the river discharge stabilization effect (Juthithep et al., 2014). The storage of a reservoir Vres (m^3) can be calculated by the following equation.

$$V_{res}^{t+\Delta t}=V_{res}^{t}+(Q_{in}^{t}-Q_{out}^{t})\times\Delta t \quad (1)$$

$$Q_{out}^{t}=Q_{pw}^{t}+Q_{spill}^{t} \quad (2)$$

$$Q_{pw}^{t}=Q_{pwmax}\times(V_{res}^{t}/V_{resmax}) \quad (3)$$

Where Q_{in} is the inflow of a reservoir (m^3/s) calculated by flow accumulation along the upstream river network, Q_{out} is the outflow of a reservoir (m^3/s), Q_{pw} is the turbine discharge (m^3/s), Q_{pw} is the spillway discharge (m^3/s), V_{resmax} is active storage(m^3) and Q_{pwmax} is maximum turbine flow (m^3/s).

1 Dam Case and 4 Dam Case Scenarios

In this study, we used the data from 2002-2010. During this period, only the Nam Ngum 1 plant was operating, so first we checked model performance under the 1dam case scenario. And then, 4 dams' case was also simulated by using the same input data and compared with the 1 dam case scenario to investigate the impact of newly developed dams on downstream river flow and hydropower generation at Nam Ngum 1 dam, considering Nam Lik 1/2, Nam Ngum 2, and Nam Ngum 5, which were newly developed after 2010. To evaluate the hydropower generation at Nam Ngum 1 dam, the relation between turbine discharge and hydropower generation was used in Fig. 3.

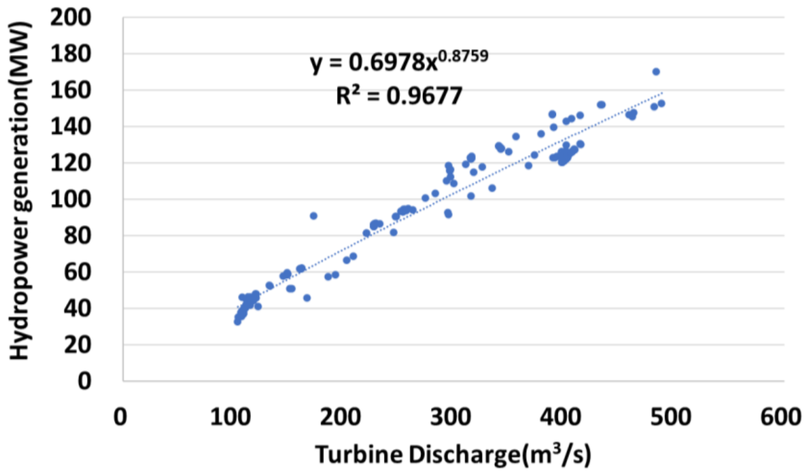


Fig. 3 Relation between turbine discharge and hydropower generation at Nam Ngum 1

RESULTS AND DISCUSSION

By using the proposed model, river flow at Pakkanhoung (catchment area of 14,300 km^2) station was simulated from 2002 to 2010. The first 5 years of data were used for parameter calibration, and the latter 4 years of data were used for validation. Parameters were calibrated by the try-and-error method to maximize the Nash-Sutcliffe efficiency (NSE). Solid line and plot in Fig. 4 show the calculated and observed river discharge at Pakkanhoung station under 1 dam case. Estimated NSE were 0.59 and 0.50 in the calibration and validation periods respectively. Model performance can be evaluated as "satisfactory" if NSE > 0.50 (Moriasi et al., 2007). The reason for the relatively low accuracy is that there is no station in a relatively high-elevation area. The dashed line in Fig.4 shows river discharge under 4 dam cases. Due to the flow regulation effect of multiple dam reservoirs in upstream, positive effects to decrease in flood flow in the rainy season and to increase discharge in the dry season were obtained. Especially, minimum discharge in the dry season increased from 221 m^3/s to 264 m^3/s and it contributed to generating more electricity. Figure 5 shows the comparison between calculated and observed monthly storage at Nam Ngum 1 reservoir for 2002-2004. The correlation coefficient between the calculated and observed values is R = 0.65. Calculated storage ranging more than 3,000 MCM shows relatively good agreement, however, the calculated values are slightly overestimated when storage became less than 3,000 MCM. Figure 6 shows the annual hydropower generation with 1 dam case and 4 dam cases. Under the 1 dam case, annual hydropower generation varied from 857.8 -1077.6 GWh. Under the 4-dam case, annual hydropower generation was increased by 6.8% due to the flow regulation effect of newly developed dams upstream, however, the increment in 2004 was only 3.2%. The year 2003 was a drought year so dam storage at the end of rainy season in 2003 was relatively small. That is why additional release discharge was insufficient to increase hydropower generation in the dry season of 2004. The electricity demand for air conditioners increases especially during the dry season when the weather becomes very hot, but the amount of electricity generated decreases due to a decrease in the flow of rivers. In 2002, 30% of domestic power consumption was imported, but the import price from Thailand was 10% higher than the price of electricity exported by the Lao PDR, resulting in a loss of foreign currency earned through exports. Under the Independent Power Producer (IPP) concession of new dam construction projects, most of the generated electricity is exported to Thailand. However, in Vientiane city capital of Laos also, electricity demand increases by around 10% per year, so even a small amount of increment in Nam Ngum 1 hydropower dam can contribute to reducing the electricity import from Thailand.

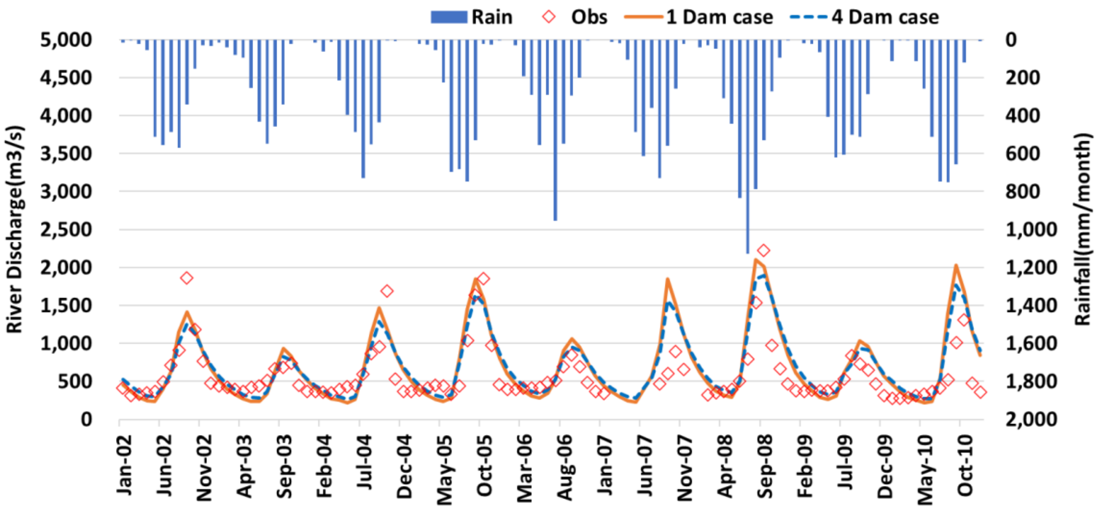


Fig. 4 Calculated and observed river discharge at Pakkanhoung station

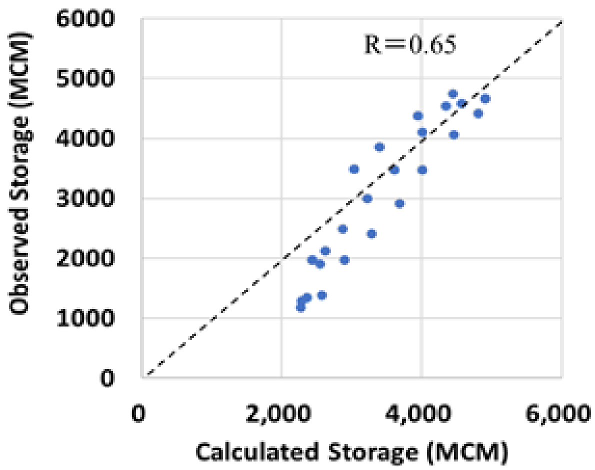


Fig. 5 Calculated and observed monthly storage at Nam Ngum 1 reservoir

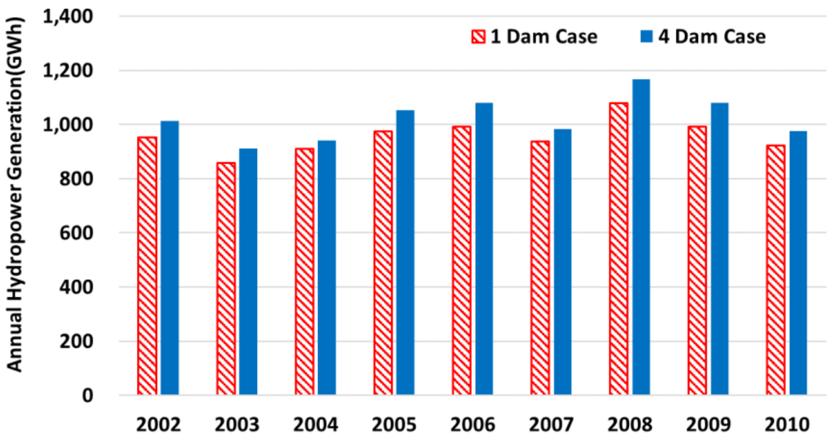


Fig. 6 Estimated annual hydropower generation under 1 Dam and 4 Dam cases

CONCLUSION

In this study, the fully distributed TOPMODEL was developed and applied to analyze the water flow in the Nam Ngum watershed to assess the impact of newly developed dams on downstream river flow and hydropower generation in the Nam Ngum 1 dam. Simulated river discharge and dam storage were in good agreement with observed data, and then, we investigated the impact of dam construction considering NamLik1/2, NamNgum2, and NamNgum5, which were newly developed after 2010. As a result, new dam constructions have positive effects to decrease flood flow in the rainy season and to increase discharge in the dry season, and electricity generation at the Nam Ngum1 dam also increased by 6.8%. In this simulation, the same simple reservoir model was used in 1 dam and 4 dam cases due to the lack of data, however, normally reservoir operation rule curve became more complex under multiple dam operations. Therefore, the dam operation model should be improved by using the actual rule curve and river flow data after 2010.

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Research article

Verifying Optimum Flying Conditions for UAV Photogrammetry in Assessing Hydro-structural Facilities

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Abstract Monitoring hydro-structural infrastructure is becoming an important and challenging issue. In Japan, there are an increasing number of aging hydro-structural facilities, which need to be inspected to guarantee their strength and durability function. Unmanned Aerial Vehicle (UAV) photogrammetric images have been used in the detection of structural deterioration of various infrastructure. However, there is a challenge in determining the optimum flying conditions (altitude, angle of camera, and flying patterns) of UAVs for obtaining images. The designs, shapes, and sizes of hydro-structural facilities also pose a challenge for obtaining ideal images. In this study, verification of various flying conditions for producing images and 3D models was proposed for water gates and open surface water channels. Additionally, an evaluation method for the images and 3D models was suggested. In this study, UAV was used for visual inspection and obtaining the image of the water gate and open surface water channel at the Tone diversion gate in Saitama, Japan. Various geometric patterns were pasted on the surface and walls of the structures to evaluate the detection of the patterns with the images taken from UAVs at different flying conditions. The obtained ortho-mosaic images were processed by a PIX4D mapper to obtain a point cloud-based 3D model and were compared with the actual measurements of the patterns. The results of the study suggested that altitude and camera angles affected the quality of images significantly. Cameras at lower angles provided better images, although cameras at high altitudes with wider angles also demonstrated a high degree of efficiency. The circular flying pattern generated satisfactory results, where flyovers were conducted multiple times while changing altitudes and angles of the camera. Additionally, this study proposes a method named “leveling” for the evaluation of images and 3D models.

Keywords UAV photogrammetry, hydro-structural assessment, 3D models, level

INTRODUCTION

In Japan, many hydro-structural facilities were constructed during the post-war period and are now in deteriorating conditions (MAFF, 2022). The Ministry of Agriculture, Forestry and Fisheries has begun full-scale efforts for 'stock management' to extend the service life of facilities and reduce life cycle costs to reduce such damage and ensure safe living conditions in the future. Stock management consists of continuous facility monitoring, periodic functional diagnosis, deterioration forecasting based on this, investigation of efficient deterioration countermeasure methods, formulation of functional maintenance plans, and implementation of appropriate countermeasure works promptly. Among these, facility monitoring, and functional diagnosis are often time-consuming and labor-intensive, such as visual inspection, percussion inspection, and surveying. However, the workforce and inspection technicians are decreasing due to a decrease in population and aging, resulting in a serious shortage of manpower, (Tabata et al., 2018). Machines and robots are expected to play an active role in solving these problems. Unmanned Aerial Vehicles (UAVs) can take aerial photographs by flying at lower altitudes than manned aircraft and other vehicles that have been commonly used with high-resolution aerial photographs (Miyazaki et al. 2018). Therefore, research is being conducted to construct 3D models and use them for inspections with the aim of recording information on deterioration and damage at a higher resolution from the aerial photographs taken (Saito et al., 2022). Previous studies have shown that a 3D model can be produced in detail from aerial images by flying a UAV at low altitude and taking photographs, however, the sides of a building cannot be accurately modeled when the camera angle is directly below the angle of a building (Miyazaki et al., 2018). It has also been found that cracks and exposed rebar can be identified from images taken by UAVs (Tabata et al., 2018). However, there lacks of optimal imaging technique for hydro-structural facilities by varying the imaging conditions, such as flight altitude and camera angle.

OBJECTIVE

The objectives of this study were to verify optimum flying patterns for UAV imaging and 3D modeling focusing on camera altitude and angles in hydro-structural facilities assessment. Additionally, this study tries to develop a method for quantitatively evaluating 3D models.

METHODOLOGY

Description of the Study Site

In this study, a field survey was conducted in two hydro-structural facilities of Tone Water Supply Works of Japan Water Agency in Gyoda City, Saitama Prefecture, Japan. The water gate and open surface water channel were the target structures for this study (Fig.1). The width and height of the water gate were approximately 17.4 m and 7.3 m respectively. Likewise, the width and height of the channel were 14.4 m, and 2.5 m, respectively.

Fig. 1 Water gate (left) and open surface water channel (right)

Installation of Ground Control Points (GCPs) and Real Time Kinetic Survey

Ground control points (GCPs) were set up around the facility and their positional information was measured. The GCPs were surveyed using the RTK satellite positioning system (Real Time Kinematic Global Navigation Satellite System). The RTK survey was done to increase the location accuracy.

Flight Conditions of UAV Survey

Small rotary-wing UAVs (Inspire 2/DJI and ANAFI/Parrot) were used for aerial photography, with the Zenmuse X5S (RGB) camera mounted on the Inspire 2 and RGB camera on ANAFI (Fig. 2). Inspire 2/DJI was used for the water gate, and ANAFI/ Parrot was used for the water channel due to its easy operation for a smaller area. Aerial photography was performed using a flight planning application (Pix4D capture/Pix4D, Pix4D scan/Pix4D) installed in UAVs. The UAV was flown in double grid and circular flight for the water gate and grid (oblique and horizontal) for the water channel with an overlap of 80% for both the top and side. The flight altitude was set to the lowest altitude at which it was possible to fly, with the grid/double-grid flight pattern flown at 20 m, and the circular flight pattern at 20 m, 30 m, and 40 m (Table 1). The camera angle was 45°, 60° and 80° for all flight paths (Table 2).

Table 1 Flight plan parameters for the Water gate survey

Flight path	Flight altitude (m)	Flight angle (°)
Double grid	20	45, 60, 80
	20	45, 60, 80
Circular flight	30	45, 60, 80
	40	45, 60, 80

Table 2 Flight plan parameters for open water channel survey

Flight path	Flight altitude (m)	Flight angle (°)
Oblique grid	20	60
Horizontal grid	20	45, 60, 80

Fig. 2 Drones used in this study
Inspire 2 (left) and ANAFI (right)

Dimensional Measurements of the Hydro-structural Facilities

Measurements of facilities were conducted for the target structures. Seven measurements were taken for sections of the water gate and two measurements were carried for the channels, respectively. A measuring tape was used for the measurements, and measurements were taken while pulling the tape at each end to prevent the center from sagging.

Conversion of Aerial Image Data into 3D Models

Pix4D mapper (Pix4D) application was used to create 3D models (point clouds) from aerial images (USDA, 2022). First, aerial images were added to the Pix4D mapper software for initial processing. In the initial processing, characteristics of geographical features were extracted as key points from the images added to the Pix4D mapper. Images with the same key points are then searched for and matched. The camera's internal and external parameters were corrected. To improve the positional accuracy of the 3D model and the ortho mosaic image, GCP latitude, longitude, and elevation data were added and optimized for re-estimation with respect to camera positioning information and image distortion. Finally, point clouds were densified based on automatic tie points and compared and evaluated from the resulting 3D models.

Evaluation of the Model

Reproducibility of 3d Models with the Actual Image

The reproducibility of the target structures in the 3D models (point clouds) created from different flying conditions was checked. The point cloud data were compared with the aerial images to assess the differences. The dimensions of the 3D model were measured by creating polylines in Pix4D mapper. The polylines were created in such a way that they were close to the positions measured during the survey; three polylines were created at one measurement site, the mean error and standard deviation from the actual measurement were calculated, and the values were compared for each flying condition.

Leveling of 3d Models and Actual Images

An evaluation method unique to this study was developed where three types of patterns (triangle, circle, and square) were classified into levels from 1 to 5 (Fig. 3). The points and levels were set so that the smaller the side length of the pattern (shown in fig. 3 by yellow line) higher the point and level. For the triangular pattern, point 1 was given for level 1 where the side length was 20 cm, likewise, points and levels were assigned for each length and pattern. Additionally, the level was set to 0 if the figure was not visible in the 3D data. These patterns were pasted on the surface of the target structures and aerial images were taken. Verification for actual images and 3D models was performed with points allotted for each level. The aerial imaging conditions were evaluated by comparing the average of the points. Furthermore, multiple regression analysis was performed to assess the influence of altitude and camera angle on the levels.

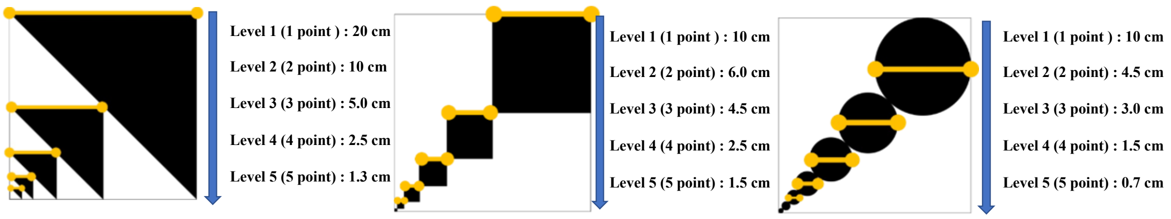

Fig. 3 Geometric patterns with dimensions and allocated points for the level

RESULTS AND DISCUSSION

Reproducibility Evaluation of 3D Models (Point Clouds)

A 3D model was created by combining aerial images obtained under various flight conditions to verify the differences and the dimensional error compared to the measured facility. The results showed that for the double grid flight pattern, the camera angle affected the results (Fig. 3, left image). The reproducibility was high for 45° followed by 60° angles for the pillar sections of the gate. Similar results were obtained for circular flight patterns, where reproducibility was high for 45° followed by 60° angles (Fig. 4, right image). On the other hand, when the camera angle was at an angle of 80°, the reproducibility increased with altitude for the upper part of the water gate indicating that modeling depended on the flight altitude (Fig. 5, left image). Furthermore, there was no difference in recognizing the pattern pasted insides of the open channel for all flight conditions, however, at a camera angle of 80°, reproducibility was lower (Fig. 5, right image). In addition, a comparison of the dimensions of the facility measured and the dimensions of the 3D model showed that the errors were within 10 cm for all flight methods (Table 3, Table 4, Table 5 and Table 6).

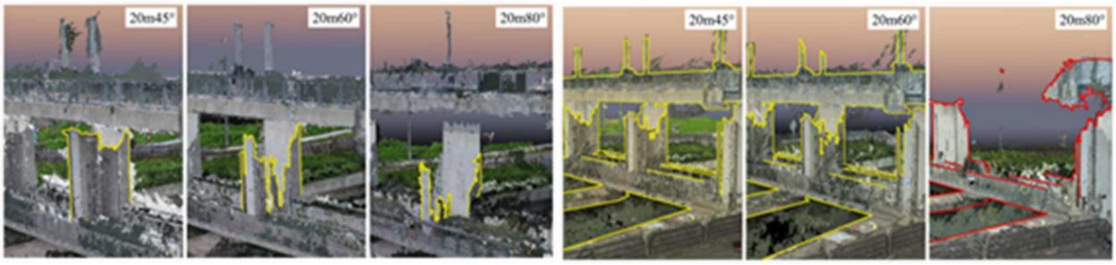

Fig. 4 3D point cloud model created from aerial images of water gate
Grid flight pattern (left) and circular flight pattern (right) at varying camera angles at an altitude of 20 m

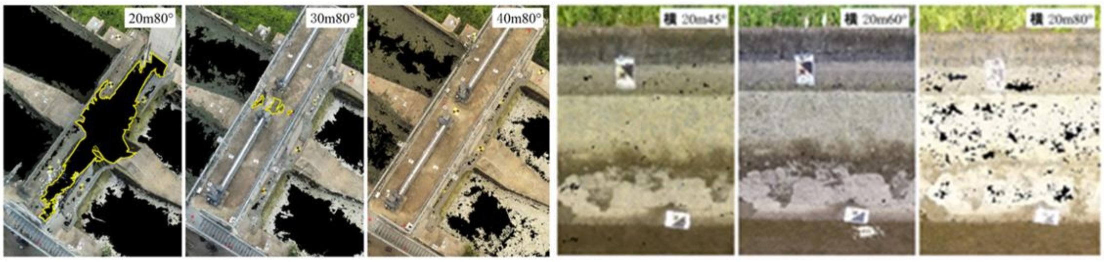

Fig. 5 3D point cloud model created from aerial images of a circular flight pattern over a flow control
Weir at different altitudes at a camera angle of 80 ° (left image), 3D points cloud model created from aerial images of a grid flight over an open channel at an altitude of 20 m with varying camera angles (right image)

Evaluation of Level

The result of the level is shown in Tables 3 to 6. In the case of the double grid flying pattern, when the UAV flying altitude was fixed and the camera angle varied, the level became lower as the camera angle was moved closer to the nadir, indicating that the camera angle had a significant effect on leveling. In addition, it was understood that too many photographs are not good for the leveling, since the level of the result of the analysis of the three patterns together was not the highest. In circular flight, the higher the flight altitude, the lower the level, indicating that the altitude of the flight also has a significant effect.

Table 3 Level and dimensional error assessment during double grid flight over water gate

Altitude (m)	Angle (°)	No. of pics	Level evaluation		Measurement error (cm)	
			Aerial image	3D model	Avg. error	Std. deviation
20	45	440	3.12	1.28	2.41	±3.51
20	60	314	2.81	1.20	1.67	±2.57
20	80	747	2.79	0.93	1.77	±2.38
Total		1501	2.97	0.84	1.35	±1.85

Furthermore, from the result of levels at each altitude when the camera angle was 80 °, it was found that it was necessary to take photographs while keeping the camera angle close to the nadir. The results of the multiple regression analysis of altitude and angle effect on the image and model levels for the double grid and circular flight are shown in Tables 7 and 8. According to the analysis, the influence of altitude is high at both the image levels and model levels. Furthermore, at the model level, the angle was also found to influence the level, although not to a large scale.

Table 4 Level and dimensional error assessment of circular flights over water gate

Altitude (m)	Angle (°)	No. of pics	Level evaluation		Measurement error (cm)	
			Aerial image	3D model	Avg. error	Std. deviation
20	45	75	2.65	0.90	2.05	±3.01
20	60	78	2.60	0.98	1.82	±2.24
20	80	80	1.66	0.56	1.60	±3.63
30	45	78	1.88	0.90	3.51	±4.71
30	60	81	1.99	0.79	2.48	±3.69
30	80	80	1.87	0.67	2.22	±3.14
40	45	76	1.39	0.68	2.77	±3.54
40	60	78	1.36	0.67	3.50	±4.53
40	80	78	1.28	0.74	1.98	±2.77

Table 5 Level and dimensional error assessment for each combined circularly flown aerial image of water gate

Combination flight pattern		No. of pics	Level evaluation		Measurement error (cm)	
Circular flight	Circular flight		Aerial image	3D Model	Avg. error	Std. deviation
20 m 45°	30 m 60°	156	2.70	1.28	1.94	±2.59
20 m 45°	30 m 80°	155	2.77	1.30	1.44	±2.18
20 m 45°	40 m 60°	153	2.83	1.24	1.73	±2.25
20 m 45°	40 m 80°	153	2.77	1.18	1.20	±2.07
20 m 60°	30 m 80°	158	2.79	1.26	1.63	±2.21
20 m 60°	40 m 80°	156	2.74	1.24	1.65	±2.61
30 m 45°	40 m 60°	156	2.07	0.90	1.37	±1.76
30 m 45°	40 m 80°	156	2.04	0.93	2.44	±2.85
30 m 60°	40 m 80°	159	2.29	0.89	1.53	±1.88
20 m 45° + 30 m 60° + 40 m 80°		234	2.79	1.21	1.87	±2.86
Total		704	2.64	0.98	1.70	±2.10

Table 6 Level and dimensional error assessment during grid flying over an open water channel

Direction	Altitude (m)	Angle (°)	No. of image	Level evaluation		Measurement error (cm)	
				Aerial image	3D model	Avg. error	Std. deviation
Oblique 1	20	60	258	3.08	2.00	2.33	±2.94
Oblique 2	20	60	240	3.03	1.96	3.17	±1.17
Oblique 1and 2	20	60	498	3.05	2.06	2.00	±1.26
Horizontal	20	45	158	2.68	1.23	4.33	±3.50
Horizontal	20	60	330	3.18	1.82	4.83	±5.32
Horizontal	20	80	126	2.37	1.18	3.00	±5.40

Table 7 Multiple regression analysis of level (Images)

	Coefficient	Std. deviation	*t*	p-value
Altitude	-0.0636	0.0115	-5.5186	***
Camera angle	-0.0105	0.0067	-1.5765	

*p < 0.01 *** p < 0.05 ** p < 0.1 **

Table 8 Multiple regression analysis of level (3D model)

	Coefficient	Std. deviation	*t*	p-value
Altitude	-0.0144	0.0059	-2.4277	**
Camera angle	-0.0063	0.0034	-1.8443	*

*p < 0.01 *** p < 0.05 ** p < 0.1 **

CONCLUSION

In this study, the optimum UAV flying conditions for UAV imaging were investigated for water gate and open surface channels. The aerial imaging conditions were compared using three methods: reproducibility of the 3D model, comparison of the measured dimensions of the facility and the dimensions of the 3D model, and an original evaluation method called 'leveling', to investigate the most suitable flight pattern. According to the results of this study, the following conclusions were made: (i) Images obtained by circular flight patterns with various combinations were effective for the water gate. (ii) For open surface water channels, the camera angle should not be close to the nadir. (iii) For quantitively assessing aerial imaging, figure leveling is useful. (iv) For planning UAV imaging assessment of hydro-structural facilities, the altitude of the UAV should be set followed by the angle of the camera. However, the results of this study showed deficiencies in modeling the upper part of the columns and shadowy areas, and the upper part of the columns from aerial images. In the future, it is desirable to analyze images taken from the ground to compensate for areas such as the tops of columns, which are difficult to take images by automatic UAV flight. In addition, as hydro-structural facilities are in different shapes and sizes, it is necessary to conduct more similar studies.

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Research article

Information Transfer among Mango Contractors: Sources, Channels, and Priorities

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Abstract Information transfer is vital in improving knowledge and proper technology implementation, especially in agriculture. This paper aimed to describe the information system among the Pangasinan mango contractors. Specifically, it aimed to 1) identify the sources of information for the mango contractors, 2) determine information channels for information transfer, 3) establish the type of information that mango contractors prioritize, 4) determine the challenges and issues in the transfer of information, and 5) recommend interventions to improve information transfer among mango contractors. The study area is Pangasinan, Philippines, the country's top mango-producing province. The research used a purposive sampling of 55 mango contractors covering six mango-producing municipalities. Descriptive statistics and correspondence analyses were employed in the study. Results showed that most mango contractors generally receive information on the production and marketing of mangoes from farm technicians and buyers. They usually get information on production technologies from farm technicians and other mango contractors. Expectedly, they get their information on mango marketing from their buyers. On the other hand, information transfer usually happens through mobile phones and during farmers' meetings. Furthermore, contractors prefer to get information on the buying price of mangoes, followed by the quality requirements of buyers. Contractors also choose to have a face-to-face conversation when obtaining information. The next preference is through text and calls using mobile phones. In summary, mango contractors still prefer the traditional information system through face-to-face conversations, text, and mobile phone calls. This has implications for the implementation of modern technologies used for information dissemination. Mango contractors might not be receptive to new ways of receiving communication, even if the information might be urgent or essential. It is recommended that contractors be trained to use modern communication technologies to make them more receptive to other communication channels.

Keywords information transfer, correspondence analysis, mango contractors, communications

INTRODUCTION

Communication within the commodity system is an invaluable component that is often overlooked. Most of the time, people focus much on production technologies or market development. However, new developments in production technologies and discovering new market opportunities will not matter if this information is not adequately communicated along the value chain. Players in the chain cannot act on the latest developments if they do not know there are new developments. For example, Indian agriculture is plagued by insufficiency and inefficiencies in conveying pertinent information to the farming industry, not a lack of technology or R and D activities. While Indian agriculture has flourishing technologies that can help their farmers, they can still improve the communication of such technologies to the farmers. This disconnect can be the key to further development of their agricultural sector. Therefore, developing agriculture's information and communication technology (ICT) can catalyze the sector's growth (Behera et al., 2015).

Agricultural information is an essential element that interacts with other production factors like land, labor, capital, and management competence. The availability of pertinent, trustworthy, and beneficial knowledge and information can arguably increase the productivity of these other components. To enable farmers to make better decisions, take advantage of market possibilities, and manage ongoing changes in their production systems, agricultural organizations have handled the information supplied by extension, research, education, and others (DEMİrYÜrEK, 2010). Vidanapathirana (2012) cited Maningas et al. (2000) and found that having information in the hands of farmers leads to their empowerment by giving them control over their resources and decision-making procedures. They pointed out that a system for delivering vital information and technological services effectively and efficiently aids the clients' crucial role in decision-making for better agricultural production, processing, trading, and marketing. Therefore, to manage and enhance specific agricultural information systems, it is necessary to understand how they work.

Attention should be given to the provision of education and training on the implementation of joint technologies and their combined impact on farms since it was discovered that education and information availability were among the factors influencing the adoption of multiple technologies (Toma et al., 2018). Proper channels for information transfer also play a critical role in technology transfer. Farmers can learn about agricultural topics from various sources, including extension services, the media, other farmers, input suppliers, etc. (Adhiguru et al., 2009). Thus, looking at the details surrounding the information system within a value chain is imperative. Likewise, Sugiarti et al. designed an e-commerce information system for mango in 2019. However, the one that they built was just for one enterprise. The authors conducted meetings directed toward the store's owners and representatives. The prepared documentation became the basis of the design of the e-commerce information system. On the other hand, Vanany et al. (2016) developed an electronic traceability system for mango in Indonesia. The abovementioned research tackled one case study with one supply chain network. They mentioned the difficulty in delivering accurate information in Indonesia regarding traceability. They recognize the importance of quality information primarily for the global market. These pieces of literature mainly focus on the role of ICT, not just in the mango industry and the agriculture sector in different countries. It shows the importance of holds and catalyzes an industry's growth. It also emphasizes how crucial the transfer of information is for the sector.

Table 1 Historical performance of mango (2000-2020)

Year	Production		Area		Yield / unit area		Yield / tree	
	Metric ton (Mt)	Growth rate (%)	Hectare	Growth rate (%)	In Mt/ha	Growth rate (%)	kg/tree	Growth rate (%)
2000-2009	925,247	-0.70	163,106	3.90	5.70	-4.50	No data available	No data available
2010-2020	793,296	-0.93	187,530	-0.14	4.20	-0.80	86.10	-2.10
2016-2020	747,987	-2.30	186,630	-0.14	4.00	-0.94	78.40	-2.20

Source: DA, 2022

On the other hand, the Philippine mango industry's performance has declined these past few years for several reasons. One of the primary reasons is the pest infestation from Cecid flies and Fruit flies. Other problems beset the industry include the following: 1) high cost of inputs/production cost; 2) improper farm practices/excessive use of chemicals; 3) lack of economies of scale; 4) production seasonality; 5) unproductive mango trees; 6) prevalence of infestation and diseases; 7) limited access to information and technologies; 8) high post-harvest losses; 9) inadequate/limited post-harvest and processing facilities; 10) limited access to resources and direct market, 11) unstable supply and prices, 12) multi-layer marketing, and 13) difficulty in accessing export markets (DA, 2022). For the past two decades, mango production has been going down for the following parameters: production, area of production, productivity per area, and productivity per tree. These pieces of information can be found in Table 1.

Despite these challenges, mango remains to be the third most highly exported fruit crop in 2020, with a PhP 35.520B ($716.019M) contribution to GVA in agriculture (Department of Agriculture (DA), 2022). This shows that mango is still one of the top-priority commodities in the country. Furthermore, this commodity system should be studied further to help improve its economic performance.

This study builds on the existing literature and analyzes the transfer of information among the mango contractors in the study area. It delves into the sources of information and channels of information transfer as well as the priorities of mango contractors regarding the information they need and the mode of information transfer.

OBJECTIVE

This paper aimed to describe the information system among the Pangasinan mango contractors. Specifically, it aimed to 1) identify the sources of information for the mango contractors, 2) determine information channels for information transfer, 3) establish the type of information that mango contractors prioritize, 4) determine the challenges and issues in the transfer of information, and 5) recommend interventions to improve information transfer among mango contractors.

METHODOLOGY

The study area for the research is Pangasinan since it is the top mango-producing province in the country, contributing about 29% of the total production in 2020 (DA, 2022). It is also strategically located since its climatic conditions and soil types are ideal for mango production (dela Cruz, 2007). Furthermore, it has developed road networks that make it accessible to processors and exporters in Metro Manila.

The primary data were collected through key informant interviews and surveys on the players. Key informants such as employees from the Office of the Provincial Agriculturist of Pangasinan, mango experts from the academe, and other mango players from other provinces were interviewed during the research. This provided a different perspective outside of the Pangasinan mango industry. On the other hand, structured questionnaires were employed for the survey on the mango players, which includes sections for the demographic profile, farm profile, production and marketing practices, sources and type of information, and channels of the information channel. The research also used purposive sampling on 55 mango contractors covering six mango-producing municipalities ranging from small to large-scale operators. Unfortunately, there is no list of mango contractors since they are considered transient players in the industry. Some mango contractors do not regularly operate annually, especially if they do not have enough capital to finance their operations. As a result, the researchers had to interview known mango contractors in the area and get recommendations from these contractors on who could be interviewed.

Secondary data were collected from online journals and online portals of the DA. Descriptive statistics and correspondence analyses were also employed in the study. This determines the association between and among the variables, such as sources, types, and information channels. XLSTAT was used to run the correspondence analysis for this research.

RESULTS AND DISCUSSION

Most mango contractors live in San Carlos City (50.91%) and Malasiqui (30.91%) since most of the mangoes come from these municipalities. On average, mango contractors who were interviewed were aged 49.48 years. The oldest who was interviewed was aged 69, while the youngest was 29 years old. On the other hand, the interviewed mango contractors are highly educated, with about 41.82% being college graduates and approximately 29.09% being high school graduates.

In terms of farming (generally), these contractors have been farming for an average of 23.18 years. However, some of them just shifted from general agriculture to mango farming specifically. On average, they have been mango farming for about 19.64 years. Approximately 38.18% (21 contractors) operate at a medium-scale (500-3,000 fruit-bearing trees or FBTs), while 32.73 (18 contractors) operate at a small-scale (less than 500 FBTs) and about 29.09% (16 contractors) operate at a large-scale (more than 3,000 FBTs).

Sources of Information

The results (Fig. 1) showed that most mango contractors generally receive information on the production and marketing of mangoes from farm technicians and buyers. They usually get information on production technologies from farm technicians and other mango contractors. Expectedly, they get their market information (price, volume, and quality specifications) from their buyers. As the computed p-value is lower than the significance level alpha=0.05, there is a link between the type of information that mango contractors and sources of information as shown in Table 2. Logically, farm technicians and other mango contractors provide production technology information. With an Eigenvalue of 100%, it can be said that the quality of the analysis is very high (shown in Table 3).

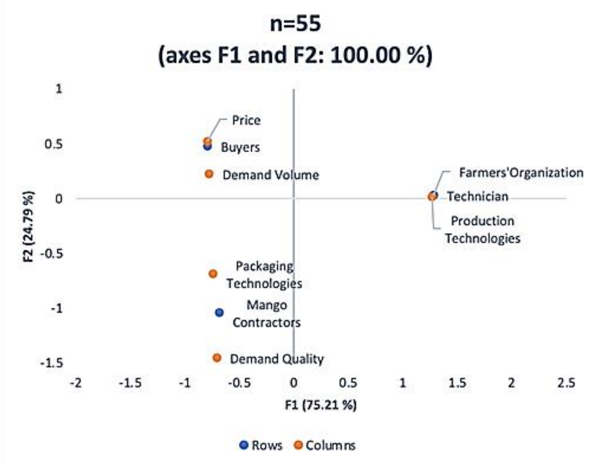

Fig. 1 Graphical representation on sources of information

Table 2 Test of independence between type of information and sources of information

Chi-square (observed value)	174.116
Chi-square (critical value)	21.026
DF	12
p-value	< 0.0001
alpha	0.05

Table 3 Eigenvalues and percentages of inertia

	F1	F2
Eigenvalue	0.970	0.320
Inertia (%)	75.207	24.793
Cumulative %	75.207	100.000

Information Channels

On the other hand, information transfer usually happens through mobile phones and during farmers' meetings (Fig. 2). Farm technicians generally hold round table discussions with contractors to show them new technologies for better mango production. On the other hand, They usually get their market information from their buyers through their mobile phones. As the computed p-value is lower than the significance level alpha=0.05, there is a link between the sources of information that mango contractors get and the information channel as shown in Table 4. Thus, these mango contractors getting their production technology information during farmers' meetings provided by farm technicians is logical. Also, since the buyers are primarily located in Manila, it would be logical for them just to use mobile phones in their transactions. With an Eigenvalue of 100%, it can be said that the quality of the analysis is very high (shown in Table 5).

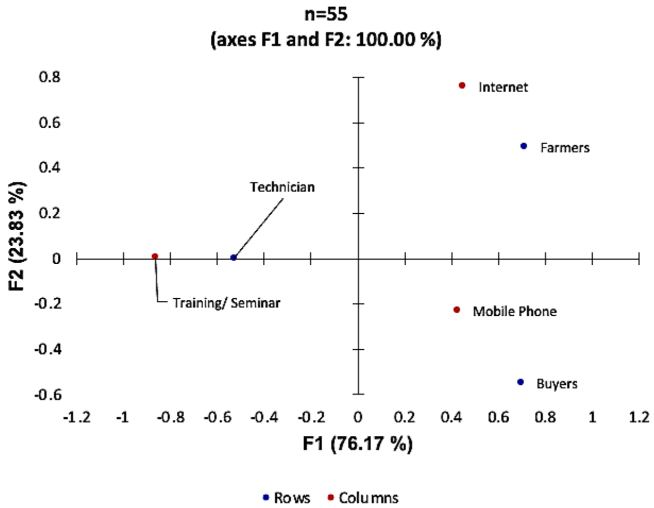

Fig. 2 Graphical representation on information channels

Table 4 Test of Independence between sources of information and information channel

Chi-square (observed value)	54.4160
Chi-square (critical value)	9.4880
DF	4.0000
p-value	< 0.0001
alpha	0.0500

Table 5 Eigenvalues and percentages of inertia

	F1	F2
Eigenvalue	0.370	0.116
Inertia (%)	76.166	23.834
Cumulative %	76.166	100.000

Priority Information

Based on the results (Fig. 3), mango contractors prioritize getting market information like price, demand quality, and demand volume, ranked 1, 2, and 3, respectively. It is followed by production processing and packaging technologies, ranked 4, 5, and 6, respectively. As the computed p-value is lower than the significance level alpha=0.05, there is a link between the rank and the type of information (shown in Table 6). Earning good money is crucial to mango contractors since their production has been low these past few years. Thus, the ranking that mango contractors gave the market information is logical. With an Eigenvalue of 87.24%, it can be said that the quality of the analysis is high as shown in Table 7.

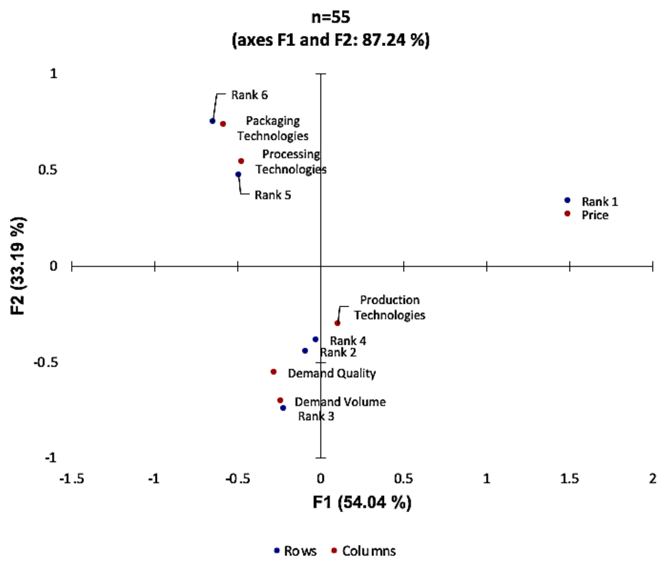

Fig. 3 Graphical representation on priority information

Table 6 Test of Independence between ranking and priority information

Chi-square (Observed value)	298.3640
Chi-square (Critical value)	37.6520
DF	25.0000
p-value	<0.0001
alpha	0.0500

Table 7 Eigenvalues and percentages of inertia

	F1	F2	F3	F4	F5
Eigenvalue	0.489	0.300	0.099	0.016	0.001
Inertia (%)	54.041	33.194	10.898	1.776	0.091
Cumulative %	54.041	87.235	98.133	99.909	100.000

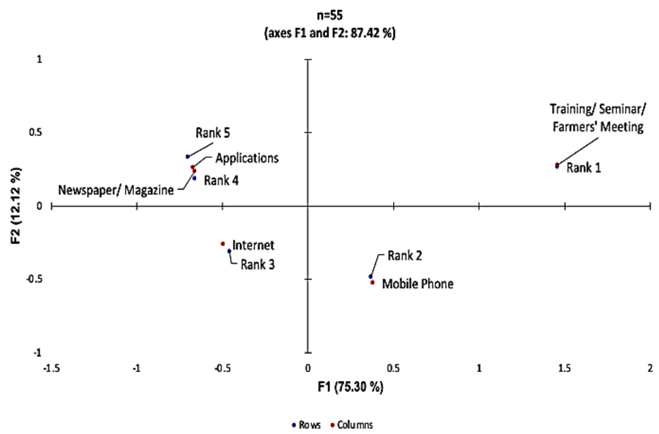

Fig. 4 Graphical representation on priority information channel

Priority Information Channel

Contractors also choose to converse face-to-face when obtaining information (Fig. 4). The next preference is through text and calls using mobile phones. As the computed p-value is lower than the significance level alpha=0.05, there is a link between the rank and the type of information channel (shown in Table 8). Mango contractors are pretty old-fashioned when it comes to communication. They prefer more traditional tracks of information transfer. Furthermore, farmers' meeting is also an excellent venue to socialize and catch up among the mango contractors since most are friends and relatives. They do not prefer using the internet or applications since they do not have Android or smartphones and are reluctant to learn to use these gadgets. With an Eigenvalue of 87.42%, it can be said that the quality of the analysis is high as shown in Table 9.

Table 8 Test of independence between ranking and priority information channel

Chi-square (Observed value)	248.000
Chi-square (Critical value)	26.2960
DF	16.0000
p-value	< 0.0001
alpha	0.0500

Table 9 Eigenvalues and percentages of inertia

	F1	F2	F3	F4
Eigenvalue	0.679	0.109	0.101	0.012
Inertia (%)	75.301	12.119	11.237	1.343
Cumulative %	75.301	87.420	98.657	100.000

CONCLUSION

In summary, most mango contractors generally receive information on the production and marketing of mangoes from farm technicians and buyers. Furthermore, information transfer usually happens through mobile phones and during farmers' meetings. Moreover, contractors prefer to get information on the buying price of mangoes, followed by the quality requirements of buyers. Mango contractors also prioritize getting market information like price, demand quality, and volume. Contractors also choose to have a face-to-face conversation when obtaining information, followed by text and mobile phone calls. Mango contractors currently get information through traditional means since they value social interaction with their colleagues in the industry. Even with the aid of technology, the contractors also appreciate personal touches like having conversations through calls and texts.

Furthermore, most mango contractors still prefer the more traditional information system through face-to-face conversations, text, and mobile phone calls. This has implications for the implementation of modern technologies used for information dissemination. Mango contractors might not be receptive to new ways of receiving communication. However, it seems like social networks are essential to these contractors. It is recommended that contractors be trained to use modern communication technologies to make them more receptive to other communication channels.

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Research article

Effect of Bio-slurry and Chemical Fertilizer on Soil Enzyme Activity

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Abstract Organic nutrient sources are an effective way to improve soil fertility and increase crop yield. Bio-slurry provides tremendous nutrient potential for the vegetative and reproductive growth of field crops and its long-term sustainability. Application of the bio-slurry on the field can help to reduce fertilizer use, maintain productivity, and improve soil health. Soil enzyme activity was enhanced by swine slurry. Enzyme activity following fertilization takes precedence over microbial biomass in the short term. The study aimed (1) to study the effect of bio-slurry and chemical fertilizer on soil enzymes activity, and (2) to compare the biomass growth of corn using bio-slurry and chemical fertilizer. The research was conducted from November to December 2022 at the Throckmorton Plant Sciences Center, Department of Agronomy, Kansas State University, United States. The experiment was conducted in pots under greenhouse conditions with 5 treatments, including Treatment 1: Control (without fertilizer), Treatment 2: bio-slurry, Treatment 3: urea, Treatment 4: NH_4NO_3 and Treatment 5: KNO_3+$NaNO_3$. Each treatment was conducted in 3 replications with 1 pot per replication and 2 seeds per pot. The activities of soil enzymes, biomass of corn above ground and root were collected and analyzed. Corn plants treated with bio-slurry and inorganic fertilizer were found to have a non-significant growth of corn soil β-glucosidase enzyme with 4.41 mg/L, 3.83 mg/L, 4.23 mg/L, 4.11 mg/L, and 4.14 mg/L, respectively. With regard to aboveground and belowground biomass, no significant differences between the control and other treatments were observed. The results showed that bio-slurry released low amounts of enzyme activity to the soil and provided good growth conditions to corn.

Keywords crop, corn, slurry, soil fertility, soil health

INTRODUCTION

Corn (*Zea mays* L.) is the most vital cereal worldwide (Ka et al., 2022). USA, China, and Brazil contribute 63% of the global corn production while Mexico, Argentina, India, Ukraine, Indonesia, France, Canada and South Africa are also major corn-producing countries (FAO, 2010). In Cambodia, commercial pig farms have increased due to their ability to control the environment necessary for fast pig growth and effective disease prevention (MAFF, 2019). Daily wastewater generated from the pig farm depends on the type of pigs such as sows, fatteners, and piglets at 64 m^3/head, 24 m^3/head, and 20 m^3/head, respectively (Kulpredarat, 2016).

Bio-slurry is a by-product of anaerobic digestion. The bio-slurry contains 93% water and 7% dry matter, of which 4.5% is organic matter and 2.5% inorganic matter, easily available plant nutrients, and high amount of nutrients and micronutrients. Total nitrogen, total phosphorus, and potassium were 2.1%, 1.1%, and 0.98% and micronutrients like Fe, Cu, Mn, and Zn were 0.34 ppm, 0.004 ppm, 0.088 ppm, and 0.023 ppm respectively. It's can be used as fertilizer directly or added with other organic materials on crops. (Kumar et al., 2015).

Soil enzymes are produced by animal manure, plants, and microorganisms. They are prominently secreted by microbes and stimulate microbial activity in this biome (Chernysheva et al., 2021). Soil microorganisms mainly synthesize extracellular enzymes such as β-glucosidase, hydrolases urease, phosphatase, glycosylating enzymes, and many more. Soil enzymes play a vital role in the biodegradation of organic compounds in soil and become the most delicate indicator of change in microbial activities that occur in the soil environment (Hueso et al., 2012).

OBJECTIVE

The objectives of the study were to determine study the effect of bio-slurry and chemical fertilizer on soil enzyme activities and to compare the biomass growth of corn using bio-slurry and chemical fertilizer.

METHODOLOGY

The experiment was conducted at Throckmorton Plant Sciences Center, Faculty of Agronomy, Kansas State University, The United States (39°11'37.3"N 96°35'04.2"W), during the autumn from November to December 2022. DKC59-82RIB corn variety was used and planted in pots in greenhouse condition. The experimental plots were followed a completely randomized design (CRD) with five treatments and 3 replications. The treatments were T1 (control), T2 (bio-slurry), T3 (urea), T4 (NH_4NO_3), and T5 (KNO_3+$NaNO_3$). Recommended doses of fertilizer applied for corn were 190, 30, and 100 kg/ha for N, P, and K, respectively. The soil was watered before planting the seeds, following maximum water holding capacity (MWHC) equivalent to 1 liter of water per pot.

The bio-slurry was collected from the College of Civil Engineering, at KSU, and used swine manure as substrate. Four samples, each about 1 kg of bio-slurry, were taken for nutrient content analysis. The samples contained 957.72 mg/L TN, 43.71 mg/L TP, 598.74 mg/L TP, 120.50 mg/L, 22.68 mg/L Mg, 12.13 mg/L S, and micronutrients (0.10 mg/L Al, 0.37 mg/L Fe, and 152.49 mg/L Na) (Kansas State Soil Testing Lab., 2022)

Soil samples were taken from two locations in each pot at the depth of 0-5 cm at 3 weeks after planted and transported back to the laboratory in plastic trays. For enzymatic analysis, 1-g of the wet soil was mixed with 1 mL of p-Nitrophenyl-β-D-glucosidase (PNG) solution, 4 mL MUB at pH 6.0-, and 0.25-mL toluene. The solution was hand-shaken slowly a few seconds, capped, and then placed in the incubator for 1 hour at 37 ^{0}C. Afterwards, the sample was withdrawn, cooled down at the room temperature, and then added with 1 mL of 0.5M $CaCL_2$ and 4 mL of 0.1M THAM buffer pH 12. This second mixture was hand-shaken for another few seconds and then poured into a beaker through a paper filter Watman No. 2. Before the prepared soil solution was tested in the spectrophotometer, this equipment had to be first tested with six levels of pre-prepared solutions to verify its accuracy. Those solutions contained p-nitrophenol diluted solutions of 0, 1, 2, 3, 4, and 5 mL; six levels of water in reverse order from 5 to 0 mL; each 1 mL of $CaCl_2$; and each 4 mL of THAM pH 12. After the accuracy was verified, the soil samples were then analyzed using this equipment. (Eivazi and Tabatabai, 1978). Values were corrected for a blank (Substrate added immediately after the addition of $CaCL_2$ and Tris NaOH) and for adsorption of released para-nitrophenol ρNP in the soil (Vuorinen, 1993). β-glucosidase activity is expressed as $\mu mol\ \rho NP\ released\ g^{-1}$ dry soil h^{-1}.

Each soil was air-dried 24 hours. Afterwards, the dried soil was ground and sieved to obtain soil particles of less than 2 mm for soil pH, soil moisture content, and plant nutrients analysis. Soil pH was determined using ORION Star A11 Bench top pH meter with a soil-water ratio of 1:10 (Bruce et al., 1982). Soil moisture content was calculated by subtracting the weight of the dry soil, oven-dried at 105 ^{0}C for 48 hours until it reached a constant weight.

Two kinds of corn biomass were measured four weeks after planting. Aboveground biomass was collected by cutting all corn stems in each pot from the stem base, then oven-dried at 60 ^{0}C for 72 hours and weighed. Underground biomass was collected by separating the soil clods and brushing the roots gently before soaked in distilled water to ensure that all soil was removed. Then, clean roots were oven-dried at 60 ^{0}C for 72 hours and weighed.

RESULTS AND DISCUSSION

Soil Enzyme (β-glucosidase)

In terms of β-glucosidase activity, there were no significant differences among the treatments (Table 1). On the other hand, the mean concertation of β-glucosidase in soil was found to decrease among grand mean of 4.13 $\mu mol\ \rho NP$ (Table 1)

Table 1 Effect of different fertilizer on Soil enzyme activity

Treatments	Mean ($\mu mol\ \rho NP$)
Control	4.33
Bio-slurry	3.83
Urea	4.23
NH_4NO_3	4.11
KNO_3+$NaNO_3$	4.14
Grand mean	4.13
SE	0.08
Pr (>F)	0.69

Source: Kansas State Soil Testing Lab., 2022

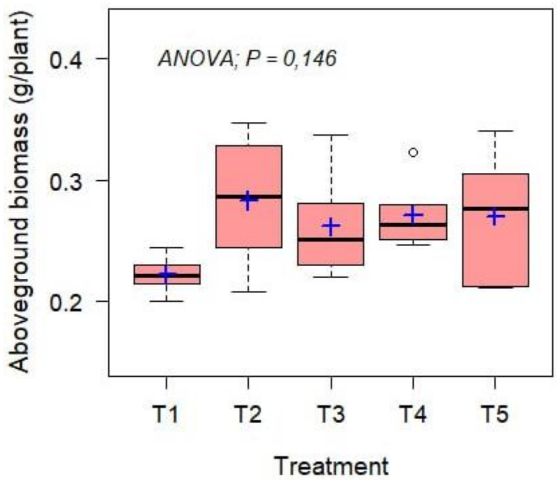

Fig. 1 Competition of corn aboveground biomass in different treatments

Soil Moisture Content

The result showed no significant difference among the treatments ($P > 0.05$). We were able to maintain the soil moisture evenly among the treatment (Table 2). In terms of aboveground biomass, it was observed that there are no significant differences between the control and the other treatments with reactions of 10.1%, 9.20%, 8.90% and 8.70%, respectively (Fig. 1; $P > 0.05$). However, aboveground biomass of swine slurry treatment was higher than others.

No significant differences in the underground biomass were observed between the control and other treatments ($P > 0.05$), with reduction of 20.10%, 20.60%, 22.07%, and 21.50% for the swine slurry, urea, NH_4NO_3 and $KNO_3 + NaNO_3$ treatments, respectively (Fig. 2).

Table 2 Effect of different fertilizer on Soil moisture

Treatment	Mean (%)	SD
Control	2.71	0.08
Bio-slurry	2.63	0.08
Urea	2.79	0.21
NH_4NO_3	2.65	0.08
$KNO_3 + NaNO_3$	2.68	0.11

Kansas State Soil Testing Lab (2022)

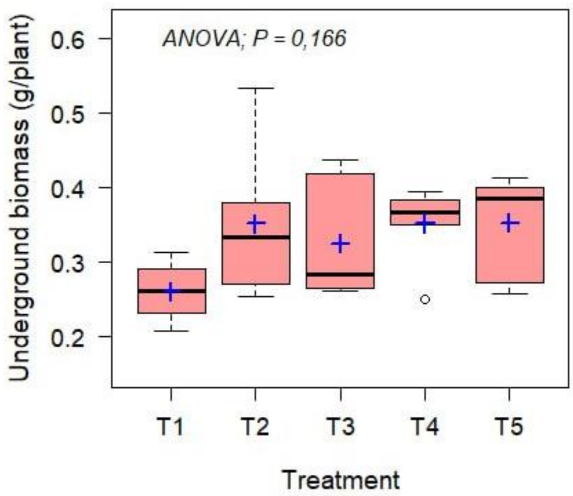

Fig. 2 Underground biomass

CONCLUSION

The results of this research demonstrated that swine slurry treatment cannot affect to soil enzyme activity (β-glucosidase), aboveground biomass, and underground biomass for a short term. According to the results obtained in this study, it is proposed to continue studying the soil enzyme activities for a long term and Phospholipid fatty acid (PLFA).

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Research article

Household Income Diversity of Small-scale Cassava Producers in Vietnam

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Abstract This study clarifies how small-scale cassava producers endeavor to stabilize their household income. We conducted the survey between April and December 2017 in Dong Nai, Tay Ninh, and Gia Lai provinces, which are major cassava-producing provinces; 182 small-scale cassava producers were randomly selected for interviews. According to the results, each household has 4.5 members, of which 2.1 are involved in cassava production. The average household income was $7,071.29 per year, while the average income per employee was $3,535.15, which is 36.8% less than the average income of Vietnamese employees. The primary income is derived from two sectors: $3,648.41 (51.59%) and $3,422.88 (48.41%) from agricultural and non-agricultural incomes, respectively, along with $25.0 (0.4%) and $14.7 (0.2%) from remittance and pensions, respectively. Further, the cassava income shared 23.57% and 12.16% of agricultural and total household incomes, respectively, with an average of $859.81. As their primary sources of income, some small-scale cassava producers produce industrial crops, such as rubber trees, sugarcane, cashew, tobacco, and acacia. Moreover, they produce vegetables and fruits and engage in animal husbandry activities and agro-processing. In terms of non-farm income, they work as hired laborers and receive a stable income from the government or private companies. Thus, small-scale cassava producers in Vietnam stabilize their household income with multiple income sources and do not rely heavily on cassava.

Keywords cassava, production, producers, socioeconomic status, income, Vietnam

INTRODUCTION

Vietnam is a lower middle-income country; however, its economy has grown by an average of approximately 6.7% annually since Doi Moi (renovation) in 1986 (Cameron et al., 2020). The agricultural, forestry, and fishery sectors constituted 12.36% of the economic structure. In 2019, labor productivity reached an annual average income of 4,159 USD per employee (GSO, 2017a). However, the average income varies between regions and provinces; for example, the central highlands had a per-employee income of 3,223.1 USD, while the Southeast had a per-employee income of 5,596.4 USD (GSO, 2017a).

After rice and corn, cassava is the third most crucial staple crop in Vietnam's agricultural sectors. In addition to rubber trees, coffee, tea, and cashew nuts, cassava is classified as an industrial crop, and it is the third most important export crop. According to Kim et al. (2000), cassava plays an important socioeconomic role. Furthermore, it generates employment opportunities in rural areas: in the north, this crop is used as food and feed for livestock, whereas in the south, it is a raw material for small-scale starch processing factories. This crop is grown on 513,000 hectares in 40 out of 63 provinces, with an annual production of 9.85 million tons (GSO, 2018a). In recent years, there has been an increase in the quantity of cassava production in Vietnam. Vietnam ranks ninth in the world in terms of cassava production, accounting for 3.5% of the world's old total cassava production (FAO, 2019). Statistical results from GSO (2018b) revealed that 7.42 million tons of cassava (75.3%) served domestic processing factories, while other 2.43 million tons (24.7%) were exported mainly to China (88.1%) and other countries, such as Korea (2.7%), Malaysia (1.6%), and the Philippines (1.5%).

Therefore, influenced by processing industries that use cassava starch and export demand, the price of cassava roots has fluctuated over the years. For example, in November 2012, the Prime Minister of Vietnam issued a decree mandating that all organizations and individuals producing, mixing, and trading petrol in Vietnam for use in conventional vehicle engines must use a biofuel known as E5 gasoline. Specifically, 95% RON 92 gasoline is blended with 5% bioethanol to produce E5 gasoline. The price of cassava roots has increased because bioethanol is made mainly from cassava starch (Nguyen et al., 2017). In January 2017, however, when the National Petroleum Group began selling RON 95 gasoline, the market share of E5 gasoline decreased significantly, resulting in a decline in the alcohol production industry. Moreover, compared with 2017, the amount of exported cassava decreased by 37.7% in 2018 (GSO, 2017b; GSO, 2018b).

Small-scale cassava producers, who play an essential role in the cassava sector in Vietnam, are highly susceptible to volatile cassava prices. Therefore, to earn a stable income, they might have income might rely on something other than cassava production. Previous studies suggested that farmers in rural areas tend to cultivate multiple crops, raise livestock and poultry in their spare time, and work as hired labor (Duong and Izumida, 2002; Minot et al., 2006; Nguyen et al., 2013; Hoang et al., 2014; Nguyen, 2017; Nguyen et al., 2019). Moreover, some farmers profit from specific crops, such as tea (Saigenji and Zeller, 2009). However, the income diversity of small-scale cassava producers in Vietnam needs to be studied. Therefore, it is necessary to discuss their income status to sustain and develop the cassava sector and increase cassava producers' income in Vietnam.

OBJECTIVE

This study discusses how small-scale cassava producers stabilize their household income in Vietnam.

METHODOLOGY

From April to December 2017, we randomly interviewed 182 cassava producers in the Xuan Loc district of Dong Nai province (60 producers), Tan Chau district of Tay Ninh province (61 producers), and Dak Po and Krong Pa districts of Gia Lai province (61 producers), regarding the 2016-2017 cassava production cycle. These three provinces occupy 26% of the total land used for cassava cultivation and produce 34% of total cassava production in Vietnam (Fig. 1) (GSO, 2018a).

The questionnaire was designed to understand farmers' management capacity including age, education, farming experience, and labor. Moreover, to analyze all income sources of cassava producers included in the study, four main income sectors, including agriculture income, non-farm income, pension, and remittance were generated in the questionnaire. In each sector, in the context of activities that generated income (plus or minus), producers were requested to clarify their respective contribution percentages. Microsoft Excel and R version 4.1.2 were used to analyze the data using descriptive and correlation statistics.

RESULTS AND DISCUSSION

Cassava Producers' Profile and Annual Income

In this study, 182 cassava producers, with an average age of 48.6 years and a gender ratio of 14.3% and 85.7% female and male, respectively, were interviewed. The interviewees' education levels were as follows: 14.3% no school, 42.9% elementary, 27.5% secondary school, 12.1% high school, and 3.3% bachelor. Their cultivation experiences were 23.8 years and 11.4 years for cassava production. Averagely, each family comprised 4.5 members, two of whom were the primary laborers for cassava production. Of the cassava farmers, 60.4% and 39.6% produced cassava full-time and part-time, respectively. Each cassava producer utilized 2.9 ha of land for a total of 5.1 ha of cultivation land.

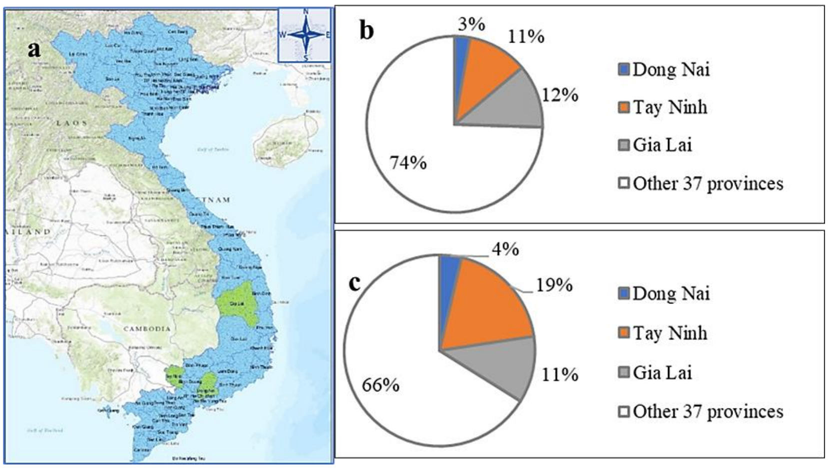

Fig. 1 Location of study sites, land use and production of cassava cultivation
(a) study site (light green); (b) land use for cassava cultivation (total: 596,000 ha);
(c) cassava production (total 10,309,700 tons), (made from GSO (2019))

As shown in Table 1, the income sources of cassava producers were categorized into four sectors. This diversity is consistent with Minot et al. (2006) and Nguyen et al. (2017) study, in the sense that rural farmers maintain their income by relying on a variety of sources, including subsistence production of staple crops, commercial production of a broader range of agricultural commodities, and non-farm activities. The annual average total income of each household was $7,071.3. The average income per employee was $3,535.7 because each household had two main laborers. This was 36.8% less than the average income of Vietnamese employees according to a government declaration (GSO, 2017a).

Two primary income sources of cassava producers were agriculture at $3,648.4 (51.6%) and non-farm at $3,383.2 (47.8%). An insignificant income was derived from remittances at $25.0 (0.4%) and pension at $14.7 (0.2%). Haggblade et al. (2010) found that the non-farm sector accounted for 51% of the income of farmers in rural areas of Asian developing countries, similar to cassava producers in Vietnam. This comparison demonstrates that agricultural income is essential for cassava producers in Vietnam.

Table 1 Sharing income ($ per year) from a different source of cassava producers (N=182)

Sectors	Average	%	SD
Total income	7,071.3	100.0	10,717.17
Agriculture	3,648.4	51.6	9,472.74
Non-farm	3,383.2	47.8	5,078.94
Remittance	25.0	0.4	336.93
Pension	14.7	0.2	139.73

Hire Labor and Agriculture Income Sources of Cassava Producers

According to Kim et al. (2015), cassava is a source of income for poor farmers as it can be easily cultivated, adapted to poor soil, and has low investment costs. Cassava producers in this study generally cultivated cassava in areas with poor soil. Other crops, such as industrial and staple crops, were grown in better soil areas. We identified eight different jobs in this study, as shown in Fig. 2. Cultivation (hired by other farmers for planting or harvesting products and so on) and work at local factories and companies were the three most attractive employments of cassava producers, sharing a total of 89.3%. Moreover, cassava producers joined the community government, soldiers, policemen, teachers, and nurses.

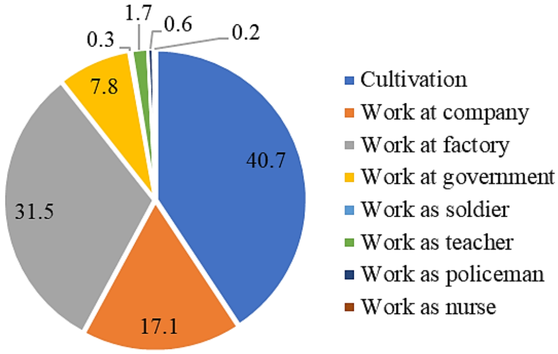

Fig. 2 Sharing employments (%) in hire labor activity of cassava producers (N = 182)

Table 2 shows that cassava cultivation accounted for 23.6% of agricultural income, with an annual average of $859.8. In contrast, income from industrial crops accounted for 76.7%, with an annual average of $2,797.1, while agro-processing products, stable crops, and vegetable and fruit crops contributed an insignificant amount of income in the agricultural sector. Concurrently, income from animal husbandry was negative $131.6 (-3.6%) annually.

Table 2 Income components of the agricultural sector ($ per year) (N = 182)

Income sources	Average	%	SD
Industrial crops	2,797.1	76.7	7,954.64
Cassava	859.8	23.6	2,617.84
Agro-processing products	49.5	1.4	440.55
Staple crops	48.7	1.3	2,339.03
Vegetables and fruits	25.1	0.7	937.15
Animal husbandry	-131.6	-3.6	1,683.22

Farmers from various rural areas rely on other main crops for their income in the agricultural sector. For example, according to Nguyen et al. (2013), rice, soya bean, and sweet potato are the main income crops for farmers in Cam My commune, Ha Tinh Province. Industrial crops, such as rubber trees (60.6%), sugarcane (21.7%), cashews (8.7.0%), tobacco (6.4%), and acacia (5.5%) are the main source of income for cassava producers in the agricultural sector (Fig. 3A). In contrast, black pepper resulted in a slightly negative income ($-9.0 per year) for cassava producers.

According to GSO (2018), areas where rubber trees, sugarcane, and cashews were planted in Vietnam were 969,700 ha, 281,000 ha, and 299,900 ha, respectively, with Dong Nai, Tay Ninh, and Gia Lai serving as the three main production areas for these crops. In this study, the cassava producers that planted rubber trees, sugarcane, cashew, tobacco, and acacia were 25 (with an average farm of 3.2 ha), 21 (with an average area of 3.9 ha), 44 (with an average farm of 1.9 ha), 9 (with an average area of 1.2 ha), and 8 (with an average farm of 3.5 ha), respectively. In addition, when cassava producers cultivated more than one industrial crop, we discovered that seven cassava producers grew rubber trees and sugarcane, six cultivated cashew and acacia, one cultivated cashew and tobacco, and another cultivated rubber trees, cashew, and acacia.

In vegetable and fruit crop cultivation (Fig. 3B), income sources were from banana (39.7%), watermelon (29.8%), dragon fruit (24.0%), and mango fruits (9.4%). Similarly, in staple crop cultivation (Fig. 3C), corn (60.7%), rice (28.2%), and bean (11.2%) were the income sources.

In animal husbandry activities, cassava producers' rear cows, pigs, goats, deer, chickens, ducks, and squabs. The negative income sources were mainly derived from rearing cattle ($-163.6 annually) and pigs ($-20 annually). The major cause of cassava production was cattle and pig deaths caused by epidemic diseases. A study by Chu et al. (2019) revealed a similar situation when animal husbandry epidemic diseases caused a lack of 47.6% of farmers in the Da River basin.

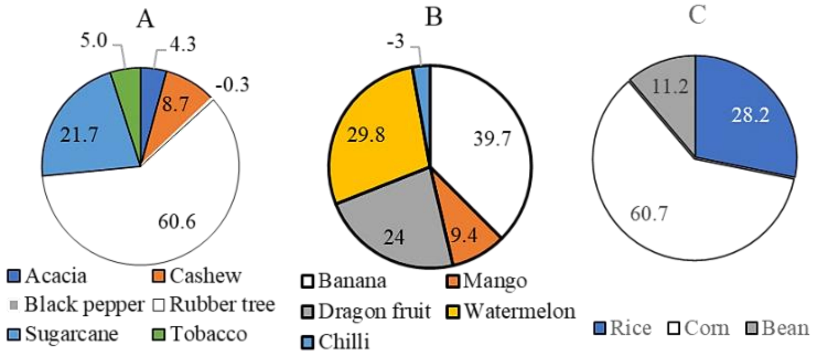

Fig. 3 Sharing income (%) in crop cultivation of cassava producers (N = 182)

Non-farm Income Sources of Cassava Producers

Non-farm activities vary from continent to country. Haggblade et al. (2010) grouped diverse rural non-farm activities as follows: mining and natural resources, manufacturing, construction, utilities, commerce, and services. Non-farm income sources of cassava producers were grouped into nine categories, as described in Section 4. The data indicates the positive and negative income derived from different activities. Hired labor activity comprised the main income source for non-farms. This activity contributed up to 81.5% ($2,757.2 annually). In this sector, middleman activity, specializing in cassava roots and stems, was the second source, gaining 10.9% ($368.6 annually). Grocery was third, at 5.83% ($195.8 yearly). A small amount was shared for the activities, including transport by a motor (1.0%), preparing motors or cars (0.8%), cashew nut businesses (0.6%), transportation by car (0.5%), and selling feed for the animal (0.1%).

Generally, cassava producers obtain a good revenue for their commercial activities. However, food booth activity resulted in a -1.3% ($-42.7 per year). This result may explain why farmers produced and sold food to inhabitants and fed their households during activities at food booths.

Table 3 Sharing annual income ($) in the non-farm sector of cassava producers (N = 182)

Income sources	Average	%	SD
Hired labor	2,757.2	81.5	3,114.14
Middleman	368.6	10.9	4,094.96
Grocery	195.8	5.8	1,147.45
Transport by motor	35.0	1.0	332.62
Repair motors or cars	27.1	0.8	271.38
Cashew nuts business	21.0	0.6	283.02
Transport by car	18.2	0.5	245.96
Selling feed for animal	3.0	0.1	40.43
Food booth	-42.7	-1.3	443.95

Correlation between Income and Total Land Area and Cassava Land Area

Analysis results indicated a correlation between total income and land use for crop production (Fig. 4A) and land use for cassava production (Fig. 4B), with the correlation coefficients (r) being 0.37 and 0.41, respectively. However, we observe that few farmers are pulling the correlation to become positive liners. The results suggest that cassava producers with more agricultural and cassava land will have more income. This finding is per the study of Minot et al. (2006), who found that expanding the areas of cultivation is one of the various methods to improve farmers' income. A study of Nguyen et al. (2017) showed that ethnic minorities in the Northern Mountains of Vietnam could increase 15% income per capita when they increase 1,000 m^2 crop land.

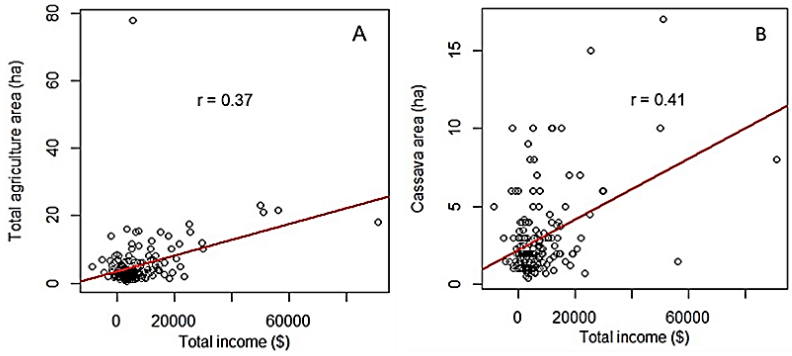

Fig. 4 Correlations between total income and total agricultural area (A) or cassava cultivated area (B) (N = 182)

Encounter Problems in Cassava Production

Other than income from cassava, we observed that cassava farmers diversified their sources of income. This section discusses the issues cassava farmers face and the possible reasons why cassava producers need to rely on more than cassava production as their primary income source. Cassava production in Vietnam has encountered various biotic and abiotic stressors. Moreover, other issues related to varieties, changing root prices, and cultivation technologies have also challenged producers. This study summarizes 11 problems in cassava production, as shown in Fig. 5. Up to 87.9% of cassava producers encountered low prices for tuber selling. Half of the cassava producers had issues with pests and diseases, and nearly one-third had problems with adverse weather during cassava farming. High-cost input and seedling die had caused trouble for approximately 10% of cassava producers. In addition, other issues, including low yield and technology, difficulty finding labor, high labor cost, counterfeit fertilizer and pesticides, and poor transportation, also affected a few cassava producers.

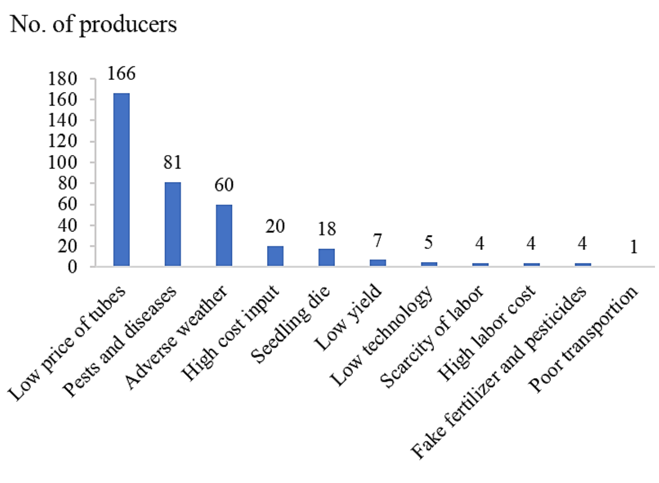

Fig. 5 Encounter problems in cassava production (N=182)

CONCLUSION

This study investigates the household income diversity of small-scale cassava producers in Vietnam. We utilized a sample of 182 cassava producers cultivating cassava fields of 2.9 ha on average, with 11.4 years of experience in cassava production in Dong Nay, Tay Ninh, and Gia Lai provinces.

The results showed that, on average and yearly, total household income was $7,071.29, of which $3,648.41 (51.59%) was from agricultural and $3,422.88 (48.41%) from non-farm sources. The average income from cassava production was $859.81, which accounted for 12.16% of the total household income and 23.57% of agricultural income. The various agricultural income sources included seven types of crops, six types of vegetables and fruits, seven types of animal husbandry operations, and three types of agro-processing businesses. Further, they engaged in eight kinds of off-farming work and were hired as laborers; this income accounted for a significant portion of the total household income. We also observed problems encountered in cassava production, which explains why cassava farmers cannot only produce cassava. Due to fluctuations in tuber prices, pests and diseases, and adverse weather, cassava producers in Vietnam diversify their income sources. They do not overly rely on cassava and stabilize their household income.

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Research article

The Effects of Green Manure on Sustainable Agriculture Soil Conservation under Open Field Conditions

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Abstract Green manure is a type of crop that is used for soil enhancement, both physical and biological. It is enriched with organic matter that provides nutrients to the soil and improves soil fertility. However, improper chemical use by farmers results in soil degradation and adverse effects on beneficial soil microorganisms. To mitigate this problem, farmers need to use fertilizer only as required. The purpose of the current study was to grasp the efficacy of green manure on soil improvement, with consideration of the principles of sustainable agriculture. The research aimed to study the effect of green manure on soil properties including soil pH, soil EC, and available nitrogen. Experiments were carried out in field conditions at the National Meanchey University, Cambodia, from June 25 to July 25, 2022. The experiment was laid out in a randomized complete block design (CRBD) with 4 treatments and 8 replications utilizing green manure produced from different plants. Treatment T0 represented the control, T1 *Glycine max*, T2 *Vigna radiata*, and T3 *Crotalaria Juncea*. The result showed that green manure has a significantly positive effect on soil properties such as pH, electric conductivity, and available nitrogen. T3 produced the highest post-treatment soil pH and reduction in soil electric conductivity (EC), which averaged 7.14 and 0.46, respectively. T2 provided the greatest amount of available nitrogen, while untreated soil was not significantly different among treatments. Therefore, the application of green manure can be a vital choice in soil improvement for sustainable agriculture and increased yield.

Keywords green manure, fertilizer, soil, sustainable agriculture

INTRODUCTION

Soil health is defined as the capacity of the soil to function as a living system, with ecosystem and land use boundaries. It sustains plant and animal productivity, maintains or enhances water and air quality, and promotes plant and animal health. It is based on the interaction, balance, and stability of the physical, chemical, and biological properties of soil, which have direct effects on nutrient cycling, soil structure, water availability, and pests and diseases, ultimately affecting crop health and yield (Patil and Solanki, 2016).

Consequently, fertilization increases efficiency and obtains better quality product recovery in agricultural activities. Fertilizer use has increased by 70%, and pesticide use has increased several-fold (Savci, 2012; Tilman et al., 2002). As a result, fertilization causes the accumulation of heavy metals in soil and plant systems. Long-term unbalanced use of agrochemicals may lead to a community shift of beneficial microorganisms with dangerous consequences for soil physical and chemical structure (Hamidov et al., 2007). Soil structure in agricultural productivity is very important and it is regarded as an indicator. Unconsciously, the fertilizing of soil, just as in the deterioration of the structure is caused by industrial emissions. Especially $NaNO_3$, NH_4NO_3, KCI, K_2SO_4, and NH_4Cl demolish the structure, such as fertilizers, soil, and soil structure, and deterioration is difficult to obtain high-quality and efficient products (Shaviv, 2001). Moreover, soil degradation has strong negative economic impacts since a large part of the population relies on agriculture as a primary source of income (Lal, 2015). More than 500 million hectares of tropical arable land and 33% of the earth's land surface globally face a decline in soil health (Lamb et al., 2005).

Therefore, green manure is considerable for use in soil improvement in terms of sustainable agriculture because it provides numerous benefits to crop production and soil health (Magdoff, 2001). According to Pandey et al., (2008), green manuring helped advance the soil's physical and biochemical anatomy, prevented leaching losses of nutrients, and added water-holding capacity. The approved use of green manuring resulted in high organic matter reserves which added both soil physical and chemical properties if compared to controlled fields. This is because they can help conserve, maintain, or replenish soil resources, including organic matter, nitrogen and other nutrient inputs, and physical and chemical properties (Sarrantonio and Gallandt, 2003). Several studies have investigated cereal-legume intercropping. Legumes are found in natural ecosystems and are key to promoting ecosystem efficiency such as nitrogen fixation, soil microbial health, and ecological network of biodiversity of soil (Duchene et al., 2017; Zhang et al., 2021). Likewise, Ablimit et al. (2022) revealed that microbial phylotypes were grouped into four major ecological clusters. The application of green manure led to significantly increased soil pH, nutrient contents, and enzyme activities, and significantly reduced the relative abundance of potential plant pathogens compared with monocropping, which should ensure high and stable maize yield under long-term continuous cropping (Charron and Sams, 1999).

We conduct research based on sustainable agriculture in an effort to achieve Cambodia's action plan of Zero Growth on Chemical Fertilizers by 2050. The outcome of the research will be shared with farmers in an effort to maintain the environment and increase food safety.

OBJECTIVE

The research aims to enhance the soil property by inoculation of green manure from different plants, (i) *Glycine max*, (ii) *Vigna radiata*, and (iii) *Crotalaria Juncea*, in an open field at the National Meanchey University, Cambodia.

METHODOLOGY

Experimental Design and Plantation

This research was carried out at National Meanchey University from June 25, 2022, to July 25, 2022. The experiment was carried out by randomized complete block design (RCBD) consisting of four treatments and three replications (Table 1). Each block had a 2 m x 2 m diameter and a length of 0.5 m for a total area of 66.5 m^2. For the plantation, each plant was planted in the experimental field by using different types of plants for comparison. Green manures were plowed into the soil to a depth of 10 cm length after one month of plantation. Each treatment was plowed two times per day after fermentation. Treatment zero was the control, treatment one (T1) used *Glycine max*, treatment two (T2) used *Vigna radiata*, and treatment three (T3) used *Crotalaria Juncea*.

Table 1 Treatment and composition

Treatment	Inoculation
Control	Uninoculated
Treatment 1	*Glycine max*
Treatment 2	*Vigna radiata*
Treatment 3	*Crotalaria Juncea*

Reference: Blomme et al. (2022)

Soil Chemical Analysis

Soil samples were collected before and after plantation in the field experiment of the National Meanchey University. Upon collection, soil samples were sent immediately to the soil laboratory for further analysis including soil pH, soil electrical conductivity (EC), and available nitrogen, which followed the method of Kjeldahl (Cunniff, 1995). Soil pH was determined using the method of Kumar et al. (2014), while EC was analyzed according to the method proposed by Kargas et al. (2022).

Data Analysis

Data were analyzed for analysis of variants (ANOVA) using the R program version (4.0.3). The differences among means were tested by Duncan's multiple range tests at $p \leq 0.05$.

RESULTS AND DISCUSSION

Before planting, soil pH was detected to be the same value for all treatments. This was due to soil experimentation being in the same condition. However, the effect of intercropping on soil pH result displayed that application of green manure enhances soil pH significantly, increasing among treatments (Fig. 1) As a result, treatment 3 (T3) and treatment 4 (T4) provided the highest soil pH values, which ranged from 6 to 7. Our research strongly agreed with Kawu (2020), and found that incorporating green manure crops significantly influenced soil pH at harvest. This phenome is due to a major contribution of soil decomposition by microbial activity when incorporated into the soil (Msimbira and Smith, 2020). Previous studies have reported higher soil organic matter, nitrogen, phosphorus, potassium, calcium, and magnesium contents due to incorporating green manure (Biswas and Mukherjee, 2001; Herrera et al., 2007).

Soil reduction regarding electrical conductivity was examined and was found without significant difference relative to the control, which ranging from 1.20 to 1.44 dSm^{-1}. However, soil EC was found significantly reduced after incorporating green manure into the soil among different treatments (Fig. 2). Moreover, treatment three (T3) resulted in the greatest reduction in soil EC, with a value of 0.49 dSm^{-1}. Similar results, indicating that green manure reduced soil EC, were obtained by Bhayal et al. (2018). This decrease was due to the addition of readily decomposable organic matter in the form of green manure with accumulation of the CO_2 either may be due to the precipitation of Fe^{2+}, Mn^{2+} and consequent adsorption of other cations on the exchange site and decomposition of organic acid (Harish and Devasenapathy, 2010).

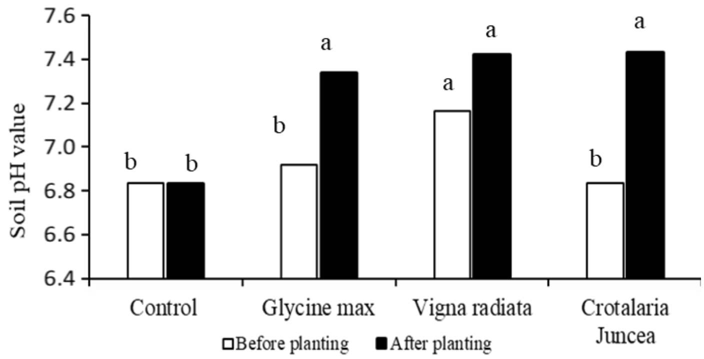

Fig. 1 The effect of green manure on soil pH before and after plantation

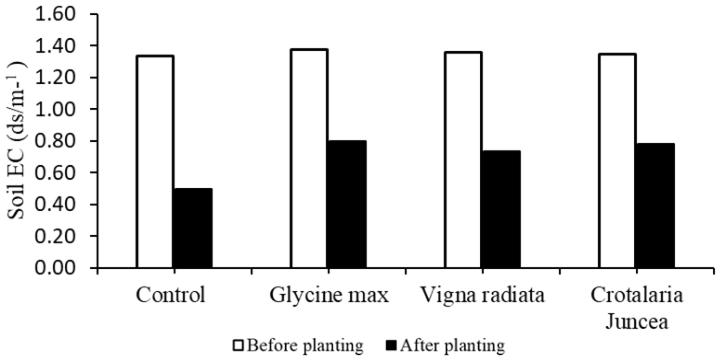

Fig. 2 The effect of green manure on soil electric conductivity

Green manure is usually considered as a cover crop sown to enhance the fertility of the soil between two crops demanding high nitrogen inputs (Sanaullah et al., 2022). After incorporation in soil, the result displayed that green manure had significantly increased the available nitrogen ($P < 0.05$). Barradas et al. (2001), in an experiment with eight species of green manure, observed that white lupine and common vetch were the species that accumulated the highest total N in the whole plant, with amounts of 251.6 and 228.1 kg/ha, respectively. Our result agreed with those of Salahin et al. (2013), finding that green manure has significantly increased soil organic matter, soil health, and crop growth. Moreover, the author found that green manure increased SOM and TN which was obtained from *V. radiata* and *S. aculeata*. There may be a difference in time and species of plant in this result. On the other hand, after incorporation into the soil, the nutrients in the plant biomass were released during the process of decomposition (Piotrowska and Wilczewski, 2012).

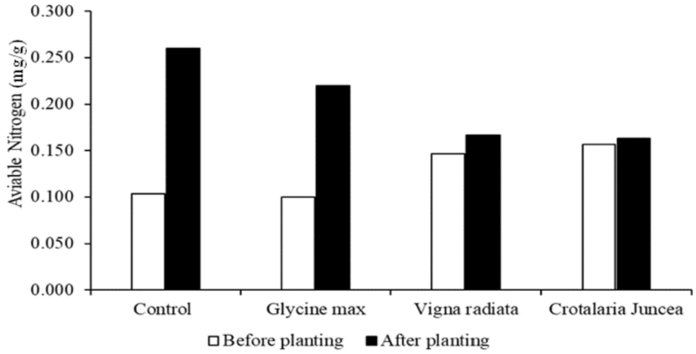

Fig. 3 The effect of green manure on soil available nitrogen

CONCLUSION

The incorporation of *Glycine max*, *Vigna radiata*, and *Crotalaria Juncea* as green manure showed a positive response on soil pH, soil electrical conductivity, and available nitrogen. Therefore, we concluded that treatments 1, 2, and 3 provided a positive result for soil health, but only treatment 2 provided the greatest value of available nitrogen.

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Research article

Habitat Evaluation of Agricultural Waterways where Environmental Improvement Was Practiced for Recreation

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Abstract In rural areas, agricultural irrigation and drainage systems developed for paddy fields have a high potential to become components of green infrastructure by providing ecosystem services. In order to manage and operate agricultural waterways as green infrastructure, the habitat evaluation of aquatic organisms is important. In this context, we conducted a habitat evaluation of aquatic organisms in the waterway network where environmental improvement was practiced to promote recreational use by residents. Based on evaluation results, the physical characteristics of canals with high biodiversity were investigated. The Evaluation Program for Fish Habitats in Agricultural Canals, which was developed for non-professional users such as residents, was applied to biological (fishes and crustaceans) and physical data collected in the waterway network in the town of Koura, Shiga Prefecture, Japan. The model generated by the program showed high fitness (0.80 for fishes, 0.76 for crustaceans), which suggests the program applies to waterway networks including various types of watercourses. The characteristics of the canals which were assigned a high habitat score by the program included 1) deeper water depth, 2) higher velocity for fish, 3) lower velocity, 4) higher vegetation coverage, and 5) gravel canal bed for crustaceans, relative to the low-scoring canals. The canals in diversion parks developed as part of environmental improvement efforts tended to have these characteristics and higher scores. Therefore, our findings suggest that conserving irrigation canals and developing diversion parks in waterway networks, which were conducted as part of environmental improvement efforts in the target area, contributes not only to promoting recreational use by residents but also to habitat conservation.

Keywords habitat evaluation, agricultural waterways, environmental improvement, green infrastructure

INTRODUCTION

Green infrastructure is defined as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services in both rural and urban settings (European Commission, 2013). Agricultural waterways for irrigation and drainage have been historically developed in rice-farming regions. Such waterways were traditionally used not only for irrigation but also for fisheries, recreation, and domestic use. Therefore, agricultural waterways have a high potential to become components of green infrastructure by providing ecosystem services.

However, recent modernization of agricultural landscapes and infrastructures modified only for efficient agricultural production and accelerated to use as grey infrastructure (Lee et al., 2015). Thus, improving irrigation infrastructures as green infrastructure based on sustainable ecosystem service use, such as recreational use, is a recent fundamental challenge (Matsuno et al., 2006; Katayama et al., 2015; Nishida, 2018). In this context, the habitat evaluation of aquatic organisms is important to manage and operate agricultural waterways as the green infrastructure.

Currently, agricultural waterways in rice-farming landscapes have been modified for the modernization of irrigation systems. Particularly, irrigation canals have been converted into pipelines to distribute water efficiently. Further, even in open canals, concrete lying degrades habitat conditions. Such negative impacts of modification for aquatic organisms have been reported (e.g., Nishida et al. 2018) and could be a significant concern for the availability of ecosystem services. However, consideration of the availability of such waterways for people is limited in planning and managing agricultural landscapes as green infrastructure in addition to habitat conservation and restoration.

In a waterway network in Koura town, Shiga Prefecture, Japan, environmental improvement was practiced promoting the recreational use of residents. Recreation constitutes cultural ecosystem services of agricultural waterways and is important from a well-being perspective for the formation of rural living environments. However, it is not known that such modification for recreational use benefits to restoration of ecosystem services (Lin et al., 2020). In restoration practice, considering the habitability of aquatic organisms with such environmental improvement is key for the availability of wider ecosystem services (Matsuno et al., 2006).

OBJECTIVE

The study aims to assess the habitability of aquatic species in agricultural waterways adapted for recreational purposes.

METHODOLOGY

Study Area

The study was conducted in a waterway network in the town of Koura (35.2°N, 136.26°E), Shiga Prefecture, Japan. Koura town is a rural area located on the alluvial fan formed by the Inukami River (Fig. 1). In this area, it was planned to convert all irrigation systems to pipelines for water shortage in 1981.

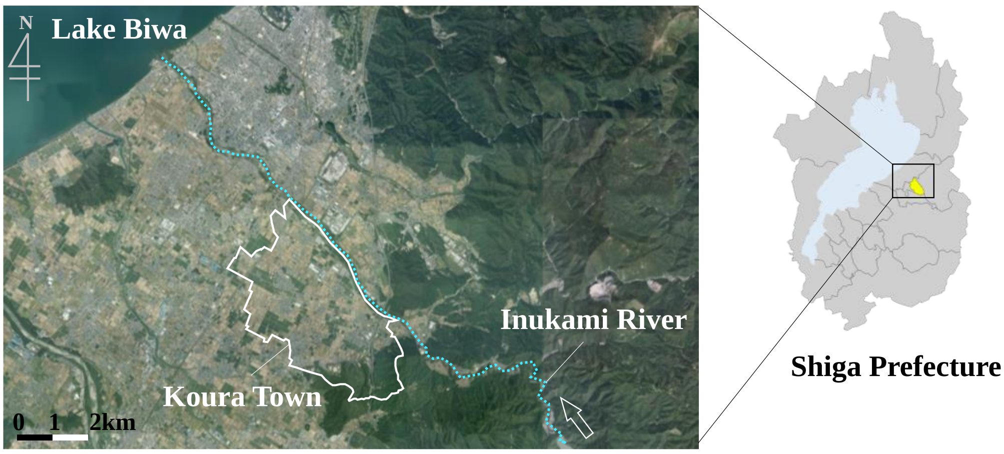


Fig. 1 Location of the study area, Koura Town, Japan

An aerial photograph is quoted by the Geospatial Information Authority of Japan and modified partially.

However, implemented the water environment improvement project in 1989, the irrigation and drainage canals were drastically altered to improve for recreational use by the residents: (1) the irrigation plan was modified to maintain open canals; (2) diversion parks were developed utilizing the pipeline discharge and diversion points; (3) the open irrigation canals were environmentally protected by masonry revetments; (4) sands and gravels were added to the irrigation canal beds; and (5) landscape facilities such as flower beds were installed

Data Collection

Based on the characteristics of the waterway network in this area, a total of 26 canal sections containing a variety of environmental conditions were selected as survey sites (Fig. 2). Each of the survey sites was 20 m in length and the width was the canal width. We conducted a biological and environmental survey on 10-18 August 2018.

As the physical environment varies depending on the type of canal, the survey sites were categorized into four canal types: diversion park (No. 1 to No. 6, Fig. 3a); drainage canal (No. 7 to No. 11, Fig. 3b); irrigation canal A (No. 12 to No. 20, Fig. 3c); and irrigation canal B (No. 21 to No. 26, Fig. 3d).

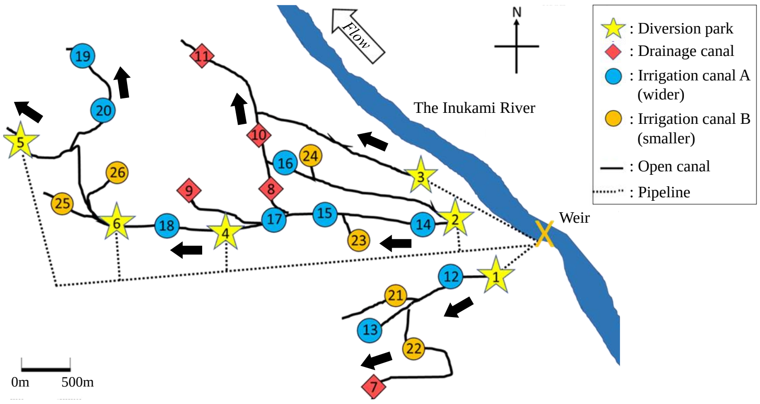
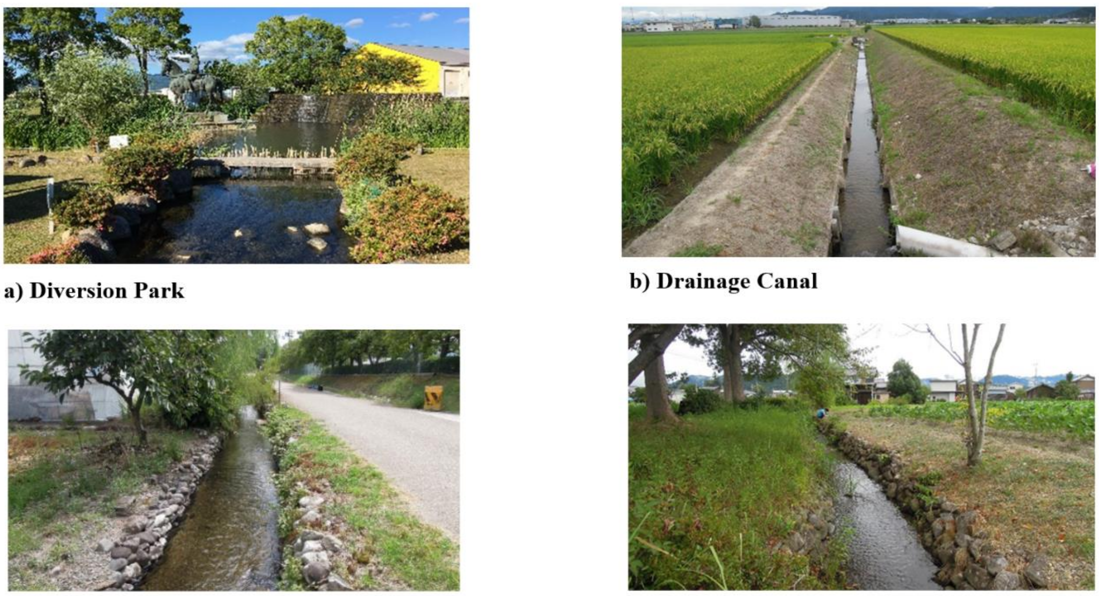


Fig. 2 Location of survey sites with canal type



a) Diversion Park

b) Drainage Canal

c) Irrigation Canal A

d) Irrigation Canal B

Fig. 3 Example of four canal types in the study area

a) diversion park; b) drainage canal; c) irrigation canal A; and d) irrigation canal B

In this waterway network, irrigation water is introduced from the Inukami River, after that, water is distributed into diversion works of each village through pipelines. The diversion park as the water park was developed in diversion points and the associated canals. The survey sites of diversion parks were located in one of the associated canals to compare other canal sites. The Irrigation Canal A is the main canal and has a wider canal width for carrying water to areas of paddy fields. Irrigation Canal B is a small canal that branches off from Canal A and supplies water directly to each paddy field. In diversion parks the environmental improvement commonly modified the canal structure for recreational use: the canal width was widened; gravel was laid on the streambed; the slope of the revetment was made gentler; and emergent plants were planted. In this waterway network, vertical drops were constructed between irrigation canals and drainage canals. However, fish migration was thought to mainly come from the Inukami River through pipelines. Thus, we did not consider the effects of barriers to fish migration.

To measure physical characteristics, cross sections were placed at 5 m intervals in each site. We conducted a field survey including both physical characteristics and biological sampling. To examine the hydraulic conditions of survey sites, water depth, water velocity, canal width, and wetted width were measured. The difference between canal width and wetted width was used as land width across the canal. Water depth and water velocity were measured across cross sections, and the points were divided into quarters. A uniaxial electromagnetic anemometer (Kenek, LP40) was used to measure water velocity. The percentage of streambed material (concrete, large gravel (cobble, > 64 mm), small gravel (pebble and granule, 2-64 mm), sand and silt (< 2 mm)) and vegetation cover were measured visually. We also measured water temperature, electric conductivity, and pH at the same time as those samples. However, the remarkable differences among sites were not shown.

We conducted biological sampling for fish and crustaceans. Two fyke-nets (mesh size: 5 mm) were set at both ends of the sampling section and hand nets (2 mm) were used to collect fish and crustaceans inside the survey site. The sampling effort of each site was fundamentally ten minutes by three persons. However, areas of the survey site (i.e., canal width) differed among sites. Thus, the sampling effort was adjusted to the area of the survey site to ensure an equivalent sampling effort among survey sites. After collecting fish and crustaceans, we identified species and counted individuals of each species. After that, we released sampled fish and crustaceans to the sampling site.

Analysis

To evaluate aquatic habitat, the "Evaluation Program for Fish Habitats in Agricultural Canals" (Watabe et al., 2018; 2020) (hereafter referred to as the "EPFH"), which was developed as a simple evaluation method by non-specialists, was applied. EPFH was developed and published free of charge by the National Agriculture and Food Research Organization (NARO, 2018). In ecosystem-friendly measures, it is important to conduct continuous monitoring surveys and adaptive management, such as updating and modifying facilities, to prevent habitat degradation. However, there are issues such as the significant cost of continuing monitoring surveys and the difficulty of interpreting the results of environmental assessments without specialists. EPFH was developed as a simple evaluation tool to address these issues. In this study, the EPFH was selected based on the assumption that it would be operated by non-specialists (local residents) who are the maintenance managers of the agricultural waterways.

In this program, the evaluation score is calculated using Eq. (1). This is a regression equation, which is positively correlated with both the number of species and the number of individuals identified and is explained by the physical environmental conditions such as water depth and water velocity (Watabe et al., 2018).

$$y=a_0+a_1x_1+a_2x_2+a_3x_3+a_4x_4+a_5x_5 \tag{1}$$

Where y is the evaluation score, a_0 is the constant term, a_1 to a_5 are the coefficients of each variable, and x_1 to x_5 are environmental indices. The values of a_0 and a_1 to a_5 are determined so that both the correlation coefficient r_1 between the evaluation score y and the number of species and the correlation coefficient r_2 between the evaluation score y and the number of individuals are high. The goodness of fit of the model F is defined by the following Eq. (2);

$$F = \frac{r_1 + r_2}{2} \quad (2)$$

where r_1 represents the correlation coefficient between the evaluation score and the number of species, and r_2 represents the correlation coefficient between the evaluation score and the number of individuals. The goodness of fit ranges from values of -1 to 1. In this study, to confirm the reliability of the accuracy of this program, a correlation test of the correlation between the evaluation score and Shannon-Wiener's diversity index H' (Whittaker, 1972) was also conducted.

The Kruskal-Wallis's test was conducted to analyze differences in scores of habitat evaluation among canal types. If the test showed significant differences, multiple comparisons were made using the Steel-Dwass method to determine a pair of canal types with significant differences among the four canal types. All of the statistical analyses were performed using R version 4.0.5 (R Core Team, 2021). The results of this analysis were shown for biological data but not for physical environments. Because the variations were very large depending on the site characteristics. Thus, we focused on the numerical difference of the physical environments.

RESULTS AND DISCUSSION

Status of Physical Environments of Waterways and Aquatic Organisms

The physical environmental conditions of canal type are shown in Fig. 4. Average canal width of survey sites ranged from 50.0 to 446.5 cm, and the land width ranged from 0 to 146.0 cm. Water depth ranged from 3.2 to 43.7 cm, and water velocity ranged from 1.7 to 38.7 cm/s. Vegetation cover ranged from 0 to 51%. Streambed materials were largely varied.

Diversion parks tended to have relatively wider canal widths and deeper water depths. Only the diversion park contained canals with a water depth of more than 30 cm. This is because the diversion park includes the canals through which pipeline water flows before it is diverted, and thus has abundant water flow. As for water velocity, the drainage canals tended to be slower. Vegetation cover tended to be higher in diversion parks and drainage canals. This is because aquatic plants were planted in the diversion park at the time of environmental improvement for landscaping, and also because sediments were deposited in the drainage canals due to the slow water velocity and vegetation growth. Comparing canal bed materials, there was no concrete in the diversion park. The percentage of small gravel tended to be lower in the drainage canal than in the diversion park. Irrigation canals A and B showed similar trends.

The results of the aquatic organism survey are shown in Table 1. In total, 657 individuals of 13 fish species and 4,039 individuals of 4 crustacean species were observed. Among the fish species, dark chub *Nipponocypris sieboldii* was most abundant (351 individuals at 12 sites), followed by Amur goby *Rhinogobius* sp. (153 individuals at 10 sites). Among crustaceans, the number of freshwater shrimps *Paratya compressa* was largely abundant (3,630 individuals at 21 sites). Japanese freshwater crab *Geothelphusa dehaani*, which is an indicator species for good water quality (Ministry of the Environment, 2017), was found at 15 sites (57.7%) with 211 individuals so water quality in the study area was suggested to be relatively good. Among fish species, Japanese medaka *Oryzias* sp. (59 individuals at 3 sites) and weather loach *Misgurnus anguillicaudatus* (14 individuals at 4 sites), which were listed as endangered species on the Red List 2020 (Ministry of the Environment, 2020), were included.

Aquatic Habitat Evaluation

1) Fitness of the model

Based on the data of physical conditions and aquatic organisms, the EPFH was performed to evaluate the habitat quality of the survey sites. As a result, the goodness-of-fit of the model F was 0.80 for fish and 0.74 for crustaceans (Table 2). The correlation between the model score and Shannon-Wiener's diversity index H' showed a strong correlation for fish (r = 0.63, p < 0.01). On the other hand, no significant correlation was detected for crustaceans (r = 0.37, p = 0.90). This is thought to be that the extremely large number of freshwater shrimps compared to other crustacean species skewed the results of the analysis, resulting in a low correlation with Shannon-Wiener's diversity index H', which takes into account the evenness of the number of individuals of each species.

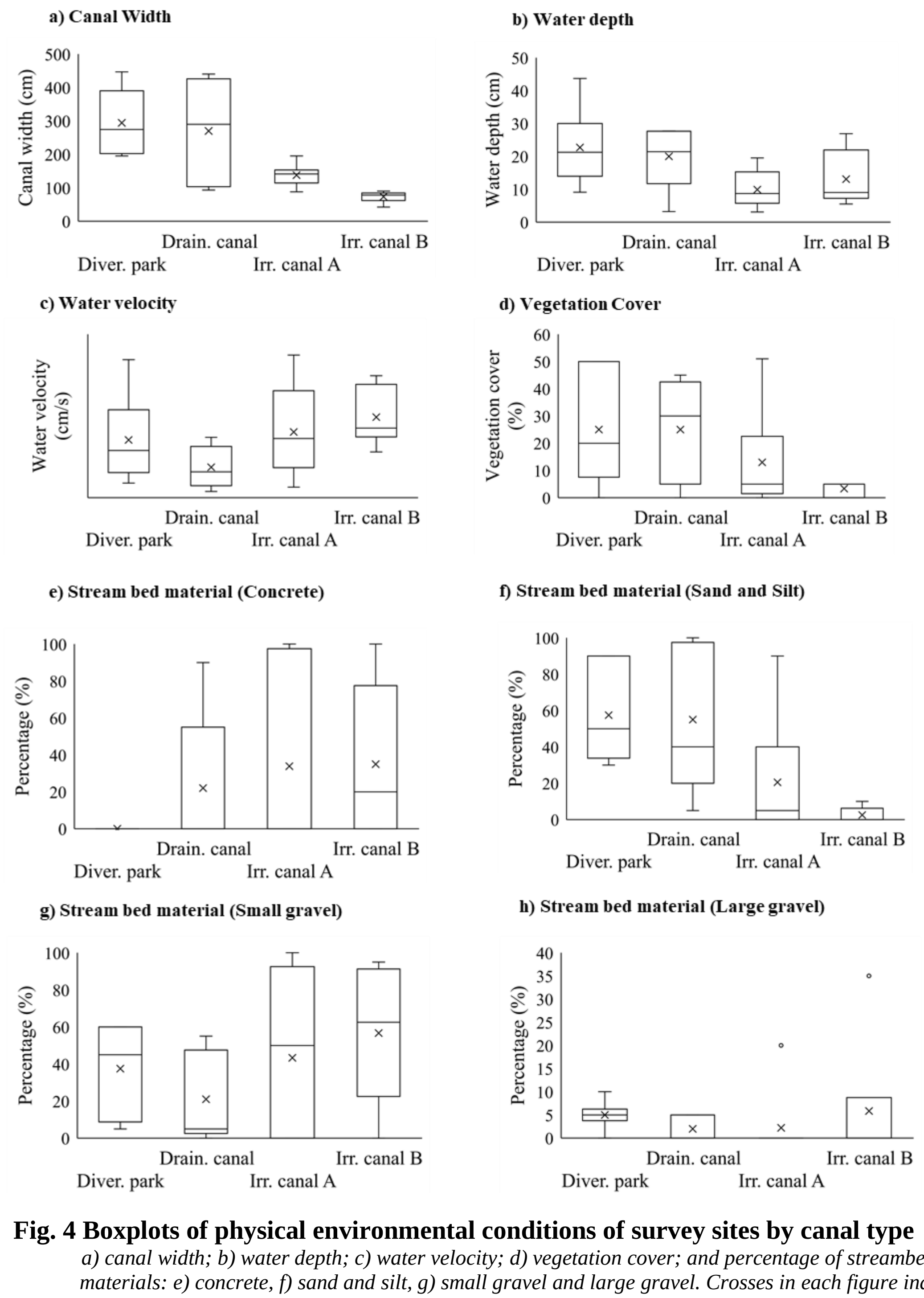


Fig. 4 Boxplots of physical environmental conditions of survey sites by canal type

a) canal width; b) water depth; c) water velocity; d) vegetation cover; and percentage of streambed materials: e) concrete, f) sand and silt, g) small gravel and large gravel. Crosses in each figure indicate the average value.

The goodness-of-fit of the model in this study was higher than that of the previous study (0.71, Watabe et al., 2018), which supports that the EPFH applies to waterway networks containing different canal types such as size, structure, and role for irrigation. On the other hand, though the goodness-of-fit of the model for crustaceans was not low, the correlation with Shannon-Wiener's diversity index was weak. Thus, the model score as an indicator of habitat quality might be useful for habitat evaluation for this taxon.

Table 1 Results of biological survey (fish and crustaceans)

Taxon	Species	Number of individuals	Observed sites		Standard length
			Number	Ratio (%)	Mean ± S.D. (cm)
Fish	*Nipponocypris sieboldii*	351	12	46.2	5.8 ± 2.7
	Rhynchocypris lagowskii steindachneri	22	5	19.2	4.7 ± 1.8
	Oryzias sp.	59	3	11.5	2.5 ± 0.6
	Rhinogobius sp.	153	10	38.5	3.5 ± 0.7
	Cobitis sp. BIWAE type B	1	1	3.8	7.0 ± 0.0
	Odontobutis obscura	3	3	11.5	3.1 ± 1.1
	Opsariichthys platypus	22	3	11.5	5.9 ± 2.1
	Plecoglossus altivelis	24	7	26.9	11.8 ± 1.3
	Misgurnus anguillicaudatus	14	4	15.4	8.0 ± 0.7
	Nipponocypris temminckii	3	2	7.7	7.8 ± 2.3
	Rhynchocypris oxycephalus jouyi	1	1	3.8	4.7 ± 0.0
	Pseudogobio esocinus	3	1	3.8	9.3 ± 1.5
	Tribolodon hakonensis	1	1	3.8	9.7 ± 0.0
Crustaceans	*Geothelphusa dehaani*	211	15	57.7	1.5 ± 0.6
	Procambarus clarkii	163	10	38.5	5.8 ± 2.2
	Paratya compressa	3,630	21	80.8	2.0 ± 0.4
	Palaemon paucidens	35	7	26.9	4.3 ± 0.4

Table 2 Fitness of the EPFH model (fish and crustaceans)

	Goodness of fit of the model *F* calculated by EPFH	Correlation coefficient of the model and Shannon-Wiener's diversity index *H'*
Fish	0.80	0.63**
Crustaceans	0.74	0.37

*Significant difference is indicated by *p < 0.05, **p < 0.01, and ***p < 0.001, if detected*

2) Environmental factors identified by the EPFH model

Based on the EPFH model for fish, five factors were identified as effective factors on fish habitat: water depth, water velocity, land width, vegetation cover, and percentage of sand in the streambed material (Table 3). Four of the factors, except land width, had a positive effect on habitat. Thus, the results indicated that good fish habitat had the following characteristics: (1) deeper water depth; (2) higher water velocity; (3) narrower land width; (4) higher vegetation cover; and (5) a greater proportion of small gravel in the streambed material.

As effective environmental factors on crustacean habitat identified by the EPFH model, five factors were identified: water depth, water velocity, land width, vegetation cover, and percentage of concrete in the streambed material. Among these factors, only vegetation cover had a positive effect on crustacean habitat, while the other four factors had negative effects. Thus, the results indicated that good crustacean habitat had the following characteristics: (1) shallower water depth; (2) lower water velocity; (3) narrower land width; (4) higher vegetation cover, and (5) a smaller proportion of concrete in the streambed material.

Table 3 Environmental factors and coefficients comprising the fish habitat model

	Water depth	Water velocity	Land width	Vegetation cover	Streambed material (small gravel)
Coefficients	0.034	0.021	-0.018	0.014	0.02

Table 4 Environmental factors and coefficients comprising the crustacean habitat model

	Water depth	Water velocity	Land width	Vegetation cover	Streambed material (concrete)
Coefficients	-0.046	-0.049	-0.005	0.022	-0.015

3) Habitat score estimated by the model and its comparison by canal type

Figure 5 shows the habitat score for fish and crustaceans of each survey site, which was calculated by the model. The score ranges from 1 to 5, with higher scores indicating better habitat at that site. The site with a score of 5 for fish habitat was only No. 2 (Diversion Park), and the sites that scored 5 for crustacean habitat were No. 1 (Diversion Park) and No. 13 (Irrigation Canal A).

To examine differences in habitat quality among channel types, the mean habitat scores and the mean Shannon-Wiener's diversity index *H'* are compared. Comparing the habitat scores, the diversion park was the highest (3.3 score), followed by the drainage canal (3.0 score), irrigation canal A (1.9 score), and irrigation canal B (1.7 score) in order of highest to lowest (Table 5). As a result of the Kruskal-Wallis's test, significant differences were detected for the fish score ($p < 0.01$), while no significant differences were detected for crustaceans ($p = 0.075$). Multiple comparisons for fish model scores suggested the scores significantly differ between the diversion park and irrigation canal A ($p = 0.029$, < 0.05, Table 6) and between the diversion park and irrigation canal B ($p = 0.012$, $<$ 0.05, Table 6). The drainage canal was not significantly different from irrigation canals A and B, although the mean habitat score was high.

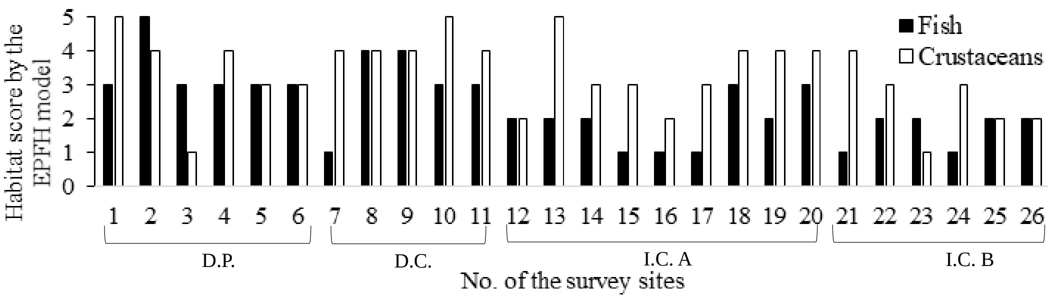


Fig. 5 Habitat score for fish and crustaceans at each survey site

D.P. indicates Diversion Park, D.C. indicates Drainage Canal, I.C.A indicates Irrigation Canal A, and I.C.B indicates Irrigation Canal B.

Table 5 Habitat score and Shannon Weiner's diversity index *H'* by canal type

Canal type	Fish		Crustaceans	
	Habitat score (Mean ± S.D.)	*H* (Mean ± S.D.)′	Habitat score (Mean ± S.D.)	*H′* (Mean ± S.D.)
Diversion park	3.3 ± 0.8	1.2 ± 0.9	3.5 ± 1.4	0.8 ± 0.5
Drainage canal	3.0 ± 1.2	1.0 ± 0.6	3.8 ± 0.4	0.4 ± 0.4
Irrigation canal A	1.9 ± 0.8	0.3 ± 0.5	3.2 ± 1.0	0.3 ± 0.3
Irrigation canal B	1.7 ± 0.5	0.3 ± 0.6	2.7 ± 1.0	0.2 ± 0.5

Table 6 Results of multiple comparisons using the Steel-Dwass method to fish habitat score

Combination of comparison			*t*-value	*p*-value
Drainage canal	vs	Diversion park	0	1
Drainage canal	vs	Irrigation canal A	1.796	0.275
Drainage canal	vs	Irrigation canal B	1.896	0.230
Diversion park	vs	Irrigation canal A	2.772	0.029
Diversion park	vs	Irrigation canal B	3.052	0.012
Irrigation canal A	vs	Irrigation canal B	0.523	0.954

The canals in the diversion park have the highest discharge among canal types. These canals are located upstream of the irrigation system and thus carry water before being diverted to canals A and B. Thus, the conservation practice would benefit from ensuring such habitat property. In addition, the environmental improvements in the canals of the diversion parks created habitat structure as follows: the canal width was widened; gravel was laid on the canal ed; the slope of the revetment was made gentler; and emergent plants were planted. Such habitat modification might support to conservation of functional habitat characteristics for fish such as higher vegetation cover (Nishida et al., 2011) and coverage of natural material on canal beds (Katano et al., 2003) among factors of fish habitat characteristics. The average habitat score (and Shannon-Wiener index) of the diversion park was higher than drainage canal, although the difference was not significant. Those environmental modifications for recreation, such as gravel beds against concrete lying, may positively affect such higher habitat value. However, the higher scores in drainage canals might not be negligible because of their greater canal width, water depth, and vegetation cover**.**

On the other hand, high scores of crustaceans were found in shallow canals, though we did not conduct a detailed analysis per canal type because of the unconfident model score. Further, their distribution was tended to different from fish. Thus, branched irrigation canals might have habitat value for crustaceans, and considering the effects of preservation of those canals as open canal and their availability for recreational use has remained a future challenge of this study.

CONCLUSION

The canals in diversion parks developed by environmental improvement had higher habitat value for fish. This habitat is characterized by the following conditions: (1) deeper water depth, (2) higher water velocity, (3) greater vegetation cover, and (4) a higher proportion of gravel in the canal bed material. Among these variables, canal bed materials in diversion parks were different from drainage canals, though both canals have higher discharge in an agricultural waterway network (i.e. higher availability for fish). Irrigation canals are generally modified into pipelines with the current modernization of irrigation systems. Our result suggested that conserving and improving the environment of irrigation canals for recreation, particularly in water diversion canals, benefits ensuring higher value of fish habitat. Therefore, our findings demonstrated a way to evaluate the multi-functionality of agricultural waterways from the aspect of recreational use and habitat conservation as green infrastructure.

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Research article

Temperature Sensitivity (Q_{10}) of Organic Carbon in Red-yellow Soils and Its Conservation Strategies

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Abstract Soil respiration (SR) is the second largest flux of carbon in most terrestrial ecosystems after photosynthesis. Research indicates that a slight change in climate conditions induces a variation of the SR that could be equal to the release of CO_2 by fossil fuel emissions. For this reason, it is important to study what conditions control the variation of SR. Soil temperature is an important predictor of SR when there is no severe drought stress. The estimation of SR rates by the effect of temperature has been expressed with the Q_{10} relationship. This study aims to determine the Temperature Sensitivity (Q_{10}) coefficient of the red-yellow soil organic carbon and estimate its conservation strategy using biochar. To analyze temperature sensitivity, each treatment was kept under 25ºC and 35ºC for 150 days, and the soil respiration ratio (SRR) as well as soil organic carbon (SOC) content were measured by the spectrophotometry method. Lastly, a treatment of biochar at 5% was added as a carbon conservation mechanism. The experimental results showed a significant difference in SOC content between different temperature conditions. After 150 days under treatment, 35ºC treatment had a significant reduction of SOC in contrast with 25ºC treatment (3.65 and 6.02 mg C/g respectively). The addition of biochar resulted in higher values of SOC at the same temperature, relative to non-biochar treatments. The Q_{10} value was higher in soil without biochar (1.82), while the addition of biochar reduces the coefficient to 1.12. The SRR was reduced gradually with higher values at 35ºC, however, the biochar reduced the emission at 25ºC lower than other treatments. The results indicated that the Q_{10} value of red-yellow soil can be affected by the addition of biochar, which works as a carbon source to maintain and increase SOC content and reduce the release of CO_2 in the short term.

Keywords soil organic carbon, soil respiration rate, temperature sensitive, biochar

INTRODUCTION

The soil organic carbon is part of the organic matter in more than 50% of the content. This fulfills an important role in plant feeding, stabilization of soil structure, soil fertility, and most important, climate change effects mitigation. The soil carbon is dynamic by the interaction of the ecosystem; however, human activity impacts can destabilize SOC into either a net of carbon or a source of greenhouse gases (GHG) in the atmosphere (Trivedi et al., 2018).

The alteration of climate has a considerable effect on the SOC stocks, although it is variable depending on the type of soil and location, Changes in temperature lead to an increase in extreme drought events, followed by the loss of carbon in the soil. Efforts towards a better understanding of the SOC dynamic have indeed been made, however, the mechanism of stabilization and conservation of SOC stocks are still complicated to apply and understand. Further research must focus on the variation of soil and temperature, as well as conservation strategies (Pribyl, 2010).

According to De Oliveira Marques et al. (2017), the Red-yellow soil (Udults soil taxonomy), mainly located in the Amazon area, represents an important amount of global soil carbon, making this area vulnerable to deforestation activities and land uses.

The conservation of carbon stocks in the Amazon area has had an impact on the political decision of governments to act on reforesting rather than permitting deforestation. However, deforestation has been accelerated and the fragmentation process of the Amazon area is resulting in significant changes in carbon stock, as well as biomass soil (Barros and Fearnside, 2016).

Lloyd and Taylor (1994) remarked that the increase of microorganism activity in soil is stimulated by the increase in temperature, leading to an augment of microbial CO_2. This process reduces the SOC, which contributes to the global warming problem. In a short period (one year), the increase in temperature results in a considerable change in microbial activity and decomposition rate.

It has been demonstrated that the decomposition of SOC is higher as the temperature increases, with the biggest proportional increase observed at low temperatures. Are important issue is to estimate in detail to what extent the rising temperature could destabilize SOC and make it available for the decomposition process. The proportion of SOC stored in the world's soils is still argued and it is vulnerable to the impacts of warming of this century (Crowther et al., 2016).

In this study, we model approaches of changes in carbon availability by microbial activity that are needed to have a better understanding of the Red-yellow soil carbon. The Amazon area has an ecological function connected with the SOC, respiration rate, decomposition of organic matter, and estimation of conservation strategies that must be investigated.

OBJECTIVE

This study aims to determine the Temperature Sensitivity (Q_{10}) coefficient of the Red-yellow soil organic carbon, under different conditions of temperature (25 and 35ºC) and estimate its conservation strategy using biochar. The present research provides a new mechanism of climate change mitigation and a better understanding of soil and biochar.

METHODOLOGY

Soil Sample Source and Preparation

The current investigation involved sampling and analyzing three different sites of Red-yellow soil to measure parameters such as SOC and SRR. The sites were selected from Miyako Island, which is located in Okinawa Prefecture, south of Japan. The soil sample was collected from a non-disturbed forested area with four repetitions at each site (Carter and Gregorich, 2008). 1000g of soil was sampled, after that, air-dried soil was sieved and weighed into a labeled tray followed by adding 5% (w/w) of biochar as a biochar treatment and 0% of biochar for control. Samples were kept at approximate field capacity moisture conditions. Each treatment was divided into soil at ambient conditions (25ºC) and warm conditions (35ºC), and biochar rate (0% and 5%).

Soil Organic Carbon Determination

Each one of the treatments and repetitions was analyzed by the spectrophotometric procedure of organic carbon contents of soil (Wallinga et al., 1992). 50 mg (±0.5 mg) of soil was weighed and it was transferred carefully to a dry 100 mL volumetric flask. 10.0 mL of 0.333 M potassium dichromate solution ($K_2Cr_2O_7$) was added to each flask. 16.0 mL of concentrated sulfuric acid was added followed by putting the flasks in a boiling water bath for 45". The samples were cooled in the sink and made up to the volume with distilled water. The samples were centrifuged for 10" at 1000 g force.

For the preparation of the standard series, 100 mL flasks containing 1000 mg sodium oxalate with volumes of 0, 25.0, 50.0, 75.0 and 100.0 mL were used as standard into the volumetric flask. These standard series worked as 0, 5, 10, 15, and 20 mmol Cr^{+3} per liter of solution of standard series.

The absorbance of spectrophotometer Beam 4 nm was measured in a 1 cm cuvette at a wavelength of 590 nm within 2 hours after oxidation. SOC percentages were calculated by multiplying the Cr^{+3} concentrations found by 0.2250/w, where "w" is the weight of the air-dry soil sampled.

Soil Respiration Rate Determination

10 g of air-dried soil was weighed from each treatment into a 450 mL glass bottle followed by adding 3 mL of distilled water. The soil and water were mixed in the bottles and then covered with perforated films to reduce evaporation. The SRR was determined by using the infrared gas analyzer IR400 at time zero and measured again at the end of 1-h incubation (Sparda et al., 2016). The soil respiration rate (SRR, μL CO_2/h/g air-dried soil) was calculated using Eq. (1),

$$SRR = \left(CO_{2f} - CO_{2i}\right) * V * \frac{1000}{S} \quad (1)$$

where CO_{2i} and CO_{2f} are the initial and final CO_2 concentrations (ppm) of the 1-h incubation, respectively, and V is the space volume of the bottle with the soil sample (450 mL). The number of soil (S) was 10.0 g. Four repetitions were measured for each one of the treatments.

Temperature Sensitivity (Q_{10})

The temperature response of SR was estimated through a Q10 function using Eq. (2),

$$Q_{10} = \left(\frac{C_{i35ºC} - C_{f35ºC}}{C_{i25ºC} - C_{f25ºC}}\right)^{\frac{10}{TR-TW}} \quad (2)$$

where Q_{10}, the dependent variable, is the temperature sensitivity of SOC (carbon fluctuation coefficient at one temperature over the flux of a temperature 10º higher), *Ci* and *Cf* are the initial and final carbon respectively (at 25ºC and 35ºC), and finally, TR is the temperature at the regular condition and TW is the warmer temperature of soil (Meyer, et al., 2018).

Statistical Analysis

The comparison of the average of each one of the treatments was analyzed using the Shapiro-Wilk Normality and Levene Homogeneity test. The one-way ANOVA tests were performed to determine if there were differences through variance analysis. Then, the Tukey test was applied to determine the differences between treatments. In addition, a Box-Cox transformation was performed to fit the ANOVA test. All the tests were performed using RStudio (version 1.2.5042) for statistical analyses of the data. Analyses were performed at the significant level of $p \leq 0.05$.

RESULTS AND DISCUSSION

The fluctuation of SOC in a period of 150 days at different treatments of temperature and biochar is shown in Fig. 1. The SOC started at similar conditions, with a value of around 10 mg/g in all treatments. However, values of SOC were decreasing gradually for different rates. Firstly, the result of soil at 25ºC vs. 35ºC with no biochar (Fig. 1a) showed a significant effect of the temperature in the loss of carbon. At day 150, the 35ºC was 3.65 mg/g, considerably lower than 25ºC soil with 6.02 mg/g ($p<0.05$). This difference was described by McTiernan et al. (2003), where the decomposition rate of carbon components increased as temperature rose and was faster in tropical systems.

The addition of biochar kept the carbon content slightly constant. This is shown in Fig. 1b, where the values of treatments started at just over 10 mg/g and decreased just above 7 mg/g. The addition of biochar can increase the SOC (Singh et al., 2012) with the carbonized biomass having a slower decomposition process than fresh plant residues that are kept in the soil for longer periods depending on the amendment type, type of soil, soil conditions and plants, values even in warm conditions kept constant most of the experiment time. Figure. 1c compares treatments in ambient conditions (25ºC) for 150 days. As expected, the reduction of soil carbon was lower than treatment at warmer conditions, moreover, the addition of biochar increased values of soil carbon by 1 mg/g.

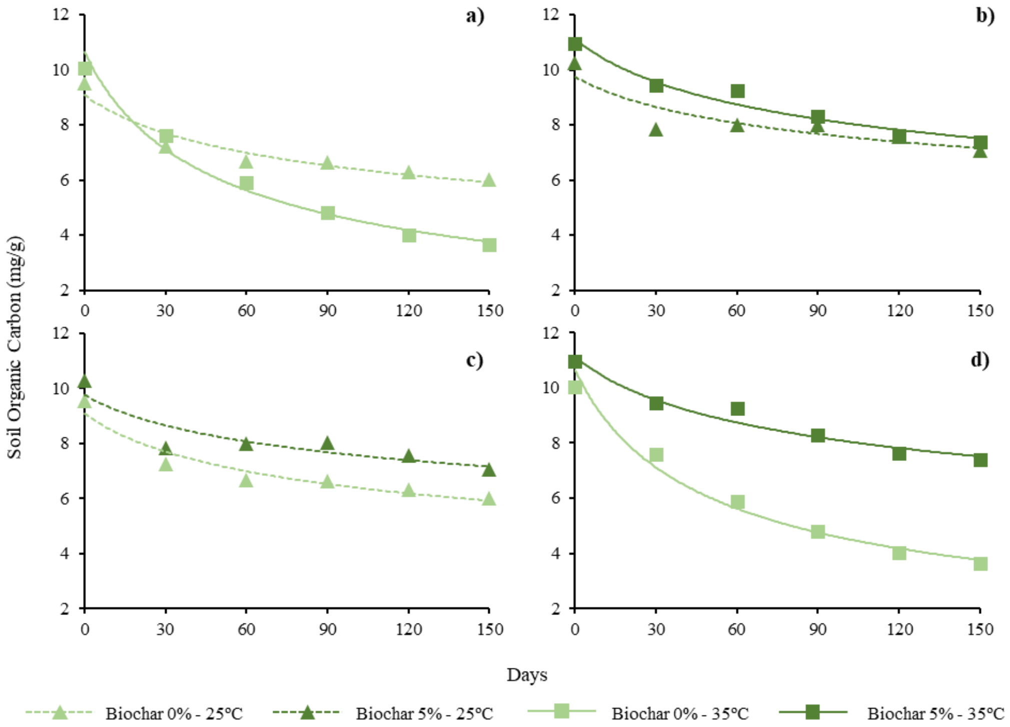

Fig. 1 Soil organic carbon decomposition in 150 days in different conditions
a) no biochar addition at 25ºC vs 35ºC; b) biochar addition at 25ºC vs 35ºC
c) 25ºC with biochar vs no biochar; and d) 35ºC with biochar vs no biochar.

The most remarkable outcome was the contrast of treatments at higher temperatures. Figure 1d provides information about the effect of temperature in soil with biochar addition. As with the previous experiment, values of SOC started above 10 mg/g, followed by a considerable reduction after 150 days. The 0% biochar sample drastically reduces the SOC amount from 10.05 mg/g at day 0 to 3.65 mg/g at day 150. This reduction is explained clearly in different experiences regarding carbon and organic matter degradation by the effect of temperature (Xu et al., 2019).

On the other hand, the addition of biochar showed a significant difference in the rate of degradation and soil organic carbon amount. This value started just below 11 mg/g (10.97 mg/g at day 0) and decreased gradually to 7.39 mg/g at day 150. This value represents more than double the 0% biochar sample at day 150. The action of biochar seems to have several features that preserve and increase the organic carbon amount in the soil. According to Zimmerman et al. (2011), the high surface area and porosity of biochar can increase the nutrient retention capacity of soil and improve the stability of SOC, as well as increase little inputs with higher C: N that will favor the growth and protection of SOC stocks. Nevertheless, Zimmerman reports the enhanced mineralization of existing soil carbon in response to biochar addition as found in the soil respiration rate (Fig. 2).

The action of biochar protects the original soil's organic carbon by reducing carbon emissions. This protection is mainly caused by the variety of aryl functional structures that are derived from aromatic rings (Atkinson et al., 2010). These two main features make the biochar recalcitrant and stable. First, the structure and porosity that physically avoid leaching and enzymatic breakdown of organic material and the chemical structure of biochar that relates to the type of biochar and temperature of production (Kasozi et al., 2010). In this case, the O/C ratio is the essential feature of the recalcitrance, which keeps the soil organic carbon at a higher level.

The soil respiration showed different rates per month. It can be seen in Fig. 2a that the effect of temperature was slightly higher at the beginning of the experiment, yet there were no significant differences at day 150. Values started over 8 µL CO_2/h/g and decreased just over 2 µL CO_2/h/g. The addition of biochar had a different effect on SRR, showing a higher release of CO_2 at 35ºC. In the last three months of the analysis, there was a significant effect between the biochar application and no application (Fig. 2b).

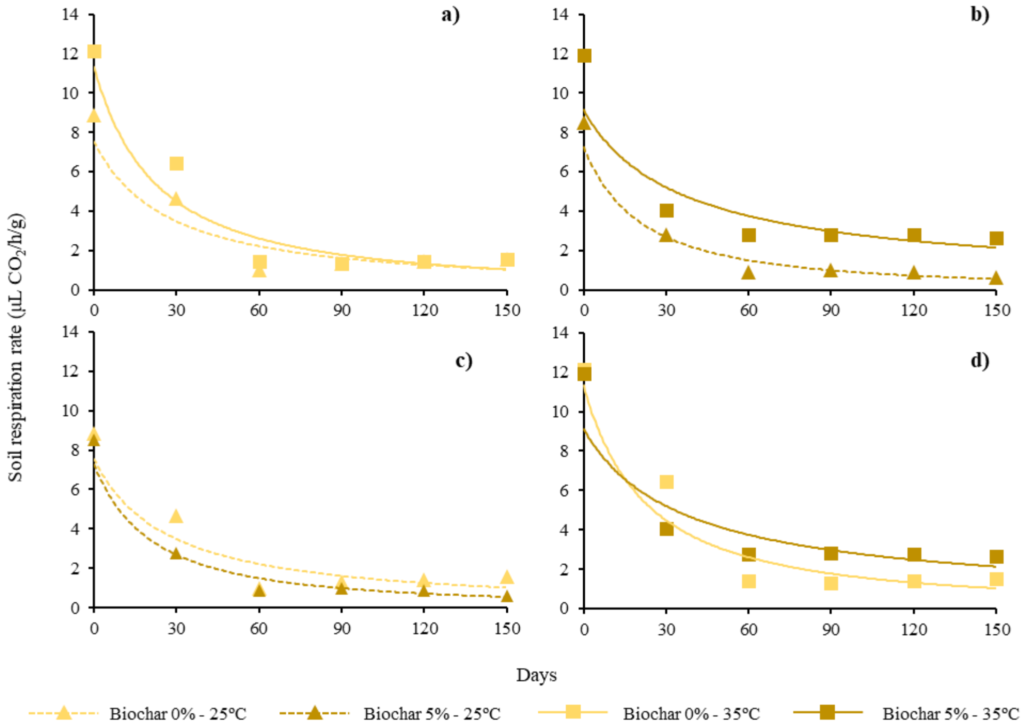

Fig. 2 Soil respiration rate in 150 days in different conditions

a) no biochar addition at 25ºC vs 35ºC; b) biochar addition at 25ºC vs 35ºC
c) 25ºC with biochar vs no biochar; and d) 35ºC with biochar vs no biochar

At ambient conditions (25ºC), the SRR did not show significant changes to the effect of biochar. Values kept constant, starting just over 8 µL CO_2/h/g and dropping just below 2 µL CO_2/h/g as shown in Fig. 2c. On the other hand, Fig. 2d shows the increase of SRR with the addition of biochar in the last period of analysis. By the addition of biochar, values started around 12 µL CO_2/h/g and dropped to 4 and 2 µL CO_2/h/g at 35ºC and 25ºC respectively. The increase in temperature in soil reflects a significant change in microbial activity in the short term. The addition of biochar in soil has affected the SOC amount but the effect on SRR does not show a stabilization in the short-term, as this depends on temperature and microbial activity (Xu et al., 2019). Additionally, Xu et al. (2019) describe the activation and stabilization of carbonized material over a longer period (more than one year), which increases the amount of soil carbon and reduction of CO_2 emission.

Finally, the temperature sensitivity (Q_{10}) described as a coefficient of the effect of temperature in soil organic carbon showed a positive effect of the biochar action. As described in Eqs. (3) and (4), the values of initial SOC were 9.53 and 10.05 mg/g for treatment without biochar and with biochar respectively at 25ºC and 10.97 and 10.27 mg/g for treatment without and with biochar respectively at 35ºC. After 150 days, final values are 3.65 and 6.02 mg/g for treatment without biochar, and 7.39 and 7.07 mg/g when biochar is applied.

$$Q_{10} = \left(\frac{C_{i35ºC} - C_{f35ºC}}{C_{i25ºC} - C_{f25ºC}}\right)^{\frac{10}{TR-TW}} = \left(\frac{10.05-3.65}{9.53-6.02}\right)^{\frac{10}{35-25}} = 1.82 \tag{3}$$

$$Q_{10} = \left(\frac{C_{i35ºC} - C_{f35ºC}}{C_{i25ºC} - C_{f25ºC}}\right)^{\frac{10}{TR-TW}} = \left(\frac{10.97-7.39}{10.27-7.07}\right)^{\frac{10}{35-25}} = 1.12 \quad (4)$$

The outcome of Eq. (3) provides information on the coefficient value of Red-Yellow soil organic carbon with no addition of biochar. This coefficient (1.82) represents a higher dependency of SOC and microbial activity by the effect of temperature. In contrast, the Eq. (4), the addition of biochar reduced this coefficient to 1.12, which represents a reduction of this dependency and an increase in resilient carbon amount. According to Yang Liu and Zhang (2017), the rate of Q_{10} reaction value increases in a certain degree of temperature dependence, thus, the more temperature-dependent the SOC, the higher the value will be Q_{10}.

CONCLUSIONS

It is demonstrated that Red-Yellow soil is highly affected by the effect of temperature, and it can be reduced significantly and so, degraded the soil. Although this type of soil has low organic carbon content, this reduction can be covered by biochar. This black material fulfills a role as a carbon source to maintain and increase SOC content. Connected to this, the addition of biochar not only affects the carbon content but increases the amount of recalcitrant carbon in the soil over longer periods. Due to the high content of Aryl Groups and higher O/C rate, the recalcitrant carbon reduces the mineralization and the degradation of carbon, this allows a higher concentration of SOC even in warm conditions of temperature. It seems to be that biochar works as an important conservation strategy by reducing temperature sensitivity (Q_{10}). Although studies over a longer period must be considered, this outcome represents an alternative for Red-yellow soil in climate change impact and conservation of carbon in the soil.

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Research article

National versus Local Climatic Variability and Implications for Communities in Protected Areas: The Case of Lake Malawi National Park

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Abstract Understanding the rainfall dynamics of a nation/region is key to decision-making, especially regarding agriculture within protected areas. This study focused on the area of Cape Maclear and the adjacent villages located within the Lake Malawi National Park (LMNP). By gaining insight into how communities whose agricultural activities interact with protected areas operate, we can gain insight into the long-term sustainability of the LMNP. This study aimed to assess the historical rainfall dynamics for Cape Maclear using 35-year annual rainfall and temperature data. Rainfall trends were established and compared with recorded events. The results indicated that Cape Maclear rainfall trends resonate with reported national drought events, though with variations. This provides a proxy possibility of making localized predictions of such events. Analysis of the return period shows annual rainfall of between 500-900 mm occurs every 2-3 years, indicating no significant shifts from what has been observed in the past. Due to the sensitivity and fragility of the LMNP ecosystem, there is a need to design local solutions for the communities living within the park to enable them to better prepare for future climatic shocks, especially rainfall inadequacies.

Keywords climate, community, drought, rainfall, protected area

INTRODUCTION

Protected areas face several challenges, and one emerging challenge is climate change. Global climatic change is receiving a lot of attention due to the diverse impacts currently felt and being projected. Besides broader climatic variabilities, local scale events have been observed. Ngongondo et al. (2021) assessed drought and floods in Malawi and found variations in the frequency and intensity of these events across all districts in Malawi, indicating that their occurrence is not nationally homogenous. It is predicted that climate change will lead to an altered frequency, intensity, and duration of localized climatic shocks such as droughts and temperature extremes (Chen et al., 2018), with diverse impacts. For communities living in protected areas, whose alternative livelihoods are sought from protected natural resources, such climatic shocks will impact ecosystems. Ecosystems impacts vary in their extent, however for communities embedded within protected areas, such impacts could be particularly pronounced for both people and the protected area itself. The existence of agriculture within protected areas is illegal in most countries (Tranquilli et al., 2014). For Lake Malawi National Park, however, there are settlements inside the National Park. This is because, at its founding in 1981, a presidential directive stopped the eviction of any persons that were already living in the park. The two key livelihood activities within the National Park are agriculture and harvesting of non-timber forest products (NTFP). Agriculture is thought of as a threat to park diversity due to people-nature conflicts that result as communities extract livelihoods from protected areas. These conflicts include deforestation for fuel needs, especially in tropical Africa (Wade et al., 2020), population growth leads to agricultural expansion at the expense of parkland (Sardjo et al., 2022; Joppa et al., 2009), agricultural inputs that negatively impact on diversity within protected areas, and other direct human-animal conflicts (Mohan, et al., 2020) due to proximity of existence. For the sustainability of agriculture within protected areas, there is a need for agriculture production approaches that minimally impact protected area diversity. In Italy, organic agriculture is a dominant agricultural practice within protected areas (Grandis and Triantafyllidis, 2010). The decision regarding what kind of agricultural practice to enact depends, to some large extent on the understanding of the climatic atmosphere of a given locality. In a predicted changing climate, and for protected areas supporting agriculture, an understanding of local climate dynamics is thus key in innovating ways to mitigate the impacts. Lake Malawi National Park provides fuelwood that is sold for income alongside other non-timber forest products that support livelihoods. For communities existing within protected areas, the need for fertile agricultural land can also lead to Park incursions. Such incursions could lead to park-community conflicts.

The Lake Malawi National Park (LMNP) was established in 1980 (Abbot and Mace, 1999) as the only protected area in Malawi with human settlements within its legal boundaries. A government order at the outset, stipulated that there should be no relocation of communities already living within the park. This scenario poses unique conservation and sustainability challenges. Key challenges include overexploitation of fisheries (Sato et al., 2008), deforestation, and climate change (Markham, 2018). Over time, agriculture is emerging as a challenge in part due to the growing human population that requires more land for food production. These challenges pose a threat to the biodiversity of LMNP.

OBJECTIVE

Climatic shocks such as droughts and their associated rainfall variability, could lead to additional direct and indirect impacts on the protected area. An understanding of historical climatic events could partially enable some preparedness. However, since the occurrence of such shocks is not nationally homogenous, this study sought to assess local rainfall dynamics in the LMNP within the national context. Specifically, this study sought to qualitatively assess how national drought events compare with localized rainfall trends. Secondly, to determine local rainfall dynamics during four known drought years in Malawi and LMNP, and finally to assess how rainfall during drought shocks relates to impact crop productivity, i.e., the onset of the growing season and overall crop water requirements.

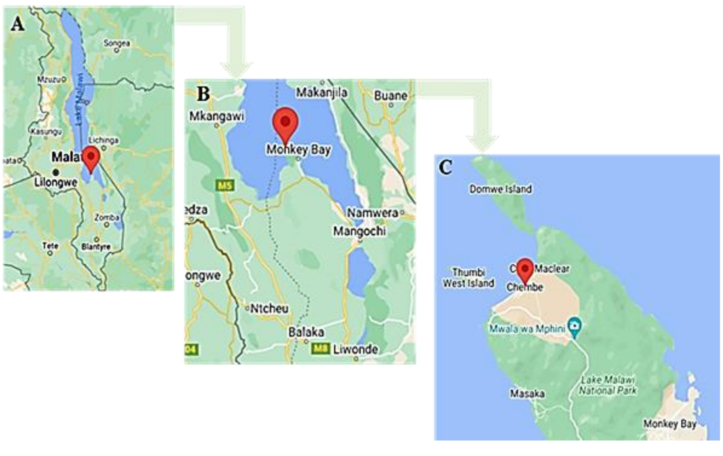

Fig. 1 The study site indicated in map of Malawi

(A) showing the relative position of the larger Chembe village community; Mangochi, (B) showing the wider Monkey Bay area and Chembe village community (within Cape Maclear), (C) and the surrounding Lake Malawi National Park

METHODOLOGY

The study area comprises five enclaved villages within LMNP; 14° 02'S by 34° 53'E (Fig. 1). The park is also a world heritage site. The climate is tropical with annual temperature ranging between 19.6 ºC to 21.4 ºC minimum and between 29 ºC to 30.7 ºC, maximum. Average annual rainfall ranges between 600 mm to 1600 mm with pronounced variations between seasons. This study used historical daily rainfall data for a period of 35 years (1st January 1979 to 31st December 2015) collected from the Department of Climate Change and Meteorological Services for Monkey Bay weather station, which is the closest to the study site. The rainfall dynamics of interest were documented drought and flooding events of 1985-1986; 1988-1989; 1991-1992; 1994-1995; 2001-2002; 2005-2006; and 2012-2013. This paper utilized the MarkSim DSSAT Weather Generator to obtain maps and a Microsoft Excel spreadsheet for computation and graphics.

RESULTS AND DISCUSSION

Reported and Local Rainfall Comparison

The study site generally showed reduced annual rainfall amounts in all the years with nationally reported drought and flooding events (Fig. 2); five droughts and 2 floods. During the 35 years, rainfall is observed to have been extremely variable with no clear trend in direction as indicated by the weak coefficient of determination (r^2 =0.003) as shown in Fig. 2. Overall, the data shows more drought than flooding. It can be noted however that annual rainfall values of above 1,200 mm and below 600 mm are associated with flooding and drought respectively. After 2015, Malawi experienced two serious flooding events; first, the 2015 La Niña driven flooding and the 2019 flooding caused by cyclone Idai (Ngongondo et al., 2021) mostly affecting the southern region of the country.

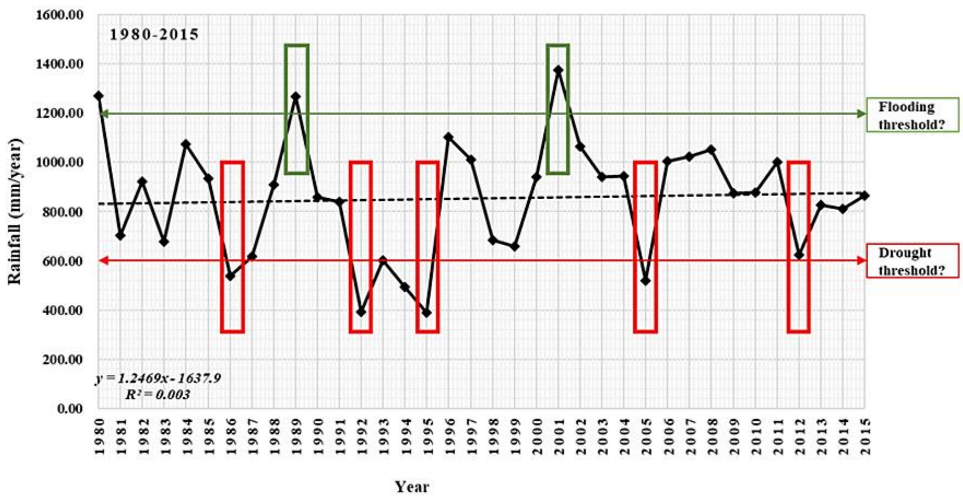

Fig. 2 Documented drought (Red) and flooding (Green) seasons/years between 1980 and 2015 in Malawi and LMNP

Regarding the prediction of localized climatic shocks from national data, this work provides some positive indications. The national drought records are in sync with local scale data (in terms of decreasing trends). This observation thus provides opportunities for the formulation of informed presumptions regarding possible future climatic shocks for climate modeling studies. While this is the case, the extent of such shocks, and associated adaptations, should be determined and understood in a local context.

Rainfall Dynamics

To assess the rainfall dynamics during these drought events, the overall distribution of rainfall was assessed (Fig. 3). The amounts of rainfall and its duration during the crop growing season in Malawi (October to April) were compared with an 1880-81 season as a reference.

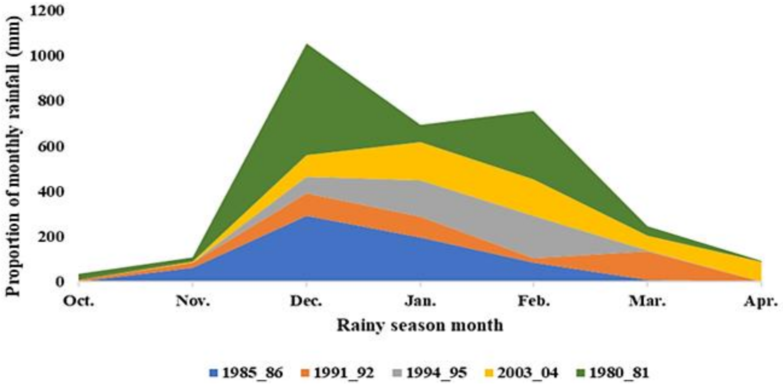

Fig. 3 Relative rainfall amounts across the six months growing season for four seasons
Including reference (Green); showing various skewness of precipitation amounts across the growing season

During the 1985-86 drought, adequate rainfall was available around December after which it steadily declined. In the 1991-92 season, inadequate rainfall was recorded early in the season and adequate rainfall amount fell after February when no cropping could be done. 1994-95 had less rainfall except only during January and February. For the 2003-04 season, there were some consistent medium rainfall amounts throughout the rainy season irrespective of the national drought.

Crop Productivity

First, the general requisite conditions for the onset of the growing season (GS) and the broader rainfall amount that support crop productivity were assessed. Fiwa et al. (2014) refer to the onset of GS as when 25 mm of rainfall is experienced in the first 10-day period from a given rainfall event, and at least some additional 20 mm within the next 20 days after the onset of GS. Based on Fiwas' determination, seasons 1991-92 and 2003-04 for the study site had adequate conditions for planting. However, Allen et al. (1998) consider an annual rainfall range of 500-700 mm as a minimum requirement for crop productivity in the case of maize. Maize has been chosen as an example as it is a staple crop for the country. From this criterion, the study site had adequate rainfall for two drought years/seasons (1985-86 and 2003-04).

Table 1 Cape Maclear rainfall dynamics during nationally reported drought events
The year/season 1980-81 is included as a reference. RE= Rainfall event; GS= growing season, and REF means reference (season)

Season	First rainfall event (amount; mm)	The onset of the growing season (Rainfall 1st 10 days) (mm)	Intervening RE (mm)	RE after the 10th day of GS onset (mm)	Annual precipitation (mm)
1985_86	10 Oct (0.1)	6 Nov (50.5)	0 (-)	6 RE (10.7)	538.8
1991_92	13 Oct (8.1)	10 Dec (76.3)	6 RE (25.8)	5 RE (21.1)	391.6
1994_95	15 Oct (0.9)	3 Dec (46.4)	0 (-)	1 RE (3.1)	388.6
200304	18 Nov (0.1)	12 Dec (71.6)	4 RE (6.9)	5 RE (20.4)	520.5
(REF)-1980_81	1 Oct (5.3)	30 Nov (185.0)	2 RE (26.4)	4 RE (42.8)	704.3

The season 1991-92 had satisfied requirements for the onset of the growing season but the annual rainfall was way below the minimum required to support crop production. The apparent discrepancy between the two crop-growing requirements necessitates that they be considered concurrently in determining optimal conditions for agricultural productivity. Another key observation during the four seasons is a lack of adequate rainfall during one or both key months of crop growth (Fig. 3). Issues of spatiotemporal rainfall distribution within the growing season are thus key in deciding what crops to grow.

Rainfall Return Period

An analysis of the return period shows that the highly expected annual rainfall ranges are between 500-900 mm/y during every 2-3 years. The Return period of 1000 mm/y of annual rainfall indicates 4 years in Fig. 4. From the analysis (and without absolutism), rainfall events above 1000mm (normally observed to be associated with floods) can be predicted to occur at least every 4-5 years. In a broader sense, the area is not particularly wet. From an agricultural perspective, it is prudent for farming communities to invest in crops with moderate to low water requirements.

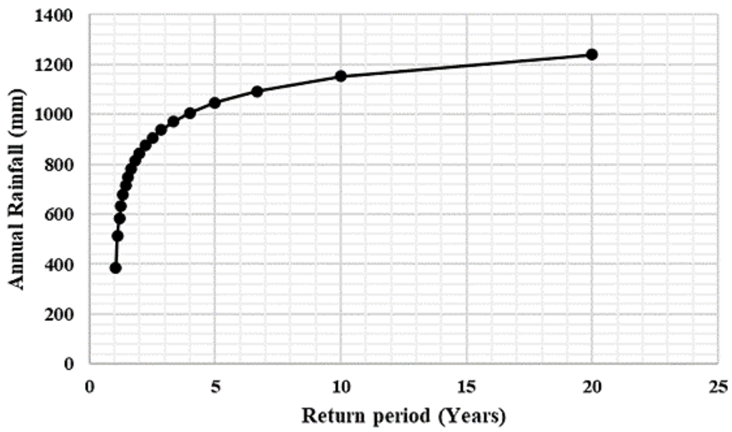

Fig. 4 Rainfall return period for Cape Maclear, Lake Malawi National Park

Implications for Park Enclave Communities

The current global climate change predictions point to an increase in the frequency of drought and flooding shocks (Zhao et al., 2020). Drought events limit crop productivity as moisture is a key determinant for plant growth. For rural communities, it entails a lack of income from Agri-based labor, general food insufficiency, and social instability. These pressures inadvertently lead to the use of other ecosystem services (specifically forests), leading to incursions into protected parkland. The desperate harvesting and overuse of NTFP and parkland incursions lead to the depreciation of protected forest resources. Ultimately, the park's long-term sustainability will be compromised. Conservation of agricultural approaches is one way to adapt to rainfall variability and droughts. Vegetables for example, due to their higher water demand than other crops (Manuel et al., 2017), might benefit from mulching technology or utilizing seasonal riverbanks with residual moisture. With the prevailing global change, climate-smart agriculture approaches must be promoted to ensure the sustainable utilization of resources from the National Park.

CONCLUSION

Understanding localized climate dynamics is key as it enables concerned stakeholders to make appropriate decisions during shock events. The rainfall trends for Cape Maclear resonate with national ones for drought years reported for Malawi. The association observed between national rainfall dynamics and those local to Cape Maclear signal the potential of using projected national future climatic events at a local level; especially where stochastic approaches are utilized. Such projection would ensure preparedness for various shocks, ensuring the preservation of the fragile protected area. Rainfall dynamics during drought years generally indicate amounts acceptable for crop production but with uneven seasonal distributions. These seasonal distributions are hard to predict, but the production of early maturing crops could be a good safety net. Overall, there exist differences in rainfall spread, amounts, and the onset of growing seasons. The main limitation of the study has been a focus on rainfall only and a lack of verification of the observed climate dynamics and actual productivity assessments. Future studies should focus on other climate variables such as temperature and how associated impacts on agricultural production.

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International Society of Environmental and Rural Development

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Recently, in developing countries, subsistence agriculture is being converted to export-oriented mono-culture, and the amounts of agricultural chemicals applied to the farmland are increasing every year. The applied chemicals in farmland cause serious environmental problems downstream such as eutrophication, unusual growth of aquatic plants, decrease in dissolved oxygen and accumulation of bottom mud in water resources. Also, there seem to be many cases in which people apply agricultural chemicals without understanding its impact to health and food safety. Therefore, it is necessary to promote and enhance understanding of sustainable rural development among local stakeholders including farmers.

Sustainable rural development aims to meet human needs while preserving the natural environment. As it should cover not only social and economic development but also natural environment conservation, no single organization can achieve sufficiently the aspirations of sustainable rural development. Collaboration among international, governmental and non-governmental organizations, together with the academe and scientific sector, is indispensable.

The knowledge and intelligence accumulated in universities and research institutions are also expected to make the programs facilitated by the international, governmental and non-governmental organizations more adequately implemented and meaningful to societal development. However, these cases especially those implemented locally have been scattered without having been summarized well or recorded in annals academic or scientific societies.

So, the International Society of Environmental and Rural Development founded in 2010, aims to discuss and develop suitable and effective processes or strategies on sustainable rural development focusing on agricultural and environmental aspects in developing countries. The ultimate goals of the society are to contribute to sustainable rural development through social and economic development in harmony with the natural environment, and to support the potential or capacity building of local institutions and stakeholders in the rural area with academic background.

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