Current status of paddy field agriculture and efficient water use in existing reservoirs for fish aquaculture in a semi-mountainous village in Vientiane Province, Laos

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Abstract

Rice is a staple food in Laos; its production has increased eightfold over the last fifty years. In hilly and mountainous areas, rainy season lowland rice is cultivated in a valley between mountains with undeveloped irrigation facilities. The area used for agricultural production is limited during the dry season due to water shortages, and most lowland fields are used as grazing land. We conducted a survey to examine the status of lowland rice production in a semi-mountainous village in Vientiane Province, then evaluated the feasibility of increasing rice yield and introducing dry season crop production using water stored in existing reservoirs for fish aquaculture. During the rainy season, low rice grain yield was observed in the fields where water shortages early in the season had delayed transplanting. In the dry season, supplemental irrigation is essential for soybean production. We determined the water requirements for preparatory irrigation for early transplanting in rainy season and for supplemental irrigation through the field experiments. An irrigation plan was formulated utilizing 8,700 m^3 of water stored in six reservoirs in the surveyed area. The potential area of the preparatory irrigation for lowland rice in the rainy season and the supplemental irrigation for soybean cultivation in the dry season using reservoir water were 10.4-11.0 ha and 3.2-3.5 ha, respectively. By irrigating with water stored in existing reservoirs, the income of the entire surveyed area is expected to increase by 80 million kip.

Introduction

Rice is a staple food in the Lao People's Democratic Republic (hereinafter referred to as Laos). The net rice production, which was 0.54 million tons in 1961, had increased to 4.15 million tons by 2016 (Food and Agriculture Organization (FAO) 2018). However, the level of rice-based self-sufficiency varies among provinces. (World Food Program (WFP) 2007). In addition to variations in rice productivity at the national level, there are discrepancies at local levels (e.g., district and village levels) as well, and 18.5% of the total Laos population was undernourished in 2014 - 2016 (FAO 2015).

Rainy season lowland rice comprises 78.3% (755,243 ha) of the total rice cultivation area (Ministry of Agriculture and Forestry, Laos (MAF) 2016). In hilly and mountainous areas, rainy season lowland rice is cultivated in low-lying zones between mountains (Anzai et al. 2019a). The differences in rice productivity are caused by farming techniques, water accessibility, planting environment, and other factors (Ikeura et al. 2016). To increase rice production in each village's low-productivity fields, the factors influencing yield reduction must be examined and necessary measures, such as irrigation and fertilization, should be considered.

Dry season lowland rice comprises 10.3% (99,018 ha) of the rainy season lowland rice area (MAF 2016). Although some paddy fields are used for dry season cropping after the rainy season rice harvest, the area is limited by water shortage; remaining fields are used mainly as grazing land for livestock during the dry season. The area equipped with irrigation facilities is only 13% of the total agricultural land (FAO 2015). Although irrigation facilities have not been enough developed, farmers have small reservoirs for fish aquaculture (Anzai et al. 2017). Supplemental irrigation using water resources stored in existing aquaculture reservoirs may be considered to extend dry season cropping.

The objectives of our study are 1) to elucidate the factors driving reduced lowland rice yield that is occurring in a semi-mountainous village, 2) to evaluate the potential for dry season cropping and water requirements for supplemental irrigation, 3) to evaluate the the volume of water available for irrigation in existing aquaculture reservoirs, and 4) to design an irrigation plan using reservoir water. This paper summarizes our results.

Materials and Methods

Field description

Field surveys were conducted in the Nameuang Village, Feuang District, Vientiane Province, Laos, which is 88 km northwest of the Vientiane Capital (Fig. 1). Paddy fields are distributed in the lowland (lowland fields: 81 ha) and mountainous areas (12 ha). This study investigated the lowland fields (Ikeura et al. 2016).

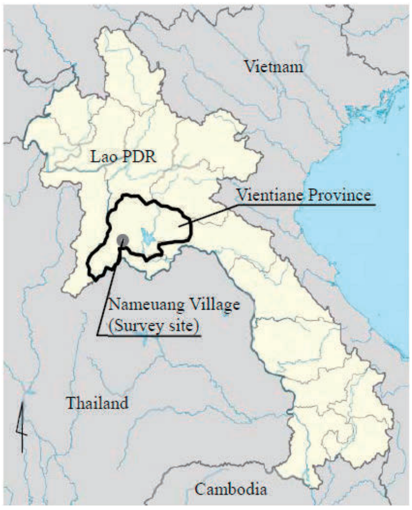

Fig. 1. Location of survey site
This figure was modified to reference Ikeura et al. (2016) and http://www.freemapviewer.com.

Field survey on water conditions and farming activities for rainy season rice planting

Fig. 2 shows the study site in Nameuang Village. Field surveys were carried out in Areas A, B, and C in River Basins A and B from June 9 to August 11, 2013. Total number of fields is 55 in the basins. Surface water depth and farming activities such as nursery establishment, plowing, puddling, transplanting or direct seeding were recorded weekly for each field. To evaluate water conditions during the rice-growing period, automatic water level gauges were installed in 6 fields. Sampling quadrats (1 m × 1 m) were installed in 47 field blocks in Areas A, B, and C in September 2013. Three large field blocks were divided into two parts, with three quadrats installed in each. At maturity, rice samples were harvested from each quadrat; grain weight and moisture content were measured after drying, threshing, and winnowing. To examine the effect of soil fertility on grain yield, soil samples were collected from the upper 10 cm of soil in each quadrat at the end of September 2013, just before flowering. Total nitrogen and available phosphorus were measured for the collected soil samples (Ikeura et al. 2016).

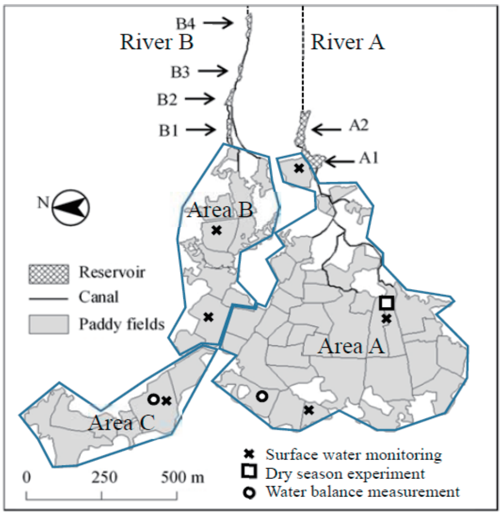

Fig. 2. Surveyed fields and reservoirs
This figure was drawn to reference Ikeura et al. (2016), Ikeura et al. (2017) and Anzai et al. (2019a).

Field experiments for dry season cropping

Rainfed (Exp. 1, December 2013 to March 2014) and irrigated (Exp. 2, December 2014 to March 2015) cropping experiments were conducted in the field shown in Fig. 2 (Ikeura et al. 2017). Soybean, maize, mung bean and upland rice were planted in Exp. 1, and soybean and maize were planted in Exp. 2. Of the 4 test crops, only soybean was grown until harvesting, and its yield and root system were measured. Groundwater depth, soil moisture content, soil moisture potential, and meteorological data were also measured. Finally, the soybean water requirements and irrigation timings were determined based on the data obtained from water balance analysis (Ikeura et al. 2017) and the evapotranspiration rate calculated by Penman-Monteith Equation (Allen et al. 1998).

Reservoir capacity surveys

To evaluate the capacity of the existing reservoirs, 2 reservoirs on River A and 4 reservoirs on River B (shown in Fig. 2) were surveyed. These 6 reservoirs, which were owned by 5 farmers, were constructed for fish aquaculture, and water overflows from the reservoirs flow into the paddy fields located downstream. Although the stored water is not used for paddy field irrigation, it is pumped out (drainage operation) at the end of each April to harvest fish. Cross section measurements were used to calculate the reservoir capacity (Anzai et al. 2017).

Irrigation planning for rainy season rice and dry season cropping

The objectives of the irrigation plan using existing reservoirs are 1) to irrigate paddy fields with low rice yield during the rainy season, and 2) to provide irrigation for dry season cropping using the remaining water. We analyzed possible water withdrawal from 6 reservoirs located on Rivers A and B (shown in Fig. 2) for Cases 1 to 4. The water balance of each reservoir, aquaculture cultivation period, minimum water level for fish survival, and timing of the drainage operation were considered (Anzai et al. 2019a).

(Case 1) Year-round fish cultivation without drainage operation.

(Case 2) Fish cultivation with drainage operation conducted on 1 April.

(Case 3) Fish cultivation with drainage operation conducted at the same time as final irrigation for dry season cropping.

(Case 4) No fish cultivation, all water can be used for irrigation.

In cases with irrigation operations, a minimum water level of 50 cm was maintained except in Case 4. Meteorological and hydrological data measured from July 2014 to June 2015 were used for water balance analysis. To estimate the water requirements prior to transplanting, soil moisture sensors and automatic water level gauges were installed into 2 of the lower fields (shown in Fig. 2). Soybean was selected as the target crop, and water requirement obtained from dry season cropping tests was applied to the irrigation plan. The water application efficiency of furrow irrigation (0.7: Ali 2011) as well as conveyance losses measured during both the rainy and dry seasons, were considered. The potential irrigation area for the rainy and dry seasons was calculated based on possible water withdrawal. Finally, we calculated the potential benefits of the proposed irrigation plan (Anzai et al. 2019a).

Results and Discussion

Water conditions and farming activities for rainy season rice planting

Water from Rivers A and B flowed into the upper fields located in Areas A and B, respectively, then flowed downward in each area. Water was supplied to Area C from the lowest fields of Areas A and B; in other words, Area C was received water from both Rivers A and B. Fig. 3 shows the surface water depth and farming practices for each field. Rainy season rice is transplanted from early July to mid-August. Although transplanting was taking place in the upper and middle parts of the lowland area, there was still no water by mid-July, and even plowing had not begun in the lower fields. In such fields, transplanting started from the beginning of August (Ikeura et al. 2016). The results of surface water monitoring for 6 fields located in the upper, middle and lower positions indicated that no serious water shortage was expected in the entire lowland field areas after the 2013 transplant. As shown in Fig. 4, the fields with greater than 4.0 t ha^{-1} (400 g m^{-2}) yields were mainly located in the upper and middle areas. In contrast, the fields with less than 2.0 t ha^{-1} yields were located in the lower areas (Ikeura et al. 2016). No correlations were found between rice grain yield and total nitrogen (R^2=0.004) or available phosphorus (R^2=0.08) (Ikeura et al. 2016).

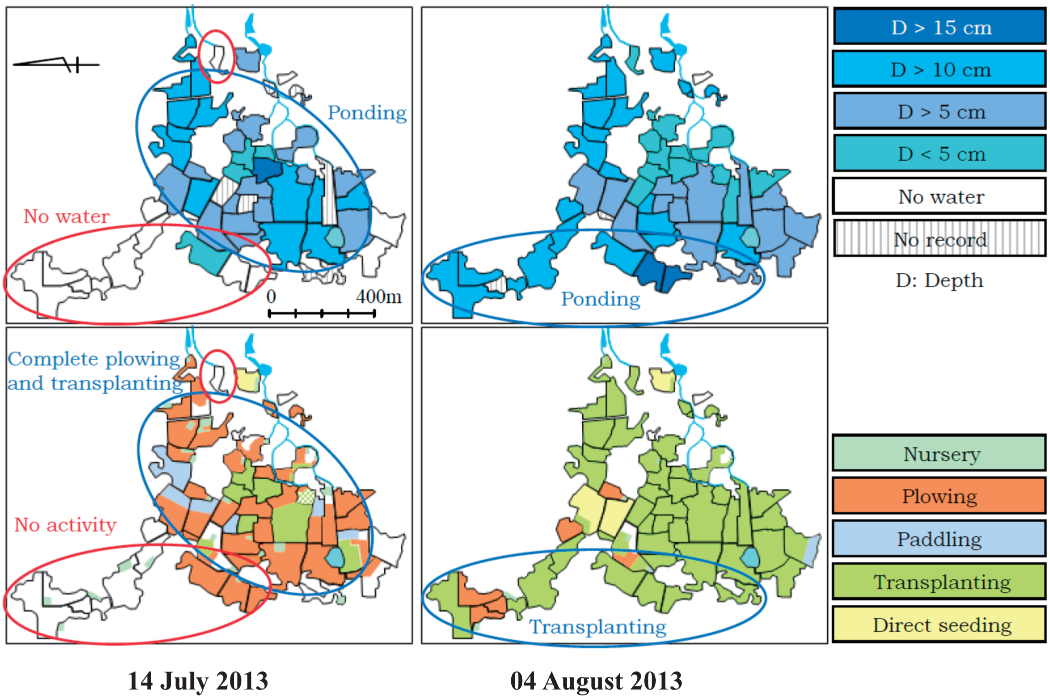

Fig. 3. Surface water depth (upper) and practiced farming activities (lower) in each field
This figure was modified to reference Ikeura et al. (2016).

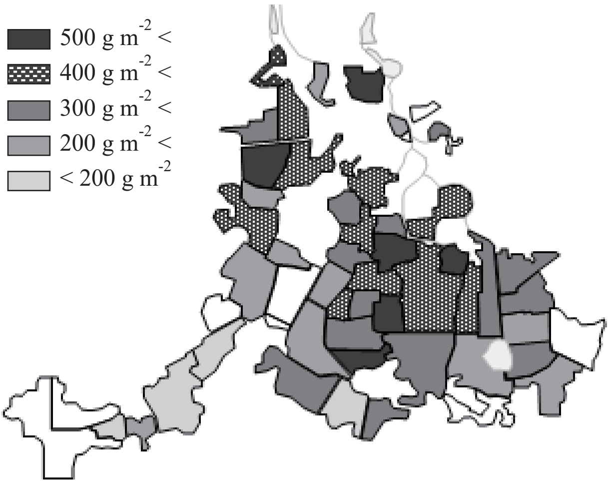

Fig. 4. Grain yield in each field
Grain yield with 14% of moisture content
Ikeura et al. (2016).

Table 1 shows the relationship between grain yield and the start times for ponding and transplanting in 137 plots. The grain yield was significantly higher in fields with early ponding (before July 20) and early transplanting (before July 28) than in fields with late ponding (after July 21) and late transplanting (after July 29) (Ikeura et al. 2016). The results suggest that late transplanting due to water shortage resulted in reduced yields in the lower fields of the plot-to-plot irrigated area. To increase grain yield in the lower fields, transplanting should be completed by mid-July, and preparatory irrigation is needed to accelerate water supply to the lower fields (Ikeura et al. 2016).

Table 1. Relationship between grain yield and starting times of ponding, transplanting

Classification		N*	Avg. grain yield (t ha^{-1})	Note
Start time of ponding	Before Jul 20	108	3.87 [a]	Significant difference between a and b at $p < 0.05$ according to t test
	After Jul 21	29	2.22 [b]	
Start time of transplanting	Before Jul 14	28	4.20 [a]	Significant difference between a and b at $p < 0.05$ according Tukey-HSD test
	Jul 15 –Jul 28	64	3.68 [a]	
	Jul 29 – Aug 11	45	2.88 [b]	

This table was modified to reference Ikeura et al. (2016)

* The 13 samples (4 plots harvested by farmers before sampling and 9 plots in direct seeding field) were excluded from the analysis (n = 137).

Dry season cropping potential and water requirements

Soil moisture content at the surface layer (0 – 20 cm depth) was 0.45 cm^3cm^{-3} at the beginning of rainfed cropping experiment (Exp. 1) and decreased to 0.34 cm^3cm^{-3} within 3 weeks, almost depletion of moisture content for optimum growth. The soil moisture became saturation after rain and decreased again to 0.33 cm^3cm^{-3} within three weeks. These results suggest that drought stress occurred after three weeks without rain or irrigation. Based on the results of changing soil moisture and soil moisture retention characteristics, we determined the water requirement for irrigated cropping experiment (Exp. 2), shown in Table 2. Before sowing began in Exp. 2, 17.6 mm of available moisture still remained in the surface layer; therefore 16 mm of water was supplied for the first irrigation. The third irrigation was skipped, because the field had been saturated by rainfall prior to the determined irrigation time (Ikeura et al. 2017).

Table 2. Water requirement and supplied water for soybean in Exp. 2

Irrigation	Date	Water requirement (mm)	Supplied water (mm)	Evapotranspiration (mm)*1
Remaining available moisture		—	17.6	—
1st	01 Dec 2014	33.6	12.8	38.3
	06 Dec 2014		3.2	
2nd	27 Dec 2014	50.4	51.2	52.5
3rd	17 Jan 2015	50.4	—*2	76.0
4th	11 Feb 2015	82.2	78.4	52.4
Total		216.6	163.2	219.2

This table was modified to reference Ikeura et al. (2017).

*1: Evapotranspiration was calculated by Penman-Monteith Equation using climate data observed in the period of Exp. 2.

*2: Third irrigation was not practiced because the field was saturated by rainfall before irrigation.

Table 3 shows the rooting ratio, dry matter weight and yield for soybean. Rooting ratio means the ratio of survived plant before harvesting. The soybean rooting ratio was 64% under rainfed conditions and 85% under irrigated conditions; rainfed conditions had a lower rooting ratio because of water shortage during the initial growth stage (Ikeura et al. 2017). Dry matter weight and yield under irrigated conditions (Exp.2) increased up to 4.5 and 7 times, respectively, compared with rainfed conditions (Exp. 1). Although the yield increased with irrigation, the yield was still 1/5 of the national average (1.4 t ha^{-1}: FAO 2017).

Table 3. Rooting ratio, dry matter weight and yield of soybean

	Rooting ratio	Dry matter weight (t ha^{-1})	Yield (t ha^{-1})
Exp. 1 (rainfed)	0.637	0.201	0.0404
Exp. 2 (irrigated)	0.854	0.894	0.285

This table was modified to reference Ikeura et al. (2017).

Fig. 5 shows precipitation, irrigation, and changes in soil suction during the planting period. Soil moisture in the surface layer decreased mainly at the beginning stage, while at the 30 cm depth it decreased 3 weeks after sowing. Although the soil moisture increased following irrigation, field capacity (-63 cm H_2O) did not effectively recover. Increased groundwater levels were observed after irrigation, suggesting that part of the irrigation water flowed into cracks caused by soil shrinkage and got through the root zone. This caused water shortage and lower soybean yields than the national average (Ikeura et al. 2017).

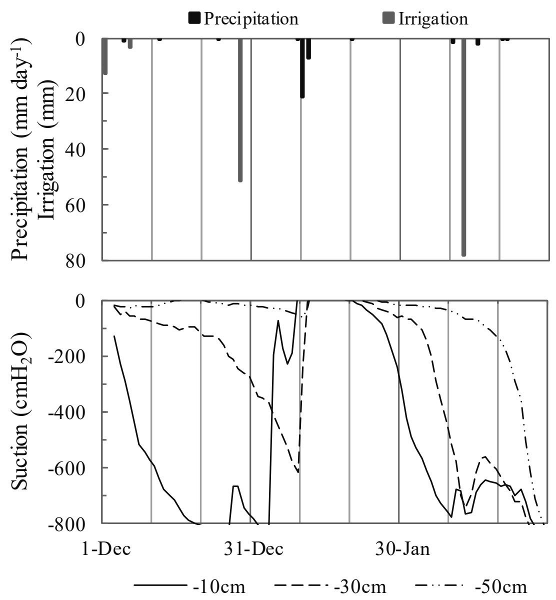

Fig. 5. Precipitation, irrigation and change in suction of field soil in soybean planting period.
This figure was modified to reference Ikeura et al. (2017).

From the experimental results, we concluded that: 1) irrigation is essential for dry season cropping, 2) the total water requirement estimated by the soil moisture balance mostly agrees with evapotranspiration calculated from meteorological data, and 3) soil cracks caused loss of infiltration and decreased soybean yield; infiltration loss must be considered for irrigation planning.

Capacity of existing aquaculture reservoir

The reservoirs had earth-type dykes 1.2 to 2.5 m high. Water outlets at the upper part of the dikes were opened, and water-controlling gates were not installed all reservoirs. Overflow occurred naturally when the water level was higher than the bottom level of the water outlets; an engine pump or syphon were required to take stored water below the outlet level (Anzai et al. 2017). Table 4 shows the reservoir storage capacities, which were obtained using cross section measurements. The maximum and minimum volumes were 2,441 m^3 in A2 and 368 m^3 in B3. The total volumes of Rivers A and B were 4,361 m^3 and 4,352 m^3, respectively; a total of 8,700 m^3 of stored water remained due to structural issues with the reservoir outlet (Anzai et al. 2017).

Table 4. Storage capacity of reservoirs

River	Reservoir	Water surface area (m^2)	Storage capacity (m^3)	
			Each reservoir	Each river
River A	A1	2,633	1,920	4,361
	A2	3,085	2,441	
River B	B1	1,363	1,271	4,352
	B2	1,294	765	
	B3	698	368	
	B4	1,902	1,945	

This table was modified to reference Anzai et al. (2017).

Potential water withdrawal and irrigation area

Preparatory irrigation for rainy season rice (PIR) and supplemental irrigation for soybean cultivation in the dry season (SID) were planned based on the rainy season rice planting survey results and the dry season cropping experiments. Fig. 6 shows the PIR target fields; the fields were selected based on two conditions; (1) less than 3.0 t ha^{-1} grain yield and (2) transplanting was not practiced at the end of July, when it was completed for a large proportion of the upper and middle parts of lowland rice fields. The target field areas were 7.8 ha and 6.3 ha in River basins A and B, respectively (Anzai et al. 2019a). PIR was planned from July 1-15, and water requirements were determined as 57.5 mm and 32.9 mm in the target fields in the River Basins A and B, respectively, based on water balance observed in two fields (Anzai et al. 2019a). Based on dry season experiments, the soybean cultivation period was planned for the three months from December to February. Four SID times were planned, as

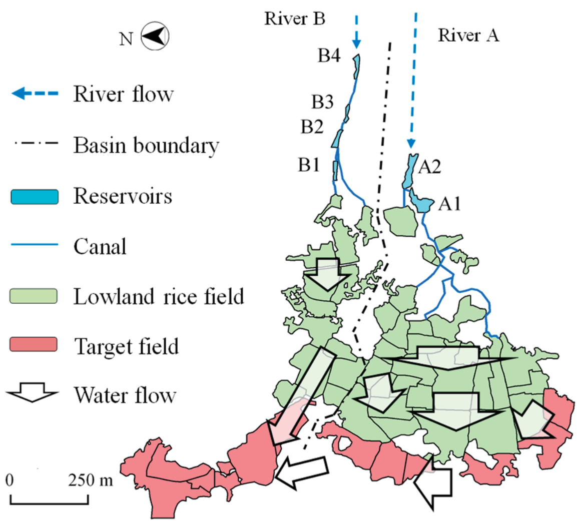

Fig. 6. Target fields of preparatory irrigation
This figure was modified to reference Anzai et al. (2019a) and Anzai et al. (2019b).

follows. First: 38.3 mm on December 1 at the time of sowing; second: 52.5 mm on December 28, four weeks after sowing; third: 76.0 mm on January 18, three weeks after the second; and fourth: 52.4 mm on 11 February, three weeks after the third. For the first irrigation event, the remaining soil moisture at sowing time was considered 17.6 mm (Ikeura et al. 2017; Anzai et al. 2019a). A reservoir water management was formulated as shown in Fig. **7** (Anzai et al. 2019a; Anzai et al. 2019b).

Table 5 shows possible water withdrawal for PIR (PW_{PIR}) and for SID (W_{SID}). In Rivers A and B, the PW_{PIR} was the same for Cases 1–3 because the stored water volume at the beginning of PIR was equal to net inflow in the PIR period. In Case 4, PW_{PIR} increased because all of the stored water could be used for PIR. For River A, W_{SID} was also same for Cases 1–3. W_{SID} was higher in Case 4 than in Cases 1–3 because the maintenance volume was zero at the third irrigation time, when the water requirement was highest. In River B, W_{SID} was same for Cases 1, 2 and 4. In Case 3, W_{SID} in Case 3 was the largest of all cases, because all of the stored water was used at the final irrigation time (Anzai et al. 2019a).

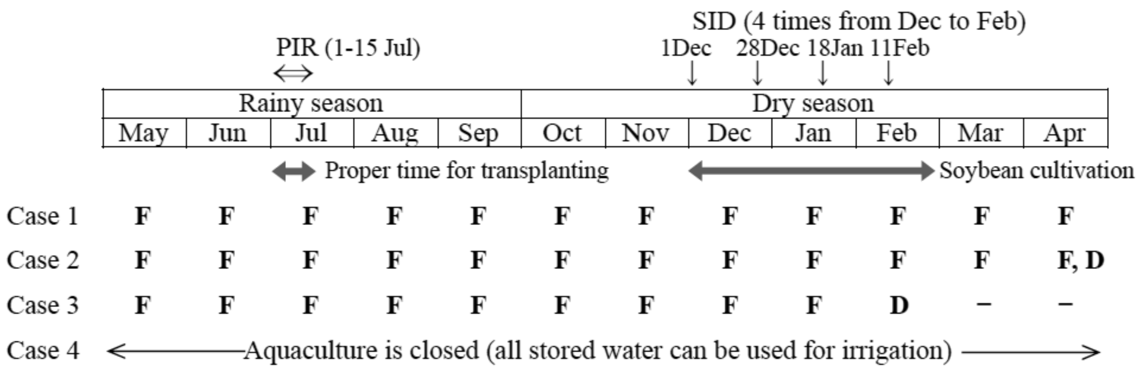

Fig. 7. Water management utilizing the reservoirs constructed for aquaculture
F: fish growing month, D: drainage operation for harvesting fish, ⇔: period PIR, ↓: time of SID.
The figure was drawn to reference Anzai et al. (2019a) and Anzai et al. (2019b).

Table 5. Water withdrawal for PIR and SID.

Case	Possible water withdrawal for PIR (m^3)		Water withdrawal for SID (m^3)*	
	River basin A	River basin B	River basin A	River basin B
1	13,235	9,331	29,379	3,614
2	13,235	9,331	29,379	3,614
3	13,235	9,331	29,379	4,306
4	15,004	11,424	34,072	3,614

* Water withdrawal for SID is the total amount of first to fourth irrigations.
This table was modified to reference Anzai et al. (2019a).

Table 6. Potential area of PIR and SID

Case	Potential area for PIR (ha)				Potential area for SID (ha)	
	River basin A		River basin B		River basin A	River Basin B
	Potential area	Deficit*	Potential area	Deficit*		
1	4.10	3.70	8.61	-2.31	2.10	1.07
2	4.10	3.70	8.61	-2.31	2.10	1.07
3	4.10	3.70	8.61	-2.31	2.10	1.27
4	4.65	3.15	10.54	-4.24	2.44	1.07

This table was modified to reference Anzai et al. (2019a).
* Deficit is the difference of potential area to the area of target fields. When it shows minus, the potential area covered target area, and surplus water remained.

Table 7. Preliminary calculation of benefit obtained by PIR and SID

Case	Potential irrigation area*1 (ha)		Rice production		Soybean	Benefits from irrigation (1,000 Kip)		
			Grain yield*2 ($t\ ha^{-1}$)	Increment in product (t)	product (t)	Total income	Compensation for feeding and loss of income [f]	Net income
	PIR [a]	SID [b]		$c = a\times(3.9\text{-}2.2)$	$d = b\times1.4^{*3}$	$e = c\times2{,}500KIP\ kg^{-1} + d\times8{,}000KIP\ kg^{-1}$ *4		e - f
Current	No irrigation		2.2	0	0	—	—	0
Case 1	10.40	3.17	3.9	17.68	4.44	79,704	0	79,704
Case 2	10.40	3.17	3.9	17.68	4.44	79,704	0	79,704
Case 3	10.40	3.37	3.9	17.68	4.72	81,944	720*5	81,224
Case 4	10.95	3.52	3.9	18.62	4.92	85,850	6,108*6	79,742

This table was modified to reference Anzai et al. (2019a) and Anzai et al. (2019b).

*1: Potential irrigation area is summation of potential areas of River Basins A and B. In the case of PIR of River Basin B, potential area overs target area; therefore target area is used for calculation of total potential irrigation area in two river basins.

*2: As referred to Ikeura et al. (2016), the grain yield of rainy season rice increases from 2.2 $t\ ha^{-1}$ to 3.9 $t\ ha^{-1}$ due to on-time transplanting trough PIR.

*3: The average yield of soybean due to SID is assumed to be 1.4 $t\ ha^{-1}$ (FAO 2017).

*4: The grain rice price was the selling price from farmer to trader obtained by interview survey in Nameuang Village in 2015 (Anzai et al. 2019b), and soybean price was the selling price from farmer to the local market in Khammouane Province in 2015 (Ikeura et al. 2017).

*5: In Case 3, reservoir owners are compensated with feeding fees.

*6: In Case 4, gross income from aquaculture is paid to reservoir owners as “loss of income compensation”.

Table 6 shows potential areas for PIR (A_{PIR}) and SID (A_{SID}). A_{PIR} was calculated as 4.1 ha (Cases 1–3) and 4.7 ha (Case 4) in River basin A, and 8.6 ha (Cases 1–3) and 10.5 ha (Case 4) in River basin B. A_{PIR} did not cover the entire target field area in River basin A, however, it covered all the target field area (6.3 ha), with a surplus area of 2.3–4.2 ha in River basin B (Anzai et al. 2019a). PIR enabled on-time transplanting for about 75% of target fields (14.1 ha) (Table 7) (Anzai et al. 2019b). A_{SID} was calculated as 2.1 ha (Cases 1–3) and 2.4 ha (Case 4) in River basin A, and 1.1 ha (Cases 1, 2, and 4) and 1.3 ha (Case 3) in River basin B (Table 6) (Anzai et al. 2019a). The total A_{SID} of the two river basins were 3.17, 3.17, 3.37, and 3.52 ha for Cases 1, 2, 3 and 4, respectively (Table 7).

To calculate the benefits of irrigation, income from the increased rice and soybean yields from irrigation and aquaculture were considered, as were aquaculture expenditures such as feed costs, compensation paid for losses caused by a shortened fish cultivation period in Case 3, and compensation costs for closing aquaculture in Case 4. The results showed expected revenue growth in all Cases (Table 7). It is desirable to maintain aquaculture (Cases 1, 2 and 3) to secure animal protein resources (Anzai et al. 2019b).

Conclusion

We conducted a survey about the current state of rice production in lowland fields located in a semi-mountainous village in Vientiane Province, Laos. Then, we studied the potential for increasing rice yield and introducing dry season crops by using water stored in existing reservoirs used for fish aquaculture. The findings were as follows;

1) Low rice grain yield was observed in fields where transplanting was delayed due to water shortages at the beginning of the rainy season. The results suggest that the yield was reduced because of delayed transplanting. Preparatory irrigation is needed to accelerate transplanting and improve the rice yield.
2) Supplemental irrigation is essential for soybean cropping in the dry season. A total of 220 mm of water is needed during the soybean planting period (December to February). The water should be divided for 4 applications at 3-week intervals.
3) Within the survey area, 6 existing reservoirs used for fish aquaculture were storing a total of 8,700 m^3 water with the potential for use in irrigation.
4) The potential area of preparatory irrigation for rainy season lowland rice and supplemental irrigation for dry season cropping were 10.4-11 and 3.2-3.5 ha, respectively. A total of 80,000,000 kip of additional income was expected through the practice of irrigating with the water stored in existing reservoirs in the surveyed river basins.

The results of this research can be applied to Nameuang Village as well as to other villages where rainy season lowland rice cultivation and aquaculture have been conducted. However, potential irrigation areas should be calculated based on each village's water resources and land use. Additionally, if engine pumps or syphons are needed to withdraw water from reservoirs, equipment costs and fuel should be considered in the calculations.

Acknowledgments

This study was conducted as part of the collaborative research project of Japan International Research Center for Agricultural Sciences (JIRCAS), National Agriculture and Forestry Research Institute and National University of Laos funded by JIRCAS. We are grateful for the helpful assistance of Agriculture and Forestry Office of Feuang District, Vientiane Province, Department of Meteorology and Hydrology, Laos, and all the residents of Nameuang Village for working with us.

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