3-1 Challenges and opportunities of utilizing small reservoirs for rice irrigation in northern Ghana

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Abstract
Rainwater-harvesting reservoirs in Africa offer substantial potential to support rice irrigation and boost productivity in rainfed lowland areas. However, the effectiveness of such irrigation initiatives hinges on multiple factors beyond hydrological conditions, including social regulations governing irrigation and facility maintenance, availability of labor and financial resources, farmers' willingness to engage in rice irrigation, and economic viability, which have been underrepresented in the literature. This chapter seeks to address these knowledge gaps and examine the challenges and opportunities of rice irrigation using small reservoirs in northern Ghana, drawing upon field survey findings by Koide et al. (2015) and Yokoyama and Koide (2018). These findings highlight the importance of restricting rice irrigation to supplementary practices during the rainy season, considering that local reservoirs experience reduced water levels during the dry season, prioritizing domestic water supply. Key challenges to the implementation of supplementary irrigation include the absence of customary rules that regulate water use to enable timely irrigation and the competition for labor and financial resources between intensified rice farming and the cultivation of upland crops. There is also a lack of institutional mechanisms to address these farm resource constraints. Based on an analysis of local major crop production costs and on-farm trials of supplementary rice irrigation, the authors further demonstrated that rice yields under supplementary irrigation are increased to a level that exceeds the profitability of pepper, the region's most lucrative crop. These findings suggest that supplementary irrigation can enhance rice productivity and support its expansion as a cash crop, potentially replacing other high-value crops.

1. Introduction

The increasing variability in rainfall patterns and excessive non-productive water losses in smallholder agricultural systems across Africa underscores the urgent need for widespread rainwater harvesting and supplementary irrigation techniques to improve water-use efficiency and long-term sustainability (Biazin et al., 2012). Crops with the greatest demand for these techniques include rice, which is highly vulnerable to water stress. Its production persistently falls short of consumption, a disparity further aggravated by urbanization and shifting dietary preferences across the continent

(Zenna et al., 2017). In rainfed lowland environments, which are a key rice-growing area in West Africa, productivity declines and variability due to intra-seasonal dry spells pose critical challenges, emphasizing the importance of appropriate water management and complementary agronomic practices to support the sustainable intensification and expansion of rice production (Katic et al., 2013).

In particular, Ghana, where rainfed lowlands represent nearly 80% of the rice cultivation area (Seck et al., 2010) and small reservoirs are abundant (Namara et al., 2010), offers a significant opportunity for efficient, stable irrigation operations utilizing existing water infrastructure to enhance rice yields in rainfed lowlands. However, the success of such operations depends on several factors beyond hydrological conditions, including social regulations governing irrigation and facility maintenance, the availability of labor and financial resources, farmers' interest in irrigated farming, and its economic viability compared to rainfed agriculture.

Research on these socioeconomic dimensions remains limited. For example, Venot et al. (2011) explored the roles and decision-making processes of stakeholders managing small reservoirs in northeastern Ghana, including local water user associations, traditional authorities, and government officials. Similarly, de Fraiture et al. (2013) examined water-use trends for small reservoirs in central Burkina Faso, identifying unsustainable practices such as the unregulated expansion of irrigated areas using motorized pumps. However, these studies primarily focused on large reservoirs, often beyond the management capacity of farmers, and did not sufficiently address the opportunities and challenges of water use for rice cultivation. Additionally, few studies have investigated the profitability of irrigated rice or its potential tradeoffs with the production of other crops. This chapter examines the potential for rice irrigation and expansion using small reservoirs in northern Ghana, drawing on field survey findings by Koide et al. (2015) and Yokoyama and Koide (2018) to address this lack of knowledge.

2. Field surveys

Koide et al. (2015) conducted preliminary surveys in 2013 in three villages (Village N, Village S, and Village D) in the former Northern Region of Ghana, the region with the highest rice production. These sites were selected due to the presence of small communal rainwater harvesting reservoirs, known as dugouts, which are surrounded by rainfed rice fields, thus presenting the potential for reservoir-based rice irrigation. Focus group discussion with village representatives, including traditional chiefs, was conducted to gather information on the current uses of the reservoirs, customary rules regarding water access and facility maintenance, and other social dimensions. Additionally, a semi-structured questionnaire survey with 15 randomly selected rice-producing households was carried out to understand the demand for rice irrigation and key requirements for its adoption, such as labor availability and financial resources. The survey results highlight the multidimensional constraints on rice irrigation, as described in Section 3, Potential for rice irrigation.

Building on the results of these preliminary surveys and parallel hydrological assessments, a more detailed survey was conducted between 2014 and 2015 in Village N, which was deemed more suitable for small-reservoir-based rice irrigation (Yokoyama and Koide, 2018). This survey targeted all rice-producing households (151 in 2014 and 167 in 2015) in Village N and two surrounding villages. A structured questionnaire was administered to collect data on production costs, yields, and sale prices of the major crops grown in the villages, including rainfed rice, maize, and pepper, as well as irrigated rice, which was experimentally grown using reservoir water under the technical guidance of the Japan International Research Center for Agricultural Sciences (JIRCAS). The collected data served to evaluate the relative profitability of these crops. The findings highlight the potential for rice expansion, including the substitutability of other crops for rice, as described in Section 4, Potential for rice expansion.

3. Potential for rice irrigation

3.1 Consistency with customary water uses and regulations

None of the surveyed villages have access to rivers or springs that provide year-round water, so water for domestic use—such as drinking, cooking, washing, and brick-making—as well as water for livestock, is mainly sourced from dugouts. These dugouts were constructed with government assistance and are used by most villagers. While wells exist in Villages N and S to secure water for domestic use, they dry up during the dry season or become murky, leading to limited use. Some residential areas in the villages have access to piped water at a cost, but this is used by only a small portion of the population. Therefore, for most villagers, dugouts represent the only source of domestic water supply throughout the year. However, the dugouts nearly dry up by the end of the dry season, making it difficult to use the water for dry-season irrigation (Koide et al., 2015).

All villages have implemented regulations to manage the quantity and quality of reserved water (Table 1). Since livestock intrusion degrades water quality, and water for livestock competes with domestic water requirements during the dry season, Villages N and D have established rules mandating that cattle be taken to alternative water sources, such as large dams in neighboring villages. In Village S, farming near the dugout is prohibited to prevent sedimentation. Maintenance of the dugouts, such as repairing embankments or dredging, involves the participation of all villagers. These rules, however, are not formalized, and there are no water user associations to oversee dugout use. Nevertheless, each village selects a few individuals to monitor the dugout and enforce the rules. Typically, the village chief organizes maintenance activities based on reports from these monitors. Violations of the rules are subject to penalties imposed by the chief (Koide et al., 2015).

Despite these regulations, there are no restrictions on water withdrawal to avoid future shortages. Villagers continue to use dugout water until it runs out, then move to neighboring villages' reservoirs to collect water. This practice complicates the storage of water surplus for irrigation but facilitates dredging activities. In Villages S and D, villagers gather at the end of the dry season, when reservoir levels are at their lowest, to dredge the dugouts and repair or raise the embankments. Neglecting these maintenance activities may significantly decrease the reservoir's storage capacity, undermining its ability to ensure a dependable water supply for both domestic and irrigation purposes. Consequently, storing water for rice cultivation during the dry season is impractical due to the challenges associated with maintenance. Effective rice irrigation will likely be confined to supplementary measures during the rainy season when reservoir water levels are substantially higher (Koide et al., 2015).

Table 1. Major enforced rules for the use of village dugouts

	Village N	Village S	Village D
Prevent cattle from drinking reservoir water in the dry season	✓		✓
Refrain from walking and swimming	✓	✓	✓
Refrain from irrigating during the dry season	✓		
No cultivation near the reservoir		✓	✓
Participation in reservoir maintenance	✓	✓	✓

Source: Koide et al. (2015)

3.2 Availability of farm resources required for irrigation farming

The households surveyed throughout villages primarily cultivate upland crops, livestock, and rice (Table 2). Farmers in Village D, characterized by abundant uncultivated land, possess larger landholdings than those in the other two villages. Conversely, farmers in Village N, where minimal uncultivated land remains, have less than half the land of those in Village D despite having a similar number of household members. While many residents in Village D practice shifting cultivation, farmers in Villages N and S frequently rotate crops in upland areas to mitigate soil fertility decline. In lowland areas, where crop rotation poses more significant challenges, many residents engage in rainfed rice cultivation supplemented with chemical fertilizers (Koide et al., 2015).

Introducing irrigation and other agronomic practices in these rainfed lowlands may greatly enhance rice yields, but this poses challenges in securing adequate labor. For instance, the efficient utilization of irrigation water necessitates land leveling, a practice that is currently infrequent yet critical. Similar to plowing, manual land leveling is labor-intensive and coincides with the sowing season (May–June) for key upland crops such as maize, resulting in seasonal labor shortages. To mitigate this issue, employing tractors or draft animals for plowing and leveling is vital; however, the number of farmers possessing tractors or draft animals is limited in all villages. Furthermore, securing funds to rent tractors and procure chemical fertilizers is crucial for irrigated rice cultivation, yet some farmers are already allowing land to lie fallow due to insufficient resources. Thus, introducing irrigation may exacerbate competing labor and financial demands between rice and upland crop farming (Koide et al., 2015).

Currently, farmers in all villages cultivate maize, pepper, yam, cassava, groundnuts, and soybeans in addition to rice, reflecting a widespread diversification of crop farming. Among these, maize and cassava are prioritized for household consumption, while rice is primarily grown as a cash crop, with many farmers selling more than half of their rice harvest. Cassava, yam, pepper, and groundnuts are planted in May, and the peak farming season commences in June and July when rice, maize, and soybeans are sown. Most farmers prioritize the production of staple food crops while diversifying their agricultural endeavors, and considering that rice planting occurs during the peak labor season, it is challenging for farmers to allocate labor and financial resources to irrigate rice without compromising those needed for upland crop farming. Moreover, the fields of groundnuts, maize, and soybeans, which represent significant cash crops for the villagers, are often plowed by tractors, similar to rice fields, thereby intensifying competition for cropping activities. Therefore, the profitability of rice cultivation becomes crucial for farmers seeking to allocate labor and financial resources toward rice production. Some farmers opt to sell rice in early spring when prices peak, enabling them to afford tractor services for the subsequent cropping season. This strategy not only enhances rice profitability but also aids in avoiding fallow periods by ensuring access to tractor services (Koide et al., 2015).

Table 2. Surveyed households' labor, land, and livestock holdings

	Village N	Village S	Village D
Avg. number of household members	16.8	10.0	17.6
Avg. number of farm laborers	7.2	5.2	6.4
Avg. size of farmland holdings (ha)	4.8	5.3	9.9
- Upland crops (ha)	2.9	2.4	5.4
- Lowland rice (ha)	0.8	1.2	1.9
- Vegetables (ha)	0.5	0.5	1.1
- Fallow (ha)	0.4	0.5	1.0
- Uncultivated land (ha)	0.2	0.7	0.5
Avg. number of cattle	5.5	2.0	8.0
Avg. number of medium livestock	7.3	12.6	25.8
Avg. number of small livestock	82.8	67.0	73.8

Note: Medium livestock includes goats and sheep. Small livestock includes chickens, guinea fowl, and rabbits.

Source: Koide et al. (2015)

3.3 Availability of institutional mechanisms to mitigate resource constraints

Agricultural funding and securing domestic water resources might be addressed through institutional mechanisms. Some farmers obtain agricultural financing by borrowing from acquaintances or merchants, while others acquire inputs like chemical fertilizers on credit, repaying them post-harvest. However, many still face substantial financial challenges that hinder their ability to maintain continuous cultivation. Moreover, access to formal financial institutions such as banks remains limited. While water supply systems could help secure domestic water, no examples exist of villagers taking loans for this purpose. These challenges highlight the critical need for broader financial services to support agricultural financing and domestic water access (Koide et al., 2015).

Organized efforts may also address these issues. According to the principal activities of farmer organizations (Table 3), some groups (B, D, F) in Villages N and S store harvested crops, such as rice, collectively, selling them during the off-season to fund tractor use, chemical fertilizers, and new water supply systems. However, these organizations are relatively new and may encounter operational difficulties similar to those of older, now inactive, farmers' groups. For example, in Village N, an organization initially formed to secure tractors and chemical fertilizers, gradually faced financial constraints, rendering it nearly inactive. Another organization in the same village, created under an agricultural development project to provide chemical fertilizers and technical support, dissolved once the project ended. Thus, addressing agricultural funding and domestic water issues through collective action will require a reassessment of fund management and stronger institutional support (Koide et al., 2015).

Table 3. Main activities of organizations in which the surveyed farmers participate

	Organization (members)	Main Activities
Village N	A (40)	Mutual assistance in agricultural work
	B (42)	Labor exchange in weeding, joint storage, and sale of maize and rice
Village S	C (16)	Joint cultivation and sale of rice
	D (65)	Joint cultivation and sale of maize and rice
	E (30)	Labor exchange in rice sowing
	F (52)	Joint marketing of maize and soybeans
Village D	G (30)	Mutual assistance in agricultural work, weddings, funerals

Source: Koide et al. (2015)

3.4 Farmers' perceptions of rice production

It is also important to note that rice irrigation may not necessarily align with farmers' perceived solutions to the practical challenges they face in rice production. Notably, farmers in all villages emphasize soil and weed issues as major factors hindering rice production (Table 4). Their awareness of water shortages is limited, particularly in Village D, where farmers observe adequate soil moisture in paddy fields due to frequent flooding. Given that rice yields in this village are lower than the other two, water scarcity may not be the primary contributing factor. Many farmers attribute annual fluctuations in rice yields to soil and weed management issues, such as the lack of funds to purchase chemical fertilizers and herbicides. However, in Villages N and S, many farmers point to rainfall instability as a concern. Farmers in Village S reported that flooding after sowing washed away seeds, resulting in reduced yields. Although farmers in Village D have not faced water shortages, they note that delays in sowing can lead to water deficits before heading. The impact of flood timing and the onset of rainfall on yield fluctuations highlight the importance of timely sowing and supplementary irrigation (Koide et al., 2015).

Table 4. Farmers' perceptions of rice production constraints and yield fluctuations

	Village N	Village S	Village D
Yield (Avg. t/ha)	3.06	1.54	1.06
Production constraints (0–5 points)			
- Water shortage	2.6	2.6	0
- Soil infertility	4.1	2.8	4
- Weed problem	3.8	5	4.8
- Pests and diseases	0.6	0.6	0
- Bird attack	2.2	1.4	2.8
Causes of yield fluctuation (person)			
- Rainfall instability	4 (80%)	5 (100%)	1 (20%)
- Lack of fertilizers	4 (80%)	2 (40%)	5 (100%)
- Lack of herbicides	2 (40%)	3 (60%)	5 (100%)

Note: Production constraints were rated from 0 for "no problem at all" to 5 for "very problematic."
Source: Koide et al. (2015)

4. Potential for rice expansion

4.1 Profitability of rice and other crops

A household census conducted in 2014 in Village N and two neighboring villages revealed that the primary crops in these three villages are maize (46% of the total cultivated area), rice (20%), and pepper (18%), collectively accounting for 84% of the total cultivated area. The primary cultivation purposes were self-consumption for maize, sales for pepper, and a mix of both for rice. The average cultivated area was 0.5 hectares for maize and rice and 0.3 hectares for pepper, with yields ranging from 1 to 3 tons per hectare for all three crops. The yield and price of rice and maize were relatively stable, while pepper, a high-market crop, exhibited significant fluctuations. Between 2014 and 2015, pepper yields halved, while prices doubled, as shown in Table 5 (Yokoyama and Koide, 2018).

Regarding production costs, labor accounted for the largest share across all three crops, with rice ranging from 50–60%, maize at 40%, and pepper as high as 90%. The reliance on hired labor was particularly pronounced for rice, reaching 37% in 2014 and 23% in 2015. Rice is harvested by cutting the stalks with a sickle, piling them in the field, threshing by beating with sticks, and winnowing using large bowls—a series of tasks often performed by groups of hired women. Consequently, there is a parallel relationship between rice yields and female employment. A 22% decrease in rice yields from 2014 to 2015 corresponded to a 27% reduction in employment. Thus, increasing rice production contributes to expanding local employment opportunities for women. Moreover, payment for threshing and winnowing is often made in paddy rather than cash, which is expected to directly improve food security for poorer households (Yokoyama and Koide, 2018).

In terms of income and profit, pepper demonstrated significantly higher profitability with its high sales price and labor-intensive nature. The expansion of pepper production is expected to substantially contribute to regional economic development. However, the potential for a price collapse due to overproduction in neighboring villages must be considered. Furthermore, pepper seedlings require frequent irrigation, currently sourced from dugouts or water systems, limiting seedling production to areas near residences. After transplanting them to the main field, considerable family labor is required for management and harvest, with water resources and labor availability being key constraints to expansion (Yokoyama and Koide, 2018).

Table 5. Profitability of the major crops (GHS/ha, 2014 and 2015 cropping seasons)

	2014 cropping season			2015 cropping season			
	Rainfed rice (n=141)	Maize (n=75)	Pepper (n=75)	Rainfed rice (n=167)	Irrigated rice [1] (n=10)	Maize (n=125)	Pepper (n=42)
Cultivated area (Avg. ha/plot)	0.45	0.61	0.33	0.49	0.125	0.56	0.33
Yield (t/ha)	2.04	1.52	2.45	1.60	4.06	1.86	1.19
Sale price (GHS/kg)	1.07	0.84	3.04	1.09	1.085	0.92	6.30
Gross income (GHS/ha) (A)[2]	2,186	1,277	6,184	1,732	4,403	1,705	6,781
Production cost (B)	2,172	1,121	5,590	1,672	5,802	1,053	4,462
- Material	604	564	611	660	785	495	539
- Family labor (C)[3]	886	395	4389	648	4,423	362	3,790
- Hired labor	526	76	554	200	182	55	83
- Custom hiring	157	86	36	164	125	142	50
- Irrigation fee	0	0	0	0	216	0	0
Income A–B+C	899	550	4,983	708	3,025	1,014	6,109
Profit A–B	14	155	594	61	-1,398	652	2,319

Notes:

1) In the experimental field established by JIRCAS, ten farmers selected from the village followed the instructions of staff from the Ghanaian experimental station regarding fertilization and crop management.

2) The average gross income was calculated individually and may not correspond exactly to the product of average yield and average sales price.

3) Labor costs were estimated as the number of labor days multiplied by the average agricultural wage rate (3.3 GHS/day in 2014 and 3.4 GHS/day in 2015). No significant differences in wage levels were observed by task or gender. In actual farm operations, no payment is made for family labor, so family labor costs are considered imputed. These were accounted for as they are necessary for calculating farm profits.

Source: Modified from Yokoyama and Koide (2018)

4.2 Substitutability of other crops for rice

While it has been established that pepper is the most profitable crop in the surveyed villages, it is important to determine the level of rice yield necessary for its profitability to match that of pepper, assuming current technologies. The following equation is obtained by performing a linear regression of per-hectare profit with rice yield.

2014 cropping season: $Y = 615.17 X - 1{,}235$ ($n = 141$, $r^2 = 0.3667$)

2015 cropping season: $Y = 757.29 X - 1{,}145$ ($n = 167$, $r^2 = 0.4889$)

Y: Profit (GHS/ha), X: Rice yield (t/ha)

From the above equation, estimating the rice yield required to achieve the average profitability of pepper (GHS 594/ha in 2014 and GHS 2,319/ha in 2015) shows that 3.0 t/ha in 2014 and 4.6 t/ha in 2015 would be necessary. The 1.5-fold difference between these years is primarily attributed to the price fluctuations of pepper, which increased by 2.1 times between 2014 and 2015 (Yokoyama and Koide, 2018).

In the supplementary irrigation trials for rice conducted by JIRCAS in Village N, yields of 4.1 t/ha (2015) and 4.7 t/ha (2016) were obtained in farmer-managed fields. Achieving these yield levels would make rice profitability comparable to the average profitability of pepper, indicating the potential for a partial shift from pepper to rice cultivation. Additionally, as rice becomes more favored as a staple food, a shift from maize to rice is also conceivable. In fact, fields located between the settlement and wetland areas already exhibit flexible cultivation of rice, maize, and pepper, depending on conditions such as rainfall. No new land development or irrigation channel construction is required in such locations, making it possible to convert to rice cultivation with only basic field preparation (Yokoyama and Koide, 2018).

However, additional labor is required when irrigated rice is cultivated in newly developed paddy fields, including repeated land preparation (which involves plowing and leveling), replanting, weeding, and irrigation labor. Although this additional labor was provided by family members during the trials, leading to incomes significantly exceeding those of current rainfed rice cultivation due to increased yields, the profits, when accounting for the imputed cost of family labor, showed a substantial deficit (Table 5). Since the additional labor associated with new paddy field development is part of the cost of introducing irrigated rice, it seems appropriate for farmers to bear this burden. However, it is expected to decrease as continuous rice cultivation stabilizes the field conditions (Yokoyama and Koide, 2018).

5. Concluding remarks

Small-scale irrigation leveraging existing local water infrastructure, such as rainwater-harvesting reservoirs, presents a viable strategy for enhancing rice production in Ghana. However, findings from Koide et al. (2015) emphasize that the current applications of these reservoirs are varied and not conducive to prioritizing rice production. Specifically, utilizing reservoir water for rice during the dry season presents challenges, as the need for domestic water supply takes precedence, resulting in inadequate water storage and complicating implementation. It appears prudent to restrict irrigation to supplementary practices during the rainy season. In such instances, it is vital to establish a framework for water allocation and the maintenance of reservoirs, necessitating enforcement of irrigation regulations and cooperation. Additionally, strategic farm management and institutional arrangements are essential to ensure the timely provision of labor and funding for land development and fertilization, which are critical to guaranteeing effective irrigation and its associated benefits. By satisfying these diverse conditions, supplementary irrigation farming utilizing small reservoirs could become feasible, enabling rice intensification and expansion. As demonstrated by Yokoyama and Koide (2018), while current rainfed rice production is significantly less profitable than pepper, a major cash crop, adopting supplementary irrigation and complementary agronomic practices could yield sufficient increases in rice yield, surpassing pepper's profitability. Alternatively, farmers could substantially increase their incomes by expanding rice cultivation in lieu of other competing, less profitable crops. However, rice expansion must be carefully balanced to avoid undermining farmers' risk management strategies, such as producing other food staples like maize and diversifying income sources.

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