Agricultural Sciences, 2026, 17(9), 1028-1046
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Low-Cost Irrigation Facilities with Cover Plants Based on Life Cycle Cost at a Paddy Field in Ghana

Haruyuki Dan[1*], Tadashi Adachi[2], Yoko Oki[2], Sampson Agodzo[3], Hannah Adzraku[3]

[1]Japan International Research Center for Agricultural Sciences (JIRCAS), Ibaraki, Japan
[2]Graduate School of Environmental and Life Science, Okayama University, Okayama, Japan
[3]Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana
Email: *danh0185@jircas.go.jp

How to cite this paper: Dan, H., Adachi, T., Oki, Y., Agodzo, S. and Adzraku, H. (2026) Low-Cost Irrigation Facilities with Cover Plants Based on Life Cycle Cost at a Paddy Field in Ghana. *Agricultural Sciences*, **17**, 1028-1046.
https://doi.org/10.4236/as.2026.179058

Received: June 5, 2026
Accepted: September 25, 2026
Published: September 28, 2026

Abstract

In Africa, rice consumption has increased more than rice production, thereby increasing the gap between supply and demand. In Ghana, irrigation and drainage canals are unlined earth canals. Therefore, farmers are burdened with maintenance work following erosion caused by drip erosion, scouring caused by water running in the canals, and the removal of accumulated sediment. Cover plants can be used to reinforce irrigation infrastructure and minimise the adverse impact of rainfall on irrigation facilities in paddy fields. However, few studies have conducted economic evaluations, especially from a life cycle perspective, while investigating actual fields where suitable cover plants are planted in a canal. In the present study, after clarifying the current situation, including the awareness of extension officers on weeds, vegetation in the research area, and plant community stability, a maintenance plan was developed, and three types of canals were evaluated economically. The construction costs of earthen and concrete canals were 642 and 5,000 GHC, respectively, and the maintenance costs over 10 years were 4,767 and 2,500 GHC, respectively. In comparison, the costs of developing canals with cover plants and their maintenance were 1,007 and 2,577 GHC, respectively (1.0 USD = 3.9 GHC, as of April 2016). In terms of the total long-term cost, including not only construction but also maintenance costs, the costs for the earth canal exceeded those of the developed canal in 4.2 years and those of the concrete canal in 19.7 years. The findings of this study could facilitate sustainable canal development in Ghana.

Keywords

Life Cycle Cost, Low-Cost Irrigation Facility, Paddy Weed,

Maintenance Plan, Unlined Earth Canal

1. Introduction

Among the three major cereal crops (wheat, rice, and corn), wheat production and consumption areas are distributed widely globally; however, rice production and consumption areas are found mostly, over 90%, in Asia [1]. Unlike corn, which is used not only for human consumption but also as livestock feed, almost all rice produced is consumed by humans [2]. Rice, being a crop that suits the climate of Asia, has supported the growth of the global population, particularly in Asia [3]. In addition, rice is consumed predominantly in areas where it is produced, with relatively low volumes traded. However, because of a decrease in consumption in Asia and an increase in demand in Africa, the international rice market has become active in recent years. For example, global rice exports increased significantly from approximately 28 million tons in the 2004-2005 period, International Year of Rice, to approximately 46.5 million tons in the 2021-2022 period [4].

Rice consumption has increased more than rice production in Africa, thereby increasing the gap between supply and demand [5]. In sub-Saharan Africa, over 215 million individuals suffer from malnutrition [6]. Rice supplies 20% of the global food energy supply, surpassing wheat (19%) and corn (5%), and is an excellent source of vitamin B and dietary fibre [7] [8]. In Ghana, rice is currently the second most important staple food after maize, and its consumption continues to increase [9] [10]. In 2009, rice consumption in Ghana was 700,000 tons, with imports of 400,000 tons [11]. Therefore, rice production can be increased to reduce the gap between consumption and imports [12].

Among the technological advances in rice farming in Asia, paddy field infrastructure improvement is a key factor that has facilitated irrigated rice farming [13]. Paddy field development has also been implemented in the inland valleys of West Africa [14]; however, the irrigation and drainage canals are unlined earth canals, so farmers are burdened with maintenance work to address erosion caused by strong raindrops, scouring caused by running water in the canals, and removal of sediment accumulation [15] [16]. The use of cover plants to reinforce irrigation structures is a potentially sustainable strategy for minimising the adverse effects of rainfall on irrigation facilities in paddy fields [17]. Against this background, the research was conducted jointly by the Japan International Research Center for Agricultural Sciences (JIRCAS) and Kwame Nkrumah University of Science and Technology (KNUST) in the Ashanti Region, Ghana, for 7 years between 2011 and 2018. Covering the ground surface in irrigation facilities with native plants mitigates the adverse effects of raindrops, such as soil erosion, which represents the initial stages of facility collapse and does not require extensive maintenance. Unlike in structural works, as plants grow, the function of planting works is enhanced, for example, via slope protection. Therefore, the present study explored strategies for the sustainable development of irrigation infrastructure in Ghana and other similar developing countries in Africa. A draft maintenance plan for farmers was developed. Furthermore, since it is necessary to evaluate low-cost irrigation facilities economically, including maintenance work [18], from a life-cycle perspective, the costs of the system were evaluated to explore its feasibility.

Few economic evaluation studies have investigated cover plant community stability in actual fields where cover plants are planted in a canal. In the present study, the maintenance plan was evaluated from technical and economic feasibility perspectives, while considering local adaptability. The findings of this study could facilitate the enhancement of rice yield in the inland valleys of Ghana sustainably.

2. Materials and Methods

2.1. Research Area

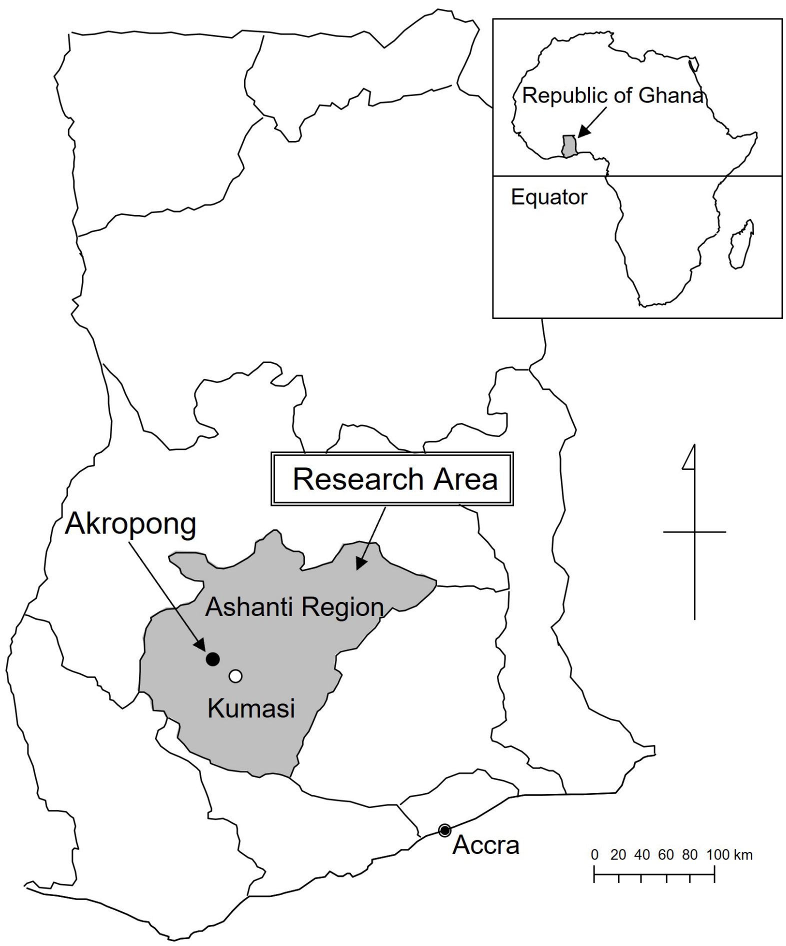


Figure 1. Location of the research area.

The study area was located around Kumasi, the capital of the Ashanti region of Ghana (**Figure 1**). The area had an annual average precipitation of 1,273 mm in 1981-2010. The region typically has two rainy seasons: a longer rainy season from April to July and a shorter rainy season in September-November (**Figure 2**). Over the same period, the annual average temperature was 26.3˚C, with a monthly average of 24.4 - 28.1˚C; the range of temperature variation throughout the year is relatively narrow and the temperatures are generally high [19]. The Warmth Index calculated for the region was 255.2, indicating that the region belongs to a tropical zone where warm-season grass can grow. In addition, the study area falls under the forest zone based on the ecological classification system formulated by the Ghanaian government [20]. Compared to the savannah zone in the north, where farming relies on rainfall, the forest zone in the central-south has relatively favourable soil conditions and receives high precipitation [21] [22].

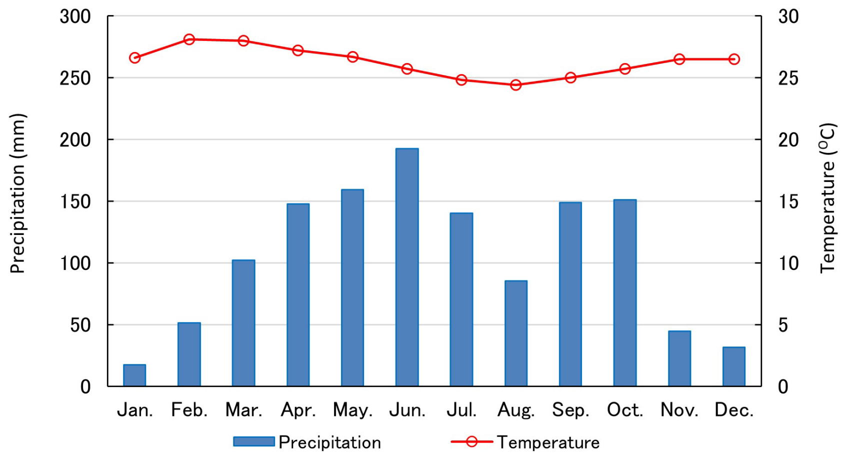


Figure 2. Climate data.

Most irrigation and drainage canals connected to paddy fields in the study area are earth canals, and their function has reportedly deteriorated [23]. Based on the assumption that the earth canals are maintained by farmers, it is critical to develop reinforcement technologies for paddy field irrigation facilities using locally available technologies and resources. Planting cover plants in existing earth canals is a promising technology considering the economic status and technological expertise of farmers in the research area.

To assess the potential utility of cover crop technology, experimental sites were set up in 2012-2018 in Akropong villages (6˚45.893′N, 1˚45.742′W), approximately 12 km west-northwest of central Kumasi (**Figure 1**). Three perennial plants in the Poaceae family, bermudagrass (*Cynodon dactylon*), love grass (*Chrysopogon aciculatus*), and St. Augustine grass (*Stenotaphrum secundatum*), were used as test plants (**Figure 3**). The plants are warm-season and procumbent-type grasses spread by both aboveground and belowground runners. The plants are indigenous to the research area and form turfs even in poor soils [24]. The plants were field-tested at the experimental site, and a bare plot without planting but treated with herbicides was used as a control. Because there was no difference in maintenance work depending on the grass species, in the present study, the unit costs and requirements per unit work were calculated and analysed using the average values of the three test plants.

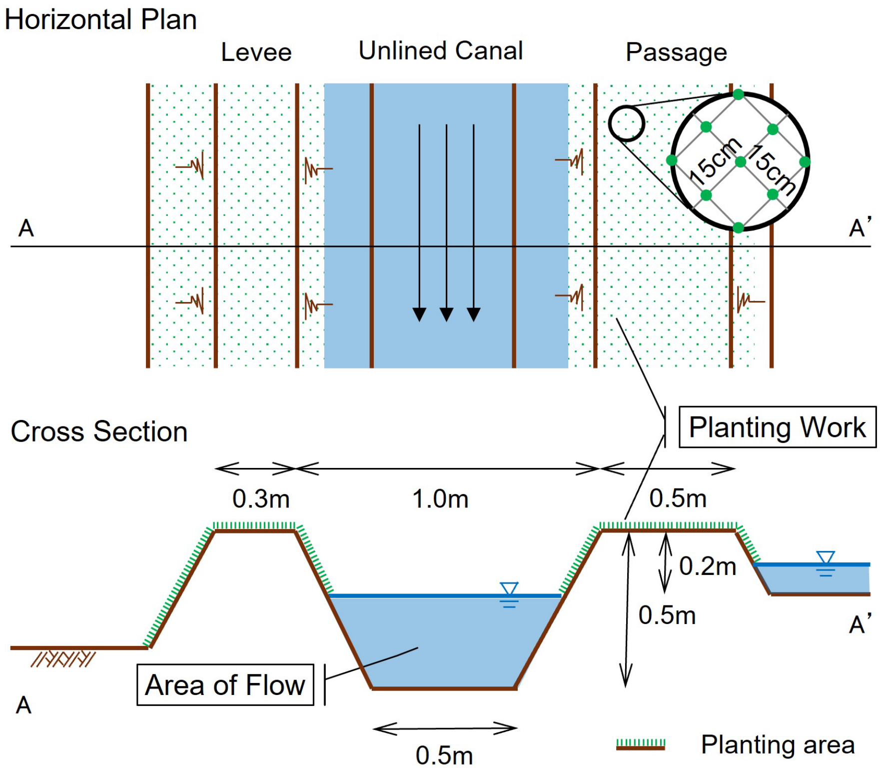


Figure 3. Standard design of the planting work.

2.2. Extension Officer Awareness of Weeds

Before establishing technology for covering irrigation facilities with native plants, it is necessary to explore the level of knowledge and awareness of farmers and agricultural extension officers regarding native plants and paddy weeds. This is closely related not only to the introduction of developing technologies, such as farmer acceptance, but also to establishment of developing technologies, such as maintenance plans and methods of acquiring the technologies.

Agricultural extension officers around Kumasi have experience providing guidance on upland field crops but have limited knowledge or experience in paddy rice cultivation, which has a short history of cultivation in Ghana. Although information is being accumulated through compilation of manuals on paddy field infrastructure development technologies and rice cultivation techniques, very few studies have focused on paddy field weeds in the region [25]. Therefore, the present study investigated the knowledge and awareness of weeds among extension officers, who are key to promoting paddy rice cultivation in the future.

The level of awareness on weeds was evaluated using a questionnaire administered to seven extension officers, and the answers were reconfirmed by probing further using semi-structured interviews as necessary. Among the participants, five had less than 3 years of training experience, whereas two had 10 years of experience. The training content was broad, covering all aspects of agriculture, and they were responsible for 10 - 20 farm households, a number that did not interfere with training.

2.3. Vegetation of the Research Area

Surveys of vegetation in the research area were conducted to obtain basic data on native plants suitable for application in canal reinforcement technologies. The surveys aimed to identify weeds that may compete with the introduced cover plants and the necessary data for determining maintenance work. Vegetation surveys were conducted five times, in November 2011, February 2012, and February 2013 during the dry season, and in June 2012 and June 2013 during the rainy season, in four villages of Adugyama, Amuni, Biemso, and Dunyan. The villages are located approximately 35 km northwest of the centre of Kumasi. Vegetation surveys targeted irrigation and drainage canals associated with rice paddies.

The plants collected were identified based on illustrated books and previous references [26]-[29]. In addition, the survey was conducted every 5 m in a 20 m section of the irrigation and drainage canal using a 1 × 1 m quadrat based on the line point method. Consequently, surveys were conducted in four canals at least three times over two years in different seasons, and data from 60 quadrats were compiled into a table. The cover degree is the proportion of the ground surface occupied by plants appearing within the quadrats and is classified into seven levels (5: covering > 75%, 4: covering 50% - 75%, 3: covering 25% - 50%, 2: covering 10% - 25%, 1: covering < 10%, +: scant, r: rare) according to Braun-Blanquet's combined estimation [30]. Appearance frequency was calculated as a percentage obtained by dividing the number of locations where a plant was observed by the total number of measurement locations. The data were then compiled in tabular form, with characteristics such as life form and growth type collected from the literature.

2.4. Stability of Plant Communities

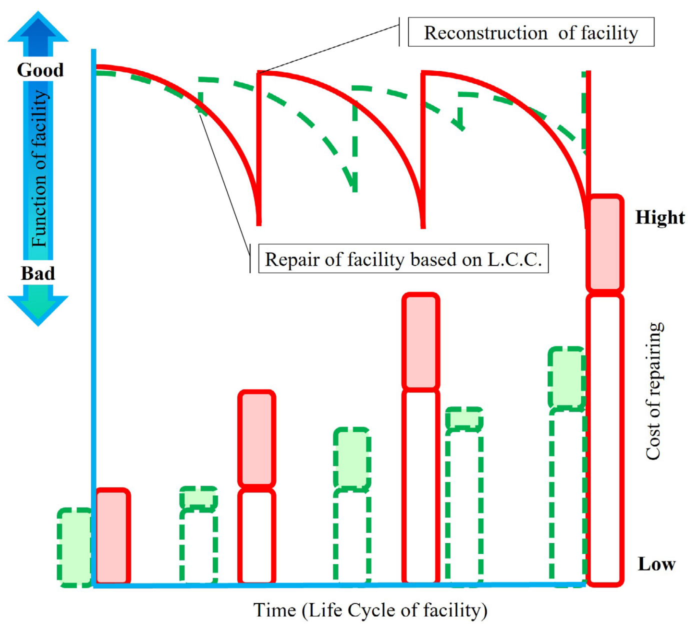
To assess the stability of the established cover plant community, the aboveground cover plants and invading weeds were collected as samples, and invading weeds were observed after maintenance work was suspended. Test plants were planted in a 5 × 10 m plot in November 2015, achieving a vegetation coverage rate of more than 95%, and weeds were removed by hand until November 2016. Afterwards, the plots were left under natural conditions without maintenance work, such as manual weeding or slashing. In November 2017, 25 × 25 cm quadrats were set up randomly, and all plants within the quadrats were cut just above ground level. The fresh weights of the test plants and other weeds were measured, and this was repeated five times. The obtained weed species were identified and discussed from a community stability perspective.

2.5. Maintenance and Management Plan for Cover Plants

Planting work is an effective technology that utilises local resources without requiring financial resources. In this regard, because plant characteristics are constantly changing, it is essential to carry out appropriate maintenance work at the right time to ensure the permanent required performance of planting work and maintain healthy plant communities. In many developed countries, it is possible to select maintenance work from numerous conventional agricultural works depending on the surrounding environment and farmer wishes or objectives. However, in the study area, options are limited because of lack of funds and low technology levels [25]. Thus, it is necessary to formulate a maintenance plan that focuses on conventional agricultural works. Therefore, agricultural works in the target area were clarified through year-round on-site observations over a 5-year period and interviews with farmers. The maintenance plan was developed and evaluated from technical and economic feasibility perspectives, while considering local adaptability.

2.6. Cost of Construction and Maintenance

In this study, a "low-cost irrigation facility" is defined as an irrigation facility whose life cycle costs, which are the total cost required over the facility's lifetime, including not only initial construction cost but also running costs, such as maintenance and renewal costs, are cheaper than that of a "conventional irrigation facility" (**Figure 4**). Lifetime refers to the period until the performance of the facility declines gradually and its function is lost as it deteriorates. If the cost of repairs at that point exceeds the cost of rebuilding, or if repairs are so frequent that rebuilding is cheaper than total repair costs, the facility is considered to have lost function. The life cycle cost analysis adopts a farmer cash-expenditure perspective. Family labor is treated as in-house labor without monetary payment. Discounting, inflation adjustment, and exchange-rate fluctuation were not applied, consistent with local farm-budgeting practice.



* This concept shows a line graph which expresses the irrigation facility's function and a column graph which expresses the construction cost and repair cost. Low-Cost facility is shown in the green graphs' case with some needed repairs when facility deteriorates on some level rather than the red graphs' case with more reconstruction when facility becomes nonfunctional.

Figure 4. Concept of life cycle cost.

In this study, whether the facility is considered a low-cost facility was evaluated over 10 years, which is generally the maximum period of land lease in Ghana [31]. Generally, when deterioration is relatively mild, there are many options for applicable countermeasures, ranging from short-term workarounds to permanent measures. However, when deterioration is more advanced, the number of options decreases, and the cost of countermeasures increases. Therefore, by adopting the idea of preventive maintenance, which involves application of countermeasures before deterioration becomes apparent, it may be possible to establish irrigation facilities at a lower cost than conventional irrigation facilities. In other words, as illustrated by the dotted green line in **Figure 4**, it is critical to develop a low-cost irrigation facility when evaluated over the long term by frequently performing simple repairs before the facilities become completely dysfunctional and require renovation.

Based on the construction schedule and maintenance plan, the 10-year maintenance cost per 100 m of two types of canals, earth canal and canal with cover plant, were calculated using the maintenance cost per 100 m^2 and the target area of a standard cross section (B_1 = 1.0, B_2 = 0.5, H = 0.5 m), as shown in **Figure 3**. For concrete canals, values from previous studies were used [32]. As a reference, functionality was evaluated based on data from previous studies on useful service life, water utilisation function, and effect of preventing raindrop erosion. The useful service life values used by the Japanese government for road asset value evaluations were applied [33]. The water utilisation function was evaluated using the roughness coefficient [34]. The roughness coefficient represents flow difficulty, and a low value indicates excellent water-utilisation function. Prevention of raindrop erosion was expressed as a ratio (%) of amount of raindrop erosion when cover was 40%, with the earthen canal set to 100 [35].

3. Results and Discussion

3.1. Extension Officer Awareness of Weeds

The results of this investigation clarified the impressions, knowledge, and control methods of agricultural extension officers regarding paddy weeds. When asked "which adjective best describes weeds," all seven-participant answered "destructive," which suggests their perception of weeds as something to be controlled and lack of appreciation of their potential for exploitation. When asked to list the advantages and disadvantages of weeds, the reported advantages were divided broadly into the role of fertiliser plants for improving farmland soil and forage plants for livestock. More than 70% of the participants reported disadvantages, including weed damage that directly leads to decreased crop yield, as well as competition for light, nutrients, and water. Therefore, weeds were considered to be eliminated.

On average, participants mentioned 5.1 species of weeds when asked to list the scientific or local names of as many weeds as possible. Among the weeds, the top three species correctly described, at least to the genus level, were millet genus

(*Panicum* spp.), which was mentioned by all participants, followed by sedge genus (*Cyprus* spp.) and spurge genus (*Euphorbia* spp.). The knowledge and awareness of weeds of the extension officers were comparable to those of general farmers, and they had no technical expertise to adopt different control methods depending on the growth status and type of weed.

The extension officers grasped the general categories of weed-control methods displayed in **Figure 5**; however, they did not understand the specific control methods and characteristics for each. Herbicide costs account for approximately 5% of all expenditure in farming households [15], and herbicides are easy to obtain in the market. Extension officers recognise these points as advantages of chemical control (**Figure 6**) and instruct farmers to use herbicides for weed control first and foremost. However, the instructions given by the officers do not include information on how to use different herbicides according to weed type or the appropriate timing for application.

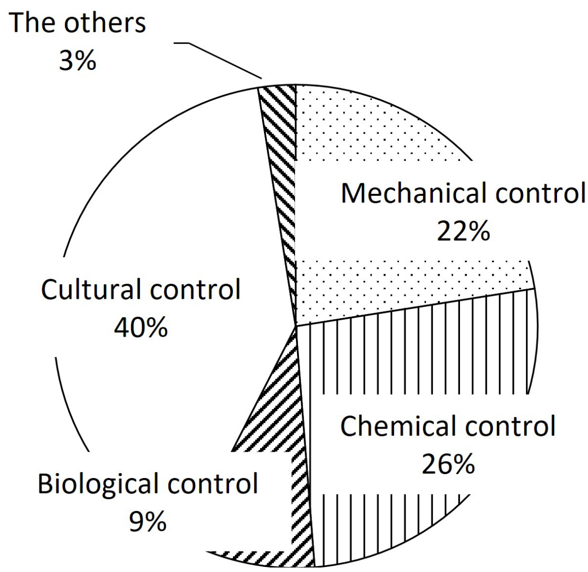


Figure 5. Methods of weed control as recognized by the extension officers.

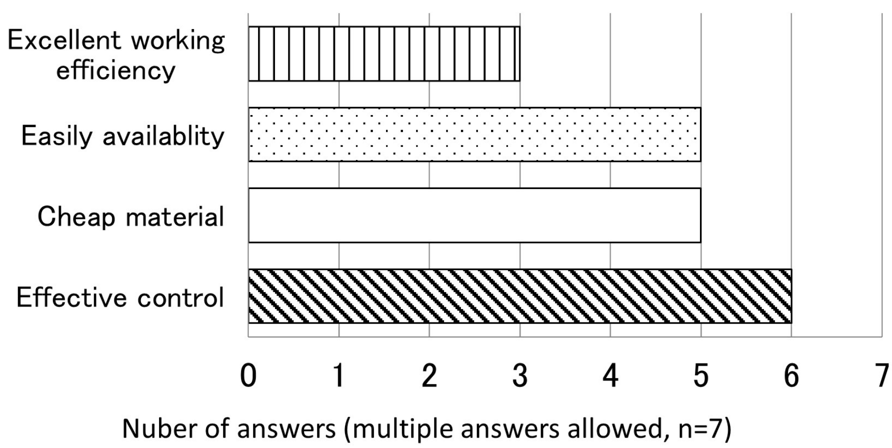


Figure 6. Advantages of chemical weed control as recognized by the extension officers.

To facilitate appropriate deployment of developed technology, farmers and agricultural extension officers should enhance their knowledge of native plants and paddy weeds. Consequently, further investigations and programmes should be conducted to enhance knowledge on weeds, in addition to the development of a system for the dissemination of accurate knowledge.

3.2. Vegetation of the Research Area

A total of 34 species were identified through a vegetation survey of four villages over 18 months (**Table 1**). The top three species with the highest frequency of appearance were Centro (*Centrosema pubescens*) at 68.8%, Billygoat weed (*Ageratum conyzoides*) at 59.4%, and Sensitive plant (*Mimosa pudica*) at 43.8%. Of all the species identified, 76% were annual plants, and even though they were on irrigation and drainage canals, the plants were influenced strongly by paddy fields, which are dominated by annual plants, owing to soil disturbance caused by annual ploughing and flooding. No aquatic weeds were observed; however, hygrophytic weeds such as Blue sprangletop (*Leptochloa caerulescens*) and False daisy (*Eclipta prostrata*) were observed. The dominant family was Poaceae, with 8 out of the 34 species, followed by Fabaceae, Cyperaceae, Euphorbiaceae, and Onagraceae, with 3 species each. The average appearance frequency of Poaceae was low compared to the number of species, whereas all three legume species observed, namely, Centro, Sensitive plant, and Calopo (*Calopogonium mucunoides*), showed high average frequency.

Table 1. Native plants identified at the irrigation facilities in research area.

Botanical Name	Common name	Family Name	Life Form	Growth Form	Cover rate	Appearance frequency
Centrosema pubescens	Centro	Fabaceae	Annual	Liane	1	68.8
Ageratum conyzoides	Billygoat-weed	Asteraceae	Annual	Erect	1	59.4
Mimosa pudica	Sensitive plant	Fabaceae	Perennial	Prostrate	1	43.8
Scoparia dulcis	Goatweed	Scrophulariaceae	Annual	Erect	1	25.0
Leptochloa cf. *caerulescens*	Blue sprangletop	Poaceae	Annual	Erect	1	25.0
Echinochloa colona	Jungle rice	Poaceae	Annual	Erect	2	25.0
Calopogonium mucunoides	Calopo	Fabaceae	Perennial	Liane	1	25.0
Panicum pansum	Rendle	Poaceae	Annual	Erect	2	25.0
Euphorbia hirta	Asthma-plant	Euphorbiaceae	Annual	Erect	1	21.9
Digitaria cf. *sanguinalis*	Hairy crabgrass	Poaceae	Annual	Erect	1	21.9
Cynodon dactylon	Durva grass	Poaceae	Perennial	Prostrate	1	18.8
Pentodon pentandrus	Hale's pentodon	Rubiaceae	Annual	Erect	1	15.6
Stachytarpheta angustifolia	Devil's coach whip	Verbenaceae	Perennial	Erect	1	12.5
Cyperus difformis L.	Variable flatsedge	Cyperaceae	Annual	Erect	1	9.4
Commelina africana	Yellow commelina	Commelinaceae	Annual	Prostrate	1	9.4

Continued

Phyllanthus amarus	Bahupatra	Euphorbiaceae	Annual	Erect	1	9.4
Euphorbia heterophylla L.	Fireplant	Euphorbiaceae	Annual	Erect	1	6.3
Ludwigia octovalvis	Primnose winnow	Onagraceae	Perennial	Erect	1	6.3
Physalis anagalis	Angular winter cherry	Solanaceae	Annual	Erect	1	6.3
Echinochloa obtusifloa	Barnyard grass	Poaceae	Annual	Erect	1	6.3
Heliotropium indicum	Indian heliotrope	Boraginaceae	Annual	Erect	1	3.1
Hyptis spicigera	Marubio	Lamiaceae	Annual	Erect	1	3.1
Ludwigia decurrens	Willow primrose	Onagraceae	Annual	Branched	1	3.1
Fimbristylis miliacea	Lesser fimbristylis	Cyperaceae	Annual	Branched	1	3.1
Basilicum polystachyon	Musk basil	Lamiaceae	Annual	Erect	1	3.1
Chloris pilose	African windmillgrass	Poaceae	Annual	Erect	r	3.1
Eclipta prostrata	False daisy	Asteraceae	Annual	Erect	r	3.1
Eragrostis sp.	Lovegrass	Poaceae	Annual	Erect	1	3.1
Hedyotis corymbosa	Diamond flower	Rubiaceae	Annual	Erect	1	3.1
Sida acuta	Common wireweed	Malvaceae	Perennial	Branched	+	0.0
Ludwigia hyssopifolia	Seedbox	Onagraceae	Annual	Branched	+	0.0
Solanum cf. *melongena*	Eggplant	Solanaceae	Annual	Erect	+	0.0
Ceratopteris cornuta	Water sprite	Adiantaceae	Perennial	Erect	+	0.0
Cyperus distans	Slender cyperus	Cyperaceae	Perennial	Erect	+	0.0

Note: * "Cover rate" and "Appearance frequency" is average value of 13 times of vegetation survey. * Zero in "Appearance frequency" means the value rounded down two decimal places.

3.3. Stability of Plant Communities

Table 2. Above-ground weight of test plants and invading weeds.

	With Maintenance			Without Maintenance			
Test plant	962	±	948.0	1,031	±	935.9	n.s.
Invading weeds	-			172	±	103.3	
Total weight	962	±	948.0	1,203	±	951.2	n.s.

Note: *n.s. indicates no significant difference between with/without maintenance at P = 0.05 by Student's t-test. *Values in the table show the average fresh weight (g) and standard deviation (n = 5) per 1 m^2.

The fresh weight of the test plants per 1 m^2 was 962 g under maintenance but 1,031 g after 1 year without maintenance. The fresh weight of weeds that grew after 1 year without maintenance was 172 g; therefore, the total biomass was 1,203 g. The cover plants generally grew well, regardless of whether maintenance work was performed, and the biomass ratio of weeds was 14.3% (Table 2). After 1 year, the biomass of the cover plants increased slightly, and a small number of invading weeds was observed, resulting in a slight increase in maintenance work. Furthermore, if the period without maintenance is long, various types of invading weeds will grow abundantly, which may increase the time required for maintenance.

Next, 11 species of weeds that invaded the test plant communities were identified, excluding those that could not be identified as young plants. According to the results of the vegetation survey described in the previous section, *Echinochloa colona*, *Calopogonium mucunoides*, *Digitaria sanguinalis*, *Cyperus difformis L.*, *Ludwigia octovalvis*, *Fimbristylis miliacea*, *Chloris pilose*, and *Eclipta prostrata* invaded, including the three most frequent species, *Centrosema pubescens*, *Ageratum conyzoides*, and *Mimosa pudica*. In considering cumulative accounting, where species are counted even if they appear multiple times in different treatments, the invading weeds were classified by family into four species from Poaceae, which was the most common in the previous survey; four species from Fabaceae, which had the highest appearance frequency in the previous survey; three species from Asteraceae; two species from Cyperaceae; and one species from Onagraceae. The most common growth form was the erect form, with nine species, followed by two climbing and procumbent forms each and one branched form. In terms of life form, there were 10 annuals and four perennials, with over 70% of the invading weeds being annuals.

Turf-established vegetation, a lawn-like layer of erect test plants forms weeds that can grow through gaps in the test plant communities, is advantageous for invasion. In addition, the test plant communities had not yet reached a stage where perennial plants could invade and establish themselves, considering the general succession trend. There are also concerns that an increase in leguminous vines, tall plants, and slippery broad-leaved plants will interfere with agricultural work. Therefore, maintaining the stability of an established single community of cover plants through scheduled maintenance work is vital for the sustainable function of paddy field irrigation facilities.

3.4. Maintenance and Management Plan of Planting Work

According to interviews with farmers, agricultural work carried out by all rice farmers in the target area included spraying herbicides, slashing by cutlass, ploughing by power tillers, and fertiliser application, excluding burning. Ploughing and fertiliser application were carried out only on the flooded surfaces of paddy fields, whereas other work was carried out on the entire paddy field, including irrigation and drainage canals and levees, which are irrigation facilities. Therefore, other works do not impose additional burdens on farmers and can be undertaken as maintenance work for cover plants.

Herbicides account for approximately 5% of the total expenditure of farmers and are readily available in the market; therefore, they are commonly used for rice cultivation in the target area [15]. However, there is no expertise required for the use of herbicides depending on the type of weed or timing of spraying [36]. Consequently, herbicide spraying was excluded from the maintenance work for cover plants, despite rice spraying twice a year being the main agronomic activity. Cover plants used in planting work were suppressed temporarily by spraying herbicides; however, they were not eradicated.

The timing and frequency of maintenance work were determined separately and divided into (i) within 1 year after planting until the introduced plant community was established and (ii) 1 year after planting to prevent overgrowth of introduced plants and suppress vegetation succession by invading weeds from the surrounding area (Figure 7). In calculating maintenance costs, the following were not included: material costs, such as the cost of mother plants of native species, rental fees for cutlass and shovels owned by farmers, and the cost of irrigation immediately after planting to enable rooting. The requirement per unit work and labour costs were calculated from the results obtained over 3 years, where farmers were employed at the 650 m^2 experimental site. The three Poaceae test plants showed no material differences in maintenance requirements [15]; therefore, the average unit price was used when calculating the construction costs and maintenance cost. The unit costs per 100 m^2 were set at 152.0 GHC for planting, 30.0 GHC for manual weeding, and 8.0 GHC for cutlass slashing (1.0 USD = 3.9 GHC, as of April 2016). When farmers perform maintenance work themselves, they are considered in-house labour costs, and there is no payment.

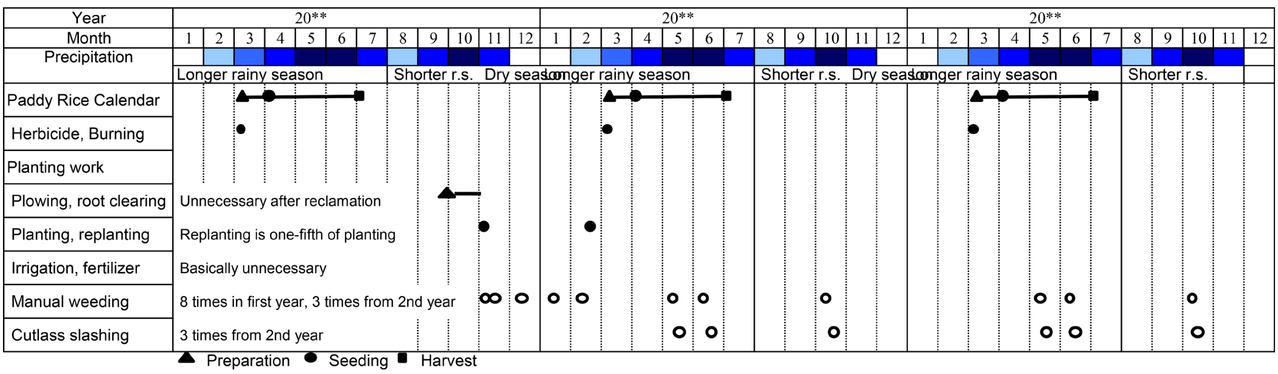


Figure 7. An example of a construction schedule and maintenance plan for planting work.

Although it was excluded from the maintenance work, the unit costs per 100 m^2 were set at 2.1 GHC for spraying herbicide. In other words, spraying herbicide is the most economical method, and 4 times of it costs the same as cutlass slashing, and 16 times of it costs the same as manual weeding, which can control perennial weeds.

3.5. Cost of Construction and Maintenance

The construction cost of the current earthen canal was 642 GHC, the maintenance cost over 10 years was 4,767 GHC (Table 3), and construction and maintenance costs of the concrete canals were 5,000 and 2,500 GHC, respectively (Table 4). In comparison, construction and maintenance costs of developing canals with cover plants were 1,007 and 2,577 GHC, respectively (Table

5). Construction costs were the highest for the "Concrete canal," followed by those for "Canal with cover plant," and "Earth canal." Maintenance costs were the highest for the "Earth canal," followed by those for "Canal with cover plant" and "Concrete canal." Figure 8 plots the total costs—the sum of construction and maintenance expenses—over a 20-year period based on Tables 3-5. When the crossover point was calculated by equating the accumulated total costs, the intersection points indicate that the cost of the existing earth canal surpasses that of the developed canal after 4.2 years and that of the concrete canal after 19.7 years. A short sensitivity check showed that the results for the developed canal remained unchanged compared to the earth canal, but for the concrete channel, the crossover point was 16.0 years if labor costs increased by 10%, and 13.5 years if they increased by 20%.

Table 3. Cost of earth canal (GHC/100 m).

Year	Excavation	Dredging	Cutlass slashing	Total
1	642.0	208.0	76.8	926.8
2	0.0	125.0	230.4	1,282.2
3	0.0	125.0	230.4	1,637.6
4	0.0	125.0	230.4	1,993.0
5	642.0	125.0	230.4	2,990.4
6	0.0	125.0	230.4	3,345.8
7	0.0	125.0	230.4	3,701.2
8	0.0	125.0	230.4	4,056.6
9	0.0	125.0	230.4	4,412.0
10	642.0	125.0	230.4	5,409.4

Table 4. Cost of concrete canal (GHC/100 m).

Year	Concrete placement	Repair	Total
1	5,000.0	250.0	5,250.0
2	0.0	250.0	5,500.0
3	0.0	250.0	5,750.0
4	0.0	250.0	6,000.0
5	0.0	250.0	6,250.0
6	0.0	250.0	6,500.0
7	0.0	250.0	6,750.0
8	0.0	250.0	7,000.0
9	0.0	250.0	7,250.0
10	0.0	250.0	7,500.0

Table 5. Cost of canal with cover-plant (GHC/100 m).

Year	Excavation	Planting	Manual weeding	Cutlass slashing	Total
1	642.0	364.8	460.8	0.0	1,467.6
2	0.0	0.0	172.8	46.1	1,686.5
3	0.0	0.0	172.8	46.1	1,905.4
4	0.0	0.0	172.8	46.1	2,124.2
5	0.0	73.0	172.8	46.1	2,416.1
6	0.0	0.0	172.8	46.1	2,635.0
7	0.0	0.0	172.8	46.1	2,853.8
8	0.0	0.0	172.8	46.1	3,072.7
9	0.0	0.0	172.8	46.1	3,291.6
10	0.0	73.0	172.8	46.1	3,583.4

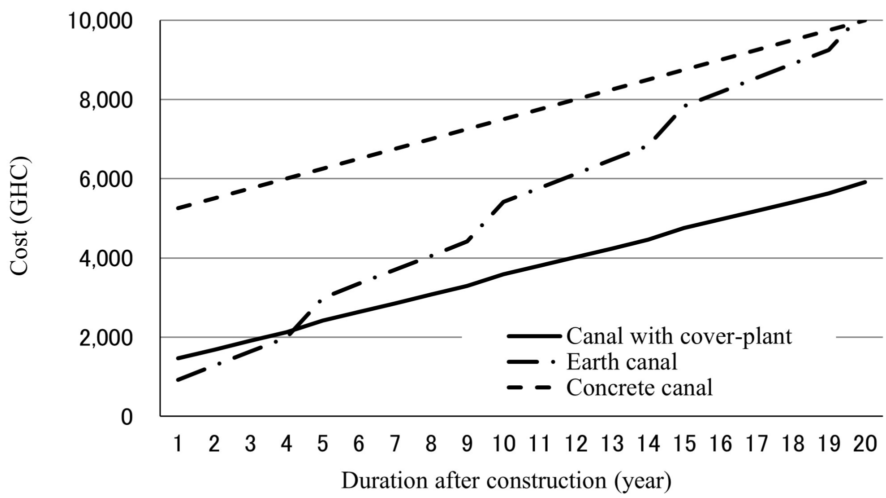


Figure 8. Cost of the canal with cover-plant and the other canals.

In addition, the useful service life, roughness coefficient, and amount of raindrop erosion were compiled from a literature survey conducted in previous years. Overall, "Canal with cover plant" was superior to "Earth canal" and inferior "Concrete canal" regarding useful service life, roughness coefficient, and degree of raindrop erosion (**Table 6**). Using cover plants to reinforce irrigation facilities function can be an effective strategy for minimising the adverse impact of raindrops, improving water-use efficiency, and achieving a long service life of the facilities. It should be noted, however, that while information regarding water-use efficiency and resistance to raindrop erosion were adopted from previous literature, data on weed biomass, cover plant stability, maintenance requirements, and related factors was obtained through direct on-site observation. We acknowledge that the combined use of data from such diverse sources imposes limitations on the generalizability of the functional comparison results.

Table 6. Comparison of the reinforcement technology using cover-plant with other canals.

		Canal with cover-plant	Earth canal	Concrete canal
Construction cost	GHC	1,007	642	5,000
Maintenance cost for 10 years	GHC	2,577	4,767	2,500
Total amount	GHC	3,584	5,409	7,500
Useful service life	year	100<	10-20	40
Roughness coefficient	$s/m^{1/3}$	0.022	0.027	0.015
Raindrop erosion ratio	%	10	100	0

4. Conclusions

The cost of a cover plant system in an irrigation canal was estimated, and a draft maintenance plan for the canal was formulated in this study. (i) Technically, farmers conducted construction and maintenance. Thus, the method was feasible. (ii) Economically, the cost of construction per 100 m and maintenance cost over 10 years of the developing canal were calculated to be 3,584 GHC (equivalent to 920 USD). The amount corresponded to the price of rice yield per 0.9 ha. In the long term, the canal with a cover plant system was more economical than the earth-lined and concrete canals. (iii) Functionally, the developing canal was inferior to the concrete canal but superior to the conventional earth canal. In conclusion, the developing canal and maintenance plan demonstrated feasibility under the controlled conditions of this study; however, broader farmer adoption would require further validation across diverse field environments.

Based on the outputs, a technical manual, including a series of tasks and basic concepts, ranging from the criteria for cover plan selection to the maintenance plan, was created and presented to the Ministry of Food and Agriculture of Ghana in 2018. Considering the termination of the joint research activity, the findings offer information that could facilitate the transfer of the technology to similar regions. Future research should focus on technologies to reinforce natural succession type irrigation facilities according to the target area, such as introducing other native plants or applying mixed communities with woody plants. Overall, the findings of the present study could promote sustainable rice cultivation in West Africa, and in turn, food security.

Acknowledgements

We are grateful for the invaluable advice and encouragement provided by the late Dr. Emmanuel OFORI and the late Ms. Chikako HIROSE in advancing our research. May their souls rest in peace. We also extend our heartfelt thanks to Mr. Stephen GERRAR and Mr. Emmanuel Osei MENSAH for their dedicated efforts at the experimental site. We express our deep appreciation to all of them for their contributions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Papademetriou, M.K. (2000) Rice Production in the Asia-Pacific Region: Issues and Perspectives. FAO-RAP, 4-25.

[2] Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K. and Prasanna, B.M. (2022) Global Maize Production, Consumption and Trade: Trends and R&D Implications. *Food Security*, **14**, 1295-1319. https://doi.org/10.1007/s12571-022-01288-7

[3] Crystal, E. and Whittlesey, P. (2004) The Role of Rice in Southeast Asia. *Education About Asia*, **9**, 50-55. https://doi.org/10.65959/eaa.622

[4] USDA (2021) World Agricultural Supply and Demand Estimates. WASDE-612, 1-38.

[5] USDA (2021) PSD. https://apps.fas.usda.gov/psdonline/app/index.html#/app/advQuery

[6] FAO (1997) Agriculture Food and Nutrition for Africa—A Resource Book for Teachers of Agriculture. https://www.fao.org/4/w0078e/w0078e00.htm#TopOfPage

[7] Juliano, B.O. (1993) Rice in Human Nutrition. FAO, 162.

[8] Juliano, B.O. and Villareal, C.P. (1993) Grain Quality Evaluation of World Rices. IRRI, 205.

[9] Baako, A.M. (2010) Effect of Levees on Soil Water Content, Growth and Yield of Upland Rice at Savelugu Nanton District in the Northern Region of Ghana. *Journal of Developments in Sustainable Agriculture*, **5**, 216-224.

[10] Ministry of Food and Agriculture (2009) National Rice Development Strategy. Ministry of Food and Agriculture in Ghana.

[11] FAOSTAT (2009) Compare Data. http://www.fao.org/faostat/en/#compare

[12] Asubonteng, K.O., Kubota, D., Hayashi, K.H., Masunaga, T., Wakatsuki, T. and Andah, E.I. (2001) Characterization and Evaluation of Inland Valley Watersheds for Sustainable Agricultural Production: Case Study of Semi-Deciduous Forest Zone in the Ashanti Region of Ghana. *Tropics*, **10**, 539-553. https://doi.org/10.3759/tropics.10.539

[13] Cassman, K.G. and Grassini, P. (2013) Can There Be a Green Revolution in Sub-Saharan Africa without Large Expansion of Irrigated Crop Production? *Global Food Security*, **2**, 203-209. https://doi.org/10.1016/j.gfs.2013.08.004

[14] Asubonteng, K.O., Kubota, D., Hayashi, K., Masunaga, T., Wakatsuki, T. and Otoo, E. (2001) Effect of a Sawah-Based Farming System on Rice Cultivation in the Inland Valley Bottom of the Ashanti Region, Ghana. *Tropics*, **10**, 555-564. https://doi.org/10.3759/tropics.10.555

[15] Dan, H., Oki, Y., Hirouchi, S. and Hirose, C. (2017) Feasible Planting Works for Irrigation Facility at the Paddy Field in Ghana. *Journal of the Japanese Society of Irrigation, Drainage and Rural Engineering*, **85**, 51-55. (In Japanese)

[16] Totin, E., Leeuwis, C., van Mierlo, B., Mongbo, R.L., Stroosnijder, L. and Kossou, D.K. (2014) Drivers of Cooperative Choice: Canal Maintenance in Smallholder Irrigated Rice Production in Benin. *International Journal of Agricultural Sustainability*, **12**, 334-354. https://doi.org/10.1080/14735903.2014.909644

[17] Dan, H., Oki, Y. and Hirouchi, S. (2018) Properties Required for Cover Plants to Reinforce the Irrigation Facilities at the Paddy Fields in the Inland Valleys of Ghana.

Research for Tropical Agriculture, **11**, 53-59. (In Japanese)

[18] Daramola, O.S., Adigun, J.A. and Olorunmaiye, P.M. (2020) Challenges of Weed Management in Rice for Food Security in Africa: A Review. *Agricultura Tropica et Subtropica*, **53**, 107-115. https://doi.org/10.2478/ats-2020-0011

[19] National Astronomical Observatory of Japan (2014) Chronological Scientific Tables. Maruzen, 290-314.

[20] Statistics, Research and Information Directorate and Ministry of Food and Agriculture in Ghana (2016) Agriculture in Ghana Facts Figures (2015) Statistics, Research and Information Directorate, 2-7.

[21] Buri, M.M., Ishida, F., Kubota, D., Masunaga, T. and Wakatsuki, T. (1999) Soils of Flood Plains of West Africa: General Fertility Status. *Soil Science and Plant Nutrition*, **45**, 37-50. https://doi.org/10.1080/00380768.1999.10409322

[22] Issaka, R.N., Masunaga, T., Kosaki, T. and Wakatsuki, T. (1996) Soils of Inland Valleys of West Africa. *Soil Science and Plant Nutrition*, **42**, 71-80. https://doi.org/10.1080/00380768.1996.10414690

[23] Dan, H., Adachi, T., Hirouchi, S. and Agodzo, S. (2022) Effect of Planting Work on Resistance to Slaking Collapse of Irrigation Facilities at Paddy Fields in Ghana. *Journal of the Japanese Society of Irrigation, Drainage and Rural Engineering*, **314**, I-29-I-36. (In Japanese)

[24] Haruyuki, D., Tadashi, A., Yoko, O., Sampson, A. and Hannah, A. (2025) Impact Assessment of Cover Plants on Soil Physiochemical Properties of Earth Canals at Paddy Field in Ghana. *Paddy and Water Environment*, **23**, 323-331. https://doi.org/10.1007/s10333-025-01017-8

[25] Rodenburg, J. and Johnson, D.E. (2009) Weed Management in Rice-Based Cropping Systems in Africa. *Advances in Agronomy*, **103**, 149-218. https://doi.org/10.1016/s0065-2113(09)03004-1

[26] Akobundu, I.O. and Agyakwa, C.W. (1987) A Handbook of West African Weeds. IITA, 1-565.

[27] Dokosi, O.B. (1998) Herbs of Ghana. Council of Scientific and Industrial Research, 1-746.

[28] JIRCAS (2017) Plants in Lowland Savanna of West Africa. https://www.jircas.go.jp/en/database/db06

[29] Johnson, D.E. (1997) Weed of Rice in West Africa. Africa, Rice, 1-312.

[30] Fuller, G.D. and Conard, H.S. (1932) Plant Sociology—The Study of Plant Communities. McGraw-Hill, 26-51. ("Braun-Blanquet, J. (1927) Pflanzensoziologie" Was Translated, Revised and Edited.)

[31] Japan International Research Center for Agricultural Sciences (2012) Manual for Improving Rice Production in Africa. Japan International Research Center for Agricultural Sciences, A1-A16.

[32] Hirouchi, S. (2016) A Study on Low-Cost Canal Protection Measures for Sustainable Irrigated Rice Cultivation in West Africa: A Case Study of Lowland Paddy Fields in Ghana. Ph.D. Thesis, Osaka Metropolitan University, 72-98. (In Japanese)

[33] Ministry of Agriculture, Forestry and Fisheries of Japan (1997) Handbook: Economic Effects of Land Improvement. Ministry of Agriculture, Forestry and Fisheries of Japan, 656-664 (In Japanese).

[34] Japan Road Association (2009) Outline of Road Earth Work. Maruzen, 137.

[35] Wischmeier, W.H. and Smith, D.D. (1978) Predicting Rainfall Erosion Losses—A

Guide to Conservation Planning. U.S. Department of Agriculture Handbook 537, 17-33.

[36] Johnson, D.E., Wopereis, M.C.S., Mbodj, D., Diallo, S., Powers, S. and Haefele, S.M. (2004) Timing of Weed Management and Yield Losses Due to Weeds in Irrigated Rice in the Sahel. *Field Crops Research*, **85**, 31-42. https://doi.org/10.1016/s0378-4290(03)00124-2