IMPROVING IRRIGATION MANAGEMENT SYSTEMS FOR RICE FARMING

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ABSTRACT

This Bulletin discusses the many challenges facing traditional rice farming, which include: the need for multi-utilization of farm land; better water resource efficiency; equipment efficiency; lowering of labor costs; and maintenance of ecological functions. In the face of all these challenges, there is a need to introduce and promote new irrigation management systems in rice farming. Some of the recommendations discussed in this Bulletin include: the expansion of rice farming management scales comprised of human, water, and farmland resources; irrigation response strategies during drought; and application of multiple agricultural water resources. It concluded by stating that, in view of recent trends in globalization and economic development, the function of agricultural irrigation water is now clustered into: production function; ecological function; and living function.

INTRODUCTION

Rice paddy is formed by confining water around field block borders with short levees. The inflow (irrigation) and outflow (drainage) functions on this mild-sloped land keep the soil within the borders under saturation conditions (Fig. 1), in which some waterborne economic crops, such as rice, or water caltrop, are planted.

Fig. 1. Basic structure of rice paddy.

Keywords: rice paddy, multi-utilization of farm land, water resource efficiency, irrigation efficiency, deep-water irrigation
From the aspect of water, the irrigation water first flows into field areas through irrigation systems to provide the evapotranspiration as required by crop growth, as well as the conditions to regulate regional climate. It then seeps underground on this vast land to recharge the groundwater, underflow, as well as return flows, then soaks within borders to form temporary reservoirs to detain downstream runoff, as well as optimize wetland to create an intimate space. Finally, the drainage water discharges into downstream farmland to improve the sanitary environment as well as to provide reuse of return flow, thus, a rice paddy irrigation mechanism is completed.

MANAGEMENT SYSTEMS OF RICE PADDIES

Rice paddies have been present since ancient history. In terms of promotion of irrigation efficiency, rice paddies can be classified into two categories by their management scales, one is the large-area rice paddies as shown in Figure 2, and the other is the small-area rice paddies as shown in Figure 3.

Large-area rice paddies mainly exist in the USA and Australia, where the land is broad and population density is comparatively low. Rough agricultural management is applied in these countries as labor costs are high, and from land-preparation, seeding, fertilizing, to harvesting, all works are carried out by large machines, or even airplanes. The advantages are that the irrigation management is simple, and the labor costs are lower; however, the disadvantages are that detailed abnormal crop phenomena can not be observed and taken care of, resulting to poor production and quality.

Small area rice paddies are focused mostly in Asian countries, such as Indonesia and the Philippines. In this case, an irregular shaped rice paddy field is confined by shallow levees in one single village where water resource is

Fig. 2. Large-area rice paddies.
attainable. Another rice paddy field is encircled at lower reach when original crop production does not meet the requirement, and a fish-scale type of land use is formed as time goes by. The advantage is that the irrigation management is simple; however, the disadvantages are that the areas are small and shapes are irregular, and enormous human labor is needed due to low machinery efficiency. Because of the fish-scale land form, no upland crops can be planted during rice cultivation period. In addition, as labor costs are high, this farming type is suitable for family or village members, and would be incompatible to the high-efficiency and low-cost large-area farming type, especially in view of the WTO.

**CHALLENGES FACING TRADITIONAL RICE FARMING MANAGEMENT SYSTEM**

Due to the advent of globalization, the effects of WTO to rice paddy management in various countries are different. There may be more opportunities for the low-cost yet high-quality industries, nonetheless, there may be more competition pressure on the high-cost yet low-quality industries. As a result, the challenges that traditional rice farming management systems face are discussed according to the multi-utilization of farm land, better utilization efficiency of water resources, promotion of equipment efficiency, lowering of labor costs, and maintenance of ecological functions.

**Multi-utilization of farm land**

The dieting habit has been changing from single main crop to multiple choices, and small-area rice paddy of single crops is fading out. Hence, rice-paddies are modified to medium-sized areas in eastern Asia, such as Taiwan, Korea, and Japan (Fig. 4), where rice paddies are well planned. Each block has its independent irrigation and drainage system, which can be operated individually on its own planted crop. However, the freedom to select crops to be planted as well as to adopt irrigation and drainage has also brought difficulties on irrigation management.
Better utilization efficiency of water resources

In order to promote the efficiency of water resources utilization, management responsibilities and obligations should be clearly defined. From the concise viewpoint of “supply” and “demand”, the internationally accepted terms of “on-farm” and “off-farm” systems, as shown in Figure 5, are introduced. The borderline dividing the two systems is defined as the water measuring facilities, where the off-farm (supply) side is normally operated by the government or water resources authorities to provide water sources, and the on-farm (demand) side is normally operated by various water-use sectors. This concept has been widely accepted internationally, and water utilization efficiencies due to institutional problems are expected to improve.

Promotion of equipment efficiency

It has been a worldwide trend to cost down rice cultivation by using large machineries. However, it is still a problem for the medium- or small-area rice farming bodies to introduce large machineries as the lengths of the field blocks are too short, thus, the expansion of management scales seems to be a must for these areas (Fig. 6). Nonetheless, accompanying problems such as dense population, as well as over-dissection of landownership, have shown it to be a rather difficult task.

Lowering of labor costs

The export of farm labor force seems to be a common trend in the areas of medium or small management scales. It can be foreseen that the need to lower labor cost would be an important subject, and can start from the management of water resources as well as farming cultivation.

Maintenance of ecological functions

For countries with medium- or small-scale farms, the interest in managing rice farming would lessen as competitiveness weakens.
Fig. 5. Differentiation between “on-farm” and “off-farm” systems.

Fig. 6. Rice cultivation management of medium- and small-scale farms.
under the WTO. However, from the viewpoint of national security as well as land protection, rice paddy land is irreplaceable and irreversible. Hence, most governments would make every effort to preserve rice paddies.

When the area for rice-paddy decreases, the abundant agricultural water resource could be diverted to other purposes. In the meantime, not only the significant agricultural “return flow” diminishes as the amount of seepage reduces, agricultural production is also affected due to water contamination from domestic and industrial wastes. As a result, the government is now promoting the policy of “water planting.” In other words, the basic functions of ponding and irrigating are retained even during fallow or when rice is not planted, and this seems a good choice to reach the sustainable use of farm land.

IMPRESSING THE MANAGEMENT OF RICE-FARMING

Among the WTO issues, the withdrawal of tariff and non-tariff trade barriers is a major concern. For those industries with comparatively low competitiveness, suffering from losses or even bankruptcy is a possibility if the management style or technology innovation is not adjusted to upgrade their global competitiveness.

Taking Taiwan as an example, the uneven precipitation both temporally and spatially has always been a headache problem in terms of water management. In order to resolve the water problem among sectors, as well as to respond to the impact of joining WTO, the Taiwan government assists farmers in promoting fallow by the unit of collective farming group (e.g., rotational tertiary block). As all plots in the rotation block of the same water supply system are covered under this fallow format, the water conservation effect is significant. Nevertheless, the fallow behavior performed by the random farmers in the non-fallow areas, as shown in Figure 7, draws considerable worries.

According to Japanese experience, these area accounts for nearly over 50% of non-fallow area. As the area as well as locations of this fallow land can not be identified, the establishment of an effective analyzing model is needed in order to reach water-saving purposes. Following are some suggestions on improving the management of rice-farming:

Expansion of rice-farming management scales

There have been plenty of resources in agriculture, however, these resources gradually diminish due to numerous reasons as explained below.

Human resources. As economy grows, the demand for living quality and material things increases, and the general low income group gradually can hardly meet the demand of young generations. The increase in incentive and job offerings of the nonagricultural sector also causes agricultural labor to diversify. The aging problem among farmers has also become significant, adding to the weakening of the quality and quantity of human resources. Lack of agricultural machineries still exists. In fact, the “man-hunting” problem of the agricultural sector from the nonagricultural sector is becoming serious.

Water resources. All civilizations started with agriculture, and agricultural water accounted for most of the total water resources after all the efforts had been put into the irrigation business. However, in many developed countries, such as Taiwan, Japan and Korea, due to the development of the industry and businesses, the improvement of living standard has led to the demand for more public, domestic, as well as industrial water supply. Again, due to the difficulties of developing new water sources as well as the environmental protest problems, the demand to transfer agricultural water resources to nonagricultural sectors has been increasing.

In addition to the decrease in quantity as a result of transferring to nonagricultural purposes, agricultural water quality is decreasing owing to the discharge of domestic and industrial waste water. In many cases, contaminated agricultural water has not been suitable for irrigation purposes.

Farmland resources. Due to economic growth, the demand for city development, city renovation, transportation, regional planning delineation, and other public infrastructure, has
led to the transformation of much fine farm land to nonagricultural uses. Although new farm land is developed, its productivity is hardly as good. Once the farm land resources are transformed to nonagricultural uses, their productivity can hardly be recovered even when returned to agricultural purposes. Nonetheless, in a free democratic society, there is no absolute yes or no on public policies, the so-called public of national interest may be the final judgment, if there is a widely-accepted standard.

If under proper control, the export of agricultural human resources is generally a normal process. The necessary effective incentive to attract or recruit new generation with creativity and competitiveness is needed.

Once the agricultural water resources are transferred, the management of farm land with water shortage would have to adjust. The possible measures include adopting water conservation method, enforcing water management, or quitting agricultural uses.

The irrigation system in rice-cultivation countries such as the USA or Australia has great difference with that in Asian countries. For example, the agricultural states are vast in farm land and low in population density. That is, each farmer owns enormous farm land, the cultivation style is rough in which land preparation, seedling, fertilizing, or harvesting are carried out by machines. Although the unit area production and crop quality at can not compete with those in the Asian countries, their low cost is a big advantage. By the time when better production and quality are reached, the agricultural products from Asian countries will loose their competitiveness.

With the advent of the WTO, farmers’ interest in planting rice has been decreasing, and rice paddies are expected to be deserted. Under this circumstance, the original irrigation water may be wasted. The following suggestions are proposed for reference as well as discussion.

In Asian countries, agricultural management is normally based on families in which the farming scales are mostly small. Hence, there is a need to design a series of accompanying rewards and controlling measures by providing enough incentives so that a collective area of farm land is formed by uniting several farmers’
land by means of leasing. The farming practice of this collective land is conducted by an expert organization, adopting the similar rough farming like that of the USA in order to reduce production cost and to promote competitiveness. As long as the legislative and controlling measures are appropriate such that people’s interests are not harmed, not only the impact of WTO on rice paddy could be reduced, but the cultivation techniques could be improved to increase rice quality for further export opportunities.

Once the small farm lands are collected and concentrated, the ridge borders as well as the small ditches in between blocks will be leveled, and the cultivation area could be increased as well. In other words, agricultural machinery could be introduced, and production could be increased consequently. In addition, the number of gate operation by the water controllers would be greatly reduced, and the irrigation management efficiency would be highly promoted. It is believed that under the profit incentive conditions, more people would participate in agricultural scientific research, and the extension of agricultural and irrigation technology worldwide is expected.

The current irrigation management in the medium-scale rice paddies has the merits of independent operation, however, irrigation and drainage practices are sophisticated that considerable labor is needed to control the gate operations, and are economically inefficient considering that labor costs are high these days. As a result, a new rotational block with an overflow type of irrigation ditches which have higher outer ridge walls and with eliminated inner ridge walls is proposed, as shown in Figure 8. This type of rotation blocks with overflow ditches could not only promote farming efficiency, but also reduce labor costs. In addition, low efficiency problems of introducing large machineries are also resolved.

In order to solve the confusion of land ownership problems when plot ridges are eliminated, a delineation method by installing marking posts is proposed, as shown in Figure 9. With these marking posts, there would be little property dispute problems, more farm land for crops, and higher efficiency for agricultural machinery operations.

As for irrigation efficiency problem, the concept of deep-water irrigation cultivation technique can be introduced. This is to provide rice crop with the right amount of irrigation water when precipitation is plenty. The number of irrigation practice could be

![Fig. 8. Expansion of rice-paddy management scales](image-url)
reduced, and irrigation efficiency could be upgraded. In the meantime, the effective rainfall ratio as well as conveyance loss problems can be effectively resolved.

For example, before 1945, the rice-paddy irrigation water depth in Taiwan followed the Japanese rule of 6 cm. In 1994, the rice-paddy water depth has been raised to 18 cm, then further to 25 cm by 2001. In Taiwan, some rules have been followed consistently for 60 years.

The reaction of people when they first heard about the term “deep-water irrigation” was the survival of the plant under 25 cm depth of water, if it would get drowned during the seedling period. As a matter of fact, “deep-water irrigation” does not start with 25 cm of water depth at the very beginning. Instead, the water depth is raised gradually according to the growth of the crop. In other words, the true meaning of deep-water irrigation is the maximum water depth the field structure could sustain, as shown in Figure 10.

Taiwan has been suffering from frequent droughts recently, so the promotion of deep-water irrigation seems a conflicting idea. Agricultural water is already insufficient for the 6-cm depth irrigation, not to mention the deep-water irrigation. But the fact is, since the temporal distribution of rainfall is uneven, if the excess water during rainfall season could be stored in the vast rice-paddy field, the percentage of agricultural water in the reservoirs could be significantly reduced. This can be exemplified by the 350 thousand acres of rice-paddy field in Taiwan, the volume of the excessive 19 cm depth of water, equivalent to 665 million tons of water, is greater that any of the reservoir capacity in the island.

Whenever rice growth is not affected, water resources, which would normally be discharged to the sea, is diverted and stored in the paddy fields. When water shortage occurs, irrigation practice could hold for some time. Furthermore, the utilization efficiency may be increased by transferring the stored water downstream for agricultural or other purposes.

In irrigation management, as the irrigation water depth in deep-water irrigation could be increased to 250 mm, the estimated rotational irrigation period could thus be lengthened to around 20 days. When the idea of the above-mentioned large-area farms is introduced, the work load of the water controller could be reduced to 1.25 day each time, the irrigation cost is greatly reduced, and the rice price
would be more globally competitive. Furthermore, if more efforts as well as research are put in, such that a rice species more suitable to deep-water irrigation, and with better quality and quantity, the feasibility would be even more favorable.

**Irrigation strategies during droughts**

The rice-paddy field is like a “natural reservoir” with vast area although shallow in depth, and should be carefully utilized. When the “excessive” agricultural water is stored in this natural reservoir, it would be recharging groundwater, underflow, and return flow continuously. The way the irrigation practice consumes water is simply to provide evapotranspiration needed for normal growth, and is far different from those of industrial and domestic water. Consequently, from the viewpoint of effective use of water resources, the introduction of water to be stored in the rice field during wet seasons should be encouraged without restrictions. In other word, water conservation during wet season when water is abundant is meaningless. Instead, how to retain excessive rainfall water in the rice field for operation purposes, to maintain appropriate seepage, to increase ground recharge, to reduce irrigation management cost, and to create a water-friendly environment, are in fact the reasonable ways to manage irrigation water.

The current irrigation water distribution strategy to aid industry by agriculture (Figure 11) is to include the industrial body as a normal operation unit in the Irrigation Association System. When water shortage or drought occurs, the industrial water demand is first fulfilled. Agricultural water distribution measures are then applied according to the drought-endurance of the crops (however, this scenario can be applied only occasionally as saline problem may be unfavorable for the sustainable development of farm land). And when extreme severe water shortage occurs when the industry could not get what it needed even when complete fallow is carried out, emergency measures such as drilling deep well in river bed are required.

The condition of the plan is solely based on the existence of agriculture. Once the agricultural water right is decreased under pressure from various sources, the lack of flexibility may lead to a worst case that even the emergency withdrawal of groundwater is inoperable because the recharge is too few.

![Fig. 10. True meaning for deep-water irrigation](image-url)
Application of multiple agricultural water resources

The increase in industrial and domestic water demand due to the development of economy as well as change in industrial structures has put pressure on agricultural water. Moreover, as the development of water resources is becoming difficult, especially with the advent of the WTO, how to effectively distribute and manage water resources has become an urgent issue. As agricultural water used to account for most part of the water resources in almost every country, a comprehensive water resources policy and regulations are needed. In the future, the goals for agricultural water would be “ecology, living, and production.” In fact, the benefits of paddy fields in ecological and living functions are far greater than their production functions, and their roles could not be ignored. The beneficiaries include not only the low-income farmers, but the entire people. Consequently, the agricultural business must stress on sustainable management in order not only to provide sufficient and safe food, but also for the sake of long-term national security. It is, thus, urged that rice-paddy fields and agricultural water need to be rationally secured and protected.

Although shallow in depth, the agricultural area is a “natural reservoir”, and should be properly used. Unfortunately, some people suggest to increasing water of other sectors by cutting down agricultural water simply because agricultural production value is lower, rice-planting area is decreasing, and consequently the application of water would be less. By doing this, only the ratio of effective use of rainfall has decreased, and it is definitely not an effective use of water resources.

An idea of leasing the fallow areas to the government or industries in order to convert to ponds for water storage purposes could be considered. The surface water storage would not be reduced because of the decrease in rice production; the functions of climate adjustment, groundwater recharge, as well as flood reduction could be retained. In other words, the conventional purpose of rice paddy irrigation is transformed from production to joint functions of production, living, and ecological.

By introducing more water during wet seasons, the stored water in paddy ponds
Table 1. Three functions of agricultural irrigation water

<table>
<thead>
<tr>
<th>Function</th>
<th>Items</th>
</tr>
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<tbody>
<tr>
<td>Production</td>
<td>1. Increase production per unit area</td>
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<tr>
<td></td>
<td>2. Increase cultivation area</td>
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<td></td>
<td>3. Avoid damages of continuous cropping</td>
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<td></td>
<td>4. Improve field soil by settling silts in the irrigation water</td>
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<td></td>
<td>5. Maintain soil productivity</td>
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<tr>
<td>Ecological</td>
<td>1. Replenish groundwater resources</td>
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<tr>
<td></td>
<td>2. Stabilize river flow</td>
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<td></td>
<td>3. Flood control by reducing peak flow (paddy fields as reservoirs)</td>
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<td></td>
<td>4. Mitigate land subsidence</td>
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<td></td>
<td>5. Maintain clean water quality; purify air</td>
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<td></td>
<td>7. Adjust micro-climate</td>
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<td>8. Prevent soil erosion</td>
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<td>9. Desalt</td>
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<td></td>
<td>10. Conserve wetland, and provide sanctuary for water birds</td>
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<td></td>
<td>11. Water resources cycles</td>
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<tr>
<td>Living</td>
<td>1. Improve living environment and sanitary of farms</td>
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<td></td>
<td>2. Provide miscellaneous water and fire hydrant in farms</td>
</tr>
<tr>
<td></td>
<td>3. Aid domestic water supply during water shortage</td>
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<td></td>
<td>4. Promote communication and cooperation among villages via management organization systems</td>
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<tr>
<td></td>
<td>5. Provide comfortable living environment and fair scenery</td>
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<td></td>
<td>6. Provide leisure of cultural education</td>
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<td></td>
<td>7. Stabilize people’s living</td>
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</table>

stays “running”, and provides the best “wetland” ecology for animals as well as plants, groundwater recharge, and environmental conservation, etc. The running water also improves the rural sanitation, creates a friendly environment for farms or villages, and satisfies the demand for the joint functions of production, living, and ecological. In addition, as the utilization ratio is high, this ponded water could not only provide the auxiliary water sources for miscellaneous purposes in normal time, but could also extend availability in times of water deficit during drought.

From the viewpoint of the three joint functions of paddy field, the effective use of water resources, and the maintenance of sustainable productivity of soils, and in order to provide the basic income for farmers without changing yet improving the current paddy field structures, the directions for future agricultural development may include:

A. Maintaining the contribution of rice paddy production;
B. Strengthening the functions of paddy fields to living and ecological;
C. Emphasizing the meaning of rice paddy irrigation to effective use of water resources as well as the maintenance of soil productivity; and
D. Finding a solution to irrigation water by making fully use of fallow areas.

Conclusion

The society has been evolving, and every business nowadays has to keep in pace in order achieve sustainable and multidirectional management of resources. Hence, the role of agriculture in the society is not simply the producer; it now has a multidirectional role, as shown in Table 1 on the three functions of agricultural irrigation water.

Taiwan has joined the WTO in 2001, and the impacts of low-priced agricultural products and cancellation of tariff protection follow. These impacts cannot be ignored in view of the fragile agriculture in island, and are similarly difficult for the countries with small farm land area as well as expensive labor costs, namely Japan and Korea. How to face the crisis, and to quickly propose effective response measures, are the urgent tasks for the governments.