Assessment of water conservation technique in rice culture to develop water use policies

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ASSESSMENT OF WATER CONSERVATION TECHNIQUE IN RICE CULTURE TO DEVELOP WATER USE POLICIES

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The Department of Environmental Studies

By
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August, 2005
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Abstract

The rapid growth of world population has resulted in significantly increased global water demand. According to a recent report on limited water supply, conservation techniques and water use policies are needed to preserve water resources. Worldwide agriculture is the largest consumer of water, particularly for growing rice. Water use for rice production was chosen because rice will continue to be a staple crop for the majority of the world’s population and because of its pervasive use of water. Hence, this thesis was designed to investigate water conservation possibilities for rice production in two water management regimes: alternate flooding and drying, and continuous flooding (the latter is the traditional water management technique in irrigated rice culture). The alternate flooding and drying treatment reduced water use by 13-29 percent and increased rice grain yield by 33-36 percent. Results demonstrate that there is great potential to increase water use efficiency in wetland rice culture without reducing rice grain yield. Moreover, the results can be used to strengthen government water use policies in irrigated rice farming systems.

Keywords: water use efficiency; rice production; water use policy
Introduction

The world’s usable freshwater supply is being depleted because of increasing population, inefficient irrigation, and contamination. Recently reports showed that 20 percent of global population does not have access to safe drinking water, and about 50 percent lack sanitary water (Kirby, 2000). Even though the UN recommends a minimum water requirement of 50 liters per day per person for drinking and other household uses, there are over a billion people having access to less than 50 liters (Kirby, 2004). However, the amount of water needed per person can vary by several factors; for example, a person doing labor in the tropics requires more water intake than a person who works in a temperate zone (Mayell, 2003).

As world population grows, the demand for freshwater is increasing for household uses, for industrial uses, and for food production. Population growth and density also affect the availability and quality of water resources in areas where people obtain their water supply through wells, construction of reservoirs and dams, or diverting the flow of rivers (Kiernan, 1996). Overuse of water can lead to the depletion of surface and groundwater resources, causing water shortages (Merla, 1998).

Water shortage is a major problem worldwide. For example, according to a recent survey in the world’s most populous country China, 60 of 514 rivers ran dry in 2000, while water volume in lakes monitored in the survey fell by 14 percent (Waterconserve, 2005). All major rivers in Northern China are severely polluted (Waterconserve, 2005). These conditions are associated with the rapid growth of Chinese cities and the increase of rice farming combined with other crop culture (Crawford, 2005).
Water levels in the Aral Sea in Central Asia, once the world’s fourth biggest inland sea following the Caspian Sea, Lake Superior, and Lake Victoria, fell by 12.9 meters from 1960 to 1987 (Micklin, 1988). “Today the Aral and surrounding territories are world-known for ecological disasters attributed mainly to anthropogenic factors. With the growth in water consumption connected to cultivation of new irrigated acreage, where mainly cotton and rice are grown, together with the increase in the population working in agriculture, the flow of water to the sea from the two major river systems -the Amu Darya and Syr Darya – has completely stopped” (Anonymous, 2000).

Groundwater is the second most important freshwater resource on earth. As farmers pump groundwater faster than it is recharged by rain, water tables are dropping. For example, the Ogallala aquifer in the U.S. is being depleted at the rate of 12 billion cubic meters per year (Kirby, 2004; UNESCO, 1997).

Agriculture is the largest consumer of water, constituting an average 80 percent of water consumption in developing countries (Gately, 1995). In agricultural cultivation, rice is the only major grain crop that is grown primarily as a human food source. By 2020, the number of rice consumers is expected to increase tremendously because of rapid population growth (IRRI, 1989). By 2025, the world’s population may be reach 8 billion, and the number of rice consumers may equal 5 billion (UN, 2002; IRRI, 2002). To maintain stability with population growth, the world's annual rice production must increase from 518 million tons in 1990 to 760 million tons in 2020 (IRRI 1989).

Rice cultivation uses a large amount of water. It takes about 5,000 liters of freshwater to produce 1 kilogram of rice (IRRI, 2002). Based on 1989 figures, the projected future water usage for rice as demand for it grows, the water requirement usage
for rice production will increase over 45 percent by the year 2020 (IRRI, 1989). Recent research has suggested that water demand in rice fields can be substantially reduced with new management techniques, for example, replacing direct-seeded rice by the traditional method of transplanting rice; developing short season rice varieties; and controlling irrigated water in the rice field. If rice water usage can be reduced, this will benefit future global water problems by maintaining rice yield while also conserving more water.

Developing optimal water management regimes in rice production to reduce water consumption will free-up water for other users. Water use in some growth stages can be reduced with proper management techniques. This research was designed to determine whether water can be conserved in rice production by introducing an alternative rice water management technique, alternate flooding and drying, to replace the conventional method (continuous flooding).

The research was carried out with the following objectives: 1) to identify and develop appropriate hydrologic regimes for improving water-use efficiency in wetland rice cultivation, 2) to verify that rice grain yield does not decrease under water-saving management strategies, 3) to introduce the identified most efficient water use policy at a rice farm scale, and 4) to show why reducing rice production water usage will help alleviate present/ future water shortages and help governments develop policies.
Review of Literature

World Water Supply

Water is continually transported via streams, rivers, ground water, and thru the atmosphere as water vapor, liquid water, and ice (USGS, 1984). Although more than 70 percent of the Earth’s surface is covered by water, the available amount of fresh water usable by humans is less than one percent. This is the water found in lakes, rivers, reservoirs and groundwater (USGS, 1984). According to WWAP (2003), world water resources are in crisis in three key areas; water scarcity, water quality, and water-related disasters. Since at least 5,000 years ago, the use of irrigated water to grow crops had been the primary purpose of fresh water supplies for humans. However, the principal demands of water now are for industrial, household, municipal, and irrigation uses (Globalchange, 2000).

Rice culture is the most intense water consuming farming practice in the world. Water saving techniques for rice culture have long been documented. There are controversial opinions, however, among rice researchers about potential yield loss associated with reducing water use. De Datta (1981) stated that rice grain yield was highly related to the amount of water use. Castillo et al. (1992) reported that draining rice fields at either vegetative or reproductive phases caused significant yield loss. However, the recent research of Shi et al. (2002); and Wardana et al. (2002) has shown that rice grain yield increased with reduced water use, and Lu et al. (2002) found that reducing water use caused no yield loss.

The development of water-use efficiency by using less water to obtain greater rice yield was begun in the early 1900’s when dams became popular as a water management
tool. In the latter part of the 20th century, the “Green Revolution” led humans to rely on irrigation for agriculture. After World War II, water quality for agriculture and household use was impacted by industrial and agricultural chemicals (Globalchange, 2000).

Agriculture is the dominant user of water worldwide, accounting for about 70 percent of all water withdrawn from rivers, lakes, and underground aquifers (Clarke, 1993). Population and economic growth will increase demand for irrigation water to meet the need for increased food production (especially production of rice) requirements, household and industrial water demand. As expressed by one author, “the success of irrigation in ensuring food security and improving rural welfare has been impressive, but past experience also indicates that inappropriate management of irrigation has contributed to environmental problems, including excessive water depletion, by overuse of both surface and underground sources, water quality reduction by contamination of chemicals and water borne diseases, and salinization by intruding of salt water from underground and sea water” (Rosegrant et al., 2002).

Contaminated water supplies also impact health through food consumption because untreated wastewater or contaminated surface water is often used for irrigation in poor communities. Merla (1998) asserts that; “in some countries, lakes and rivers have become receptacles for a vile assortment of wastes, including untreated municipal sewage, toxic industrial effluents, and harmful chemicals from agricultural activities.”

In the regions where groundwater is a major source of irrigation water, such as rice farming in the western part of the U.S., groundwater is depleted when pumping rates exceed the rate of natural recharge. This practice also results in lowered water tables and induced saline water to contaminate the aquifer (Rosegrant et al., 2002). For example,
lateral movement of saline water into fresh water by migration resulting from pumping was detected in areas of eastern and southern Arkansas (Newport, 1977; U.S. Geological Survey, 1984). Saline water can affect plant growth, decrease crop productivity, cause corrosion, and taste problems with drinking water. In addition, chloride concentration can increase above 100 mg/L, which can be harmful to plants and animals (Broom et al., 1984; Morris, 1988). Increased ground water pumping will cause saline water intrusion problems to become more widespread and impact more irrigation and drinking water supplies.

Some scientists believe that freshwater will be a critical limiting resource for many regions. About one-third of the world’s population lives in countries that are experiencing water shortages. In Asia, where water has always been regarded as an abundant resource, per capita availability of water declined by 40-60 percent between 1955 and 1990. Projections suggest that most Asian countries will have severe water problems by the year 2025 (Globalchange, 2000). As one recent article expresses the problem; “by 2050, 54 countries will face water scarcity, with a combined population of about 4 billion people from the world projected population of 9.4 billion” (Gander-Outlaw and Engleman, 1997).

World Water Demand

Recent global water consumption has almost doubled compared to 1950. Rapid growth of the world’s population has been one of the most dramatic changes to the earth over the last century (WWAP, 2003). Population growth has huge implications for all aspects of resource use, including water. Water demand in developed countries has increased because of increasing living standards and population growth. UNFRA (1997)
reported that a child born in the developed world consumes thirty to fifty times the water resources greater than of the one in the developing world. As population increases, freshwater demand increases and supplies per person certainly decrease (Gardner-Outlaw and Engelman, 1997). The recent UN projection for the world’s population is 7.8 billion in 2025, of which 1.2 billion will be in more developed and 6.6 in less developed countries. In 2050, the world’s population will reach 9 billion, an increase from 2025 by 1.2 billion, and the majority of this growth will occur in the less developed countries (UN, 2002). Nearly 7 billion people from sixty countries will confront water scarcity by 2050 (Gardner-Outlaw and Engelman, 1997).

Population growth also increases food demand that requires more water for agricultural production and more irrigated land (WWAP, 2003). Dry-season agriculture has been expanded to increase agricultural production in many countries, particularly in Asia. During the dry season, rainfall is insufficient to support agricultural activities, which must depend on irrigated water. This activities resulted in depleting natural water resources both surface and underground.

Water Use Conflict

Freshwater resources are finite, unevenly distributed worldwide, and often shared by several stakeholders at the local level and by more than one country at the international level. Water scarcity is a serious threat to regional stability, peace, and relationship between countries. According to the United Nations figures show that “some 3000 basins are the scenes of current conflicts” (Swartzberg, 1997). There are many cases of upstream / downstream controversies worldwide. In the Middle East, for example, Israel and the Palestinians continue to negotiate their rights and obligations concerning
their shared water (Demsey, 1999). In Asia, China has plans to build dams on the upper Mekong River, which is regulated only in its lower reaches by a recent agreement concluded between Vietnam, Cambodia, Laos and Thailand (Jacobs, 1996). Thus, freshwater can be a cause of conflict, but it can also become a reason for cooperation, as parties in water-scarce regions combine to manage this crucial shared resource. Water and water-supply systems may become instruments of political confrontation and objectives of military operations as the global population expands (Isaac and Hosh, 1992). Water quality has also become a crucial factor in water availability and source of conflict. In many countries, both developing and developed, current water use is not sustainable because of poor distribution (Charrier et al., 2000).

Water Use for Agriculture

As mentioned earlier, agriculture is the biggest consumer of water worldwide (UN, 2002; IRRI, 2002). Approximately 80 percent of agricultural water supplies go to irrigation. Declining water availability in many countries is a real threat to the sustainability of irrigated rice farming.

Irrigation water for rice farmers in most countries is free and supported by the government. Even though rice growers have to pay for irrigation water in some regions, the current price of water is not reasonable in most of the agricultural areas worldwide (IRRC, 2002). According to Bailey (2002) “the market values of the water ranges from $50 to $100 acre-foot but farmers usually pay about $20-$30. There would be no new federal water projects at all, if evaluated on true cost-benefit value.”

The average rate of water application for agricultural withdrawals is 12,000 m³/ha x world irrigated area (240 million hectares in 1990) = 2,880 km³ (Globalchange, 2000).
In Asia, the availability of freshwater for agriculture is declining because of overuse and pollution (Postel, 1997) while demand for rice is increasing because of population growth (Pingali et al., 1997). Approximately 50 percent of the freshwater used in Asian agriculture is used for rice production (Guerra et al., 1998). Because substantial expansion of the rice growing area is unlikely (Guerra et al., 1998), future rice production gains will have to come mainly from increased yield. Facing increasing demand for food and the increasing scarcity of water, rice producers in Asia and other regions must endeavor to produce more rice with less water (Guerra et al., 1998).

Rice Production

Rice is the world's most important wetland food crop, and the pressure to increase rice production is accelerating. Rice is the only major grain crop that is grown almost exclusively as food. In 30 years, the earth’s population may be 8 billion people (UN, 2002; Rosegrant et al., 2002) and the number people dependent on rice for food may equal 5 billion (IRRI, 2002). Feeding them will require a massive increase in global rice production, and which thus will increase demand for water. Allowing for substitutions of other foods for rice in diets as incomes increase, the world's annual rice production still must increase from 518 million tons in 1990 to 760 million tons in 2020 (IRRI, 1989). This 47 percent increase would merely maintain current nutrition levels, which already are inadequate for hundreds of millions of people (IRRI, 1989).

More than 90 percent of the world's rice is produced in Asia (China and India account for 50 percent of the world rice cultivation area), 3.2 percent in Latin America (Brazil and Colombia account for 62 percent of that production), 2.1 percent in Africa (Egypt and Madagascar account for 48 percent of that production), and 2.5 percent in the
rest of the world (IRRI, 1989). Less than 5 percent of world rice production is traded on the international market (IRRI, 2002). In the United States, rice production is dominant in 6 states; Arkansas, California, Louisiana, Mississippi, Missouri, and Texas. Even though the production acreage is small, the export market share of U.S. rice is in the top five among the rice exporting countries.

Globally cultivated rice using irrigated water supply accounts for 55 percent of all rice acreage (Table 1, p 10). The potential to reduce water use in these rice fields and achieve efficient water use by water management techniques is feasible, especially for countries such as China, India, Thailand, where farmers grow 2-3 rice crops per year (Bouman, 2001).

Table 1. Rice harvested area in the main rice production countries in Asia and USA.

<table>
<thead>
<tr>
<th>Country</th>
<th>Harvested area (1,000 ha)</th>
<th>% Irrigated</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigated</td>
<td>non-irrigated</td>
</tr>
<tr>
<td>India</td>
<td>19,660</td>
<td>22,856</td>
</tr>
<tr>
<td>China</td>
<td>29,636</td>
<td>2,489</td>
</tr>
<tr>
<td>Indonesia</td>
<td>5,926</td>
<td>5,089</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>2,618</td>
<td>8,061</td>
</tr>
<tr>
<td>Thailand</td>
<td>939</td>
<td>8,705</td>
</tr>
<tr>
<td>Vietnam</td>
<td>3,260</td>
<td>3,113</td>
</tr>
<tr>
<td>Myanmar</td>
<td>3,198</td>
<td>3,087</td>
</tr>
<tr>
<td>Philippines</td>
<td>2,204</td>
<td>1,417</td>
</tr>
<tr>
<td>Pakistan</td>
<td>2,125</td>
<td>0</td>
</tr>
<tr>
<td>Cambodia</td>
<td>305</td>
<td>1,594</td>
</tr>
<tr>
<td>Nepal</td>
<td>730</td>
<td>758</td>
</tr>
<tr>
<td>Korea (Rep. of)</td>
<td>776</td>
<td>327</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>628</td>
<td>239</td>
</tr>
<tr>
<td>USA*</td>
<td>1,199</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>73,204</td>
<td>57,735</td>
</tr>
</tbody>
</table>

Source: IRRI 2002; *USDA 2004
Wetland Rice Ecosystem

Wetland rice ecosystems can be classified as irrigated, rain-fed, deepwater, or upland. In irrigated rice fields, the floodwater is fully controlled and kept shallow. In rain-fed rice fields, precipitation controls flooding of soils. During the growing season, soils of rain-fed rice fields may be dried up if rainfall is less, or may be flooded up to 50 cm if rainfall is more. In deepwater rice fields, floodwater rises above 50 cm and it may reach several meters during the growing season. In upland rice fields, the soils are neither flooded nor saturated for any growing period (De Datta, 1981). Most rice is grown in wetlands (irrigated, rain-fed, and deepwater rice); only 13 percent is cultivated in uplands (IRRI, 1989). However, water conserving techniques can only be practiced in the irrigated rice ecosystem.

Major rice acreage in Asia and Africa, which represent over 90% of global rice acreage, is cultivated under irrigated water regime (Figure 1, p 12). In order to increased rice production, demand for water is proportional increased with this irrigated acreage. Usually wetland rice fields have at least one wet growing season (rainy season), but they may be dry in other seasons. These fields may therefore alternately support wetland and upland crops. The transition from wetland and upland cultivation is often gradual and may fluctuate yearly depending on variations in precipitation. Thus, if water (drainage and irrigation) can be fully controlled, farmer has the discretion to establish wetland or upland crops.

Water Management Practices in Wetland Rice Cultivation

Historically, rice is cultivated under a continuously flooded condition in most rice growing countries. A tremendous amount of water is used for rice growing under this
traditional flooded rice culture. Since 1970s, water shortages have been recognized as an important factor in rice production, and the study of water reduction in rice production has become more of a priority in research.

![Figure 1. Rice cultivated area in Asia and Africa, group by water regimes (IRRI, 2002).](image)

Like in other rice producing countries, in the United States (Arkansas, Texas, Mississippi, Missouri, and Florida) rice is grown in both water seeding and dry seeding systems (Linscombe et al., 1999; Miller and Street, 1999) but in California and Louisiana, rice is cultured almost entirely by water seeding.

There are three basic water management practices in the U.S and elsewhere: 1) delayed flooding, 2) pinpoint flooding, and 3) continuous flooding (Street and Bollich, 2003). When a delayed flood is used, fields are drained after seeding for an extended period (usually three to four weeks) before the permanent flood is applied. Pinpoint
flooding is practiced after seeding. The field is drained briefly and then permanently flooded until the rice nears maturity. In continuous flood system, the field is never drained after seeding. This system consumes the most water as compared to other water management practices.

Water Conservation in Rice Culture

Several water saving techniques for irrigated rice have been reported (Bouman, 2001; Bouman and Tuong, 2001). In China, for example, as a result of water depletion in parts of the country, the most widely adopted water saving practice is alternative wetting and drying (AWD). The rice field is allowed to dry for a few days between irrigation events, including a mid season drainage in which the field is allowed to dry for 7-15 days at the end of the tillering stage (4-5 weeks after planting). The potential for water savings in irrigated rice culture is substantial (Bouman and Toung, 2001; Shi et al., 2002; Lu et al., 2002; Wardana et al., 2002).

Tabbal et al. (2002) reported reduced water inputs and increased productivity of rice grown under saturated soil conditions, as compared with traditional flooded rice. Borell et al. (1997) reported that saturated soil culture with rice grown on raised beds reduced the amount of water use by approximately 32 percent as compared with conventional methods.

Water volume requirements for rice culture varies depending on soil texture, number and length of irrigation ditches, soil moisture before flooding, perimeter levees and irrigation ditch seepage, transpiration by plants, and evaporation. These factors play significant role in controlling amount of water requirement in rice culture.
Intermittent drying or keeping soils only saturated during the growing season considerably lowers water requirement in rice culture. In subtropical China, Japan, and Korea, intermittent drying periods are associated with maximal rice yields (Borell et al., 1991). Probably, drying the field can reduce toxicity of organic and inorganic toxins that accumulate from the decomposition of organic materials at the beginning of cropping season (Kongchum, 2005). Short aeration periods at the end of the tillering stage and just before flowering improve wetland rice yields only if followed by flooding (Neue, 1993).

The growing scarcity and competition for water is occurring worldwide. Even in the U.S., which has plenty of water on a national basis, groundwater reserves are being depleted in many areas. Agriculture’s share of total water use will decline because of increasing competition for available water from urban and industrial sectors (van der Hoek et al., 2001). Therefore, water conservation practices are the most priority task for increasing agricultural production, particularly rice culture.

In this research, a strategy and practice was proposed to increase water use efficiently in irrigated rice culture using an alternate flooding and drying water management technique. The advantage of this technique is to reduced water use by keeping field continuously flooded but allowing it to dry intermittently during the growing season. With this water management technique, the potential to produce more rice with less water from irrigated systems would provide opportunities to conserve water resource and improve food security.
Methodology

This study included data collected from two experiments; a pot experiment at the LSU campus during July to October 2002, and a field experiment at the Rice Research Station, Crowley, Louisiana in 2003.

In the pot experiment, water consumption was compared between the continuous flooding treatment (which is the most popular water management system in irrigated rice culture worldwide) and the alternate flooding and drying treatment, which was proposed to be an alternative water management practices in irrigated rice culture. In the alternate flooding and drying treatment, the pots were kept dry for a one week period at the second and the fifth week after planting while in the continuous flooding treatment, the pots was kept flooded for the entire growing season. Water use in the treatment was calculated and compared on weekly basis for the entire season.

In the field experiment, the water management treatments evaluated were similar to the pot experiment. The alternate flooding and drying treatment, the fields were kept dry (no flood water added) for 10 days at the fifth week after planting. Water-use in the field experiment was directly obtained from the daily measurement. In addition, other growth parameters such as dry matter weight, agronomic efficiency, nitrogen use efficiency were measured to verify the effect of water treatments on plant growth.

The main objective of this experiment is to compare amount of water use in both water management treatments used for rice production. Water use was also analyzed as related to other production parameters such as yield, income, and energy consumption. More details for this section are described by Kongchum (2005) and also in Appendix A.
Results and Discussion

Water Use

For the pot experiment the number of flooded days for the alternate flooding and drying treatment was 74 days; in the continuous flooding treatment it was 88 days. Average water level from both water management treatments was decreased 0.6 cm per day during the first week. The highest water level (2.2 cm per day) was reached between the 9th and 12th week (Figure 2, p 17). The average daily water consumption in both water management treatments was 360 mL per pot in the first week and increased up to 1,200 mL per pot per week from the ninth week to the 12th week (Figure 2, p 17).

Total amount of water used over the entire growing season (from planting till harvesting) in the alternate flooding and drying treatment was 85.8 liters, whereas in the continuous flooding treatment was 99.4 liters. These results showed that the alternate flooding and drying water management technique reduced water use by 13.6 percent (Table 2, p 18) as compared to the continuous flooding treatment (traditional water management in irrigated rice farming).

In the field experiment, the number of flooding days in alternate flooding and drying treatment was 79 days, whereas the continuous flooding treatment was 90 days (Table 2, p 18). Total amount of water use in the alternate flooding and drying treatment was 40.6 ha-cm, while the amount of water used in the continuous flooding treatment was 57.2 ha-cm. The alternate flooding and drying water management resulted in reducing water use by 29 percent compared to the continuous flooding treatment. The results from this experiment were similar to results obtained elsewhere (Shi et al., 2002; Lu et al., 2002; and Wardana et al., 2002).
Figure 2. Water consumption in pot experiment, weekly basis.
Table 2. Effect of water management treatments on water-use and energy consumption from the pot experiment (2002), and field experiment (2003).

<table>
<thead>
<tr>
<th>Year</th>
<th>Activities</th>
<th>Energy source</th>
<th>Alt. Flooded and Drained</th>
<th>Continuously Flooded</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>Pumping (d)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flooding (d)</td>
<td>81</td>
<td>95</td>
<td>-14.7 (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water use (liter/pot)</td>
<td>85.8</td>
<td>99.4</td>
<td>-13.6 (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy consumption</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy cost</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>Pumping</td>
<td>64</td>
<td>90</td>
<td>-28.8 (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flooding (d)</td>
<td>79</td>
<td>90</td>
<td>-12.2 (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Water use (ha-cm)</td>
<td>40.6</td>
<td>57.2</td>
<td>-29.0 (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Energy consumption</td>
<td>Diesel (Liter)</td>
<td>136</td>
<td>191</td>
<td>-28.7 (%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric (kWh)</td>
<td>512</td>
<td>720</td>
<td>-28.9 (%)</td>
</tr>
<tr>
<td></td>
<td>Energy cost</td>
<td>Diesel ($) U.S.</td>
<td>67</td>
<td>94</td>
<td>-27 ($)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electric ($) U.S.</td>
<td>49</td>
<td>80</td>
<td>-31 ($)</td>
</tr>
</tbody>
</table>

1 = average of Cocodrie variety  
2 = not include 10 cm for initial flooded  
3 = based on per 1 Hectare-cm (lift from 30 m)  
4 = based on 2003 fuel cost  
5 = www.Louisianagasprice.com  
6 = www.Entergy.com
This research supported that field water management is the important practice for reducing water use in irrigated rice cultivation worldwide.

In the field experiment, the proposed drying period for the alternate flooding and drying treatment was 14 days. Unfortunately, there were many consecutive days of no rainfall (Figure 3, p 20) during the drying period (May 2003). Thus the drying period was cut down to 11 days.

The cost of energy used for the water management techniques used in rice farming varies. The energy use for pumping water associated with water consumption was roughly calculated based on both electricity and diesel fuel prices in 2003. Electricity and diesel used per hectare per season in both water management treatments are showed in Table 2 (p 18). The estimated energy costs in the alternate flooding and drying treatment was $31 and $27 US less expensive than the continuous flooding treatment based on cost of diesel and electricity, respectively. Such results suggested that under the alternate flooding and drying water management practice, farmers would benefit by reducing cost of production rice.

Effect of Water Management Treatments on Rice Plant Growth

Based on the results of the pot and field experiments, plant growth was not affected in the treatment receiving smaller amounts of water (alternate flooding and drying). The effect of flooding alone resulted in increased above ground dry matter weight by 4.67 t/ha in field experiment but no different was measured in the pot experiment. Plant growth measurements are showed in Appendix B. In the field experiment, the rice grain yield dry weight of the alternate flooding and drying treatment
was significantly greater than the continuous flooding treatment by 4.20 t/ha (Appendix C.). The results from these

Figure 3. Monthly rainfall (mm) distribution at the Rice Research Station, Crowley, in 2003.
Experiments demonstrated that the alternate flooding and drying water management treatment increased rice grain yield. These results will be important for use by farmers in making cultivation decisions. Even though the proposed water management techniques can significantly reduce water use, farmers will not accept the alternate flooding and drying water management practice if the growth and yield decrease.

Effect of Water Management Treatments on Agronomic and Nitrogen Use efficiency

Nitrogen fertilizer is important rice growth. Usually, farmers applied nitrogen fertilizer about 2-3 times higher than potassium (K) and phosphorus (P). Agronomic efficiency (kg grain per kg above ground plant nitrogen) and nitrogen use efficiency (kg grain per kg fertilizer N applied) are the indicators to examine grain yield production potential as influenced by nitrogen fertilizer application. Both values are important parameters for use by agronomist in terms of recommending or not recommending alternate flooding and drying water management practice to farmers. The agronomic efficiency in the alternate flooding and drying treatment in both experiments was significantly greater than that of the continuous flooding treatment (Appendix D). The results also showed that nitrogen use efficiency in the alternate flooding and drying treatment was greater than the continuous flooding treatment (Appendix E). Thus, this indicates that the alternate flooding and drying practice would be accepted by agronomists and farmers.

Effect of Water Management Treatments on Farm Income

Farm income is the main objective of most rice farmers. For this research, farm income was calculated based on the grain yield from each of the water management treatments without deducting expenses farmers spend for water management (fuel or
electricity), labor etc. The income from the alternate flooding and drying treatment was significantly higher than the continuous flooding treatment (Table 3, p 22).

Table 3. Effect of water management treatments on total income ($US / ha)*.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rice straw (t/ha)</th>
<th>Alt. Flooded and Drained</th>
<th>Continuously Flooded</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
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<td>559 b</td>
<td>587 ab</td>
<td>-28</td>
</tr>
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<td></td>
<td>4</td>
<td>843 a</td>
<td>636 a</td>
<td>208</td>
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<tr>
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</tr>
<tr>
<td></td>
<td>16</td>
<td>809 a</td>
<td>587 ab</td>
<td>222</td>
</tr>
<tr>
<td>2003</td>
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<td>1026 a</td>
<td>657 b</td>
<td>369</td>
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<td>6</td>
<td>1080 a</td>
<td>679 b</td>
<td>401</td>
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<td></td>
<td>12</td>
<td>1046 a</td>
<td>811 a</td>
<td>235</td>
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<tr>
<td></td>
<td>24</td>
<td>1111 a</td>
<td>897 a</td>
<td>214</td>
</tr>
</tbody>
</table>

In a column under each year, means followed by a common letter are not significantly different at the 5% level by DMRT.

Factors Influencing Water Management Practices

Amount of water use in rice farming varies depending on several factors such as rainfall, soil type, and rice variety. The factors that influence water management treatments implemented by rice farmers are:

1) Rainfall. Rainfall plays a significant role in terms of water supply for the rice farming. In many rice producing countries, farmers rely only on rainfall. Thus, total amount of rainfall over the growing period is the most important factor for reducing water use. The distribution of rainfall is also highly related to amount of water use. From the field experiment, the uneven distribution of rainfall in May (Figure 3, p 20) resulted in greater amount of water use in the alternate flooding and drying treatment.

2) Soil type. Rice soils are ranked from waterlogged and poorly drained to well drained. Soil texture is an expression of the distribution of the various particle sizes in the soils. Soil texture influences transmission and storage of water, flow of air in the soil, and nutrients supplying capacity (De Datta, 1981). Water movement in fine-textured soils (high clay content) is slower than coarse-textured soils (high sand content). Application of irrigated water to coarse-textured soils may increase water losses due to deep percolation and seepage.

Percolation losses occur naturally with the amount governed by topography and soil texture. When the water input is greater than soil water holding capacity it will result in increasing downward movement of water. Where the soil is high in clay content and shallow water table, the losses by percolation are low. In contrast,
where the soil is low in clay content and deep water table, the losses by percolation are high (De Datta, 1981).

This experiment which was conducted in silt loam soil texture (low clay content soil) there might be more water loss via percolation than in high clay content soil.

3) Rice variety. Rice variety plays a significant role in water consumption both by direct consumptive of water (transpiration) and by growing duration or length of maturity. Plant characteristics, which vary among rice varieties, also influenced water consumption. Cocodrie variety was used in this experiment, which was 110-day maturity. Thus if replace this variety with the short-duration rice variety, with less than 100-day maturity, it would use water more efficiently as compared to the variety requiring longer day for maturity.

4) Growing season. The season for growing rice can be classified as wet season and dry season, particularly in tropical countries. Water requirement in dry season is usually greater than in the wet season due to greater evapotranspiration in the dry season.
Conclusions

The results of this research support the thesis that alternate flooding and drying treatment (known elsewhere as alternately flooded and drained, intermittent flooded and dry, or alternately submerged and nonsubmerged) improves water use efficiency as compared to the continuous flooding treatment (traditional water management in irrigated rice ecosystem worldwide). The practice of keeping rice fields dry for some period of time during the growing season resulted in a significant reduction in water use.

Maintaining the rice field dry during mid season not only reduced water use by 29 percent but also significantly increased grain yield by 36 percent as compared to continuous flooding treatment. If alternate flooding and drying practice is adopted worldwide, particularly in the major rice growing countries such as China, India and other Asian countries, where the farmers grow 2-3 rice crops per year, water use would significantly decrease. Using water more efficiently over several geographical regions of the world would help alleviate global water shortages allowing water to be used for other needs.
Recommendations

As a result of these research findings, global water shortages could be alleviated by adapting proper water use protocol, which is the use of alternate flooding and drying water management practice in rice production. Consequently, the IIMI (International Irrigation Management Institute), IWMI (International Water Management Institute), UNEP (United Nations Environmental Program), FAO (Food and Agriculture Organization of the United Nations), IFPRI (International Food Policy Research Institute) etc. should conduct research and encourage use of the alternate flooding and drying water management technique in rice culture.

Groundwater was a major source of irrigated water used in this field experiment. Even though this research does not measure the depletion of groundwater in the study area, there are several articles reported that the depletion of ground water is extremely high, particularly in the country that use groundwater as a main source of irrigation water. Therefore the use of groundwater should be controlled and monitored by concerned agencies in order to prevent overuse.
Proposed Future Water Use Policy in Rice Farming

Real costs of new irrigation systems in many countries more than doubled between 1970 and 1990 (Rosegrant and Svendson, 1993). The increases in cost, together with declining grain prices, result in low rates of economic return for new irrigation construction. If the current trends in water and food demand continue to increase along with the rapid increase in urban populations, the demand for domestic water consumption will rapidly increase, resulting in water crisis worldwide. Overall, the most effective means of dealing with water scarcity is to use water more efficiently in cultivation. Either command and control or economic incentive methods are needed in all sectors both national and international level regulating water use in agricultural. The water use policy should be complied using the following information.

1) Setting the target of reducing water use in rice farms within a definite time period. For example, the target may be for reducing water use by 20% within 10 years. Water use efficiency can be achieved in several ways such as by water management and conservation practices, establishing or increase price of water to farmer and consumer.

2) Educating farmers by providing special training programs on water use efficient and management strategy for reducing consumption. The alternate flooding and drying water management in rice farming should be recommended to rice grower for reducing water use.

3) Pricing—current price of water is not reasonable in most of the agricultural areas worldwide. In most rice producing countries, especially in Asia, agriculture water is worthless resulted in over consumption of water use for agriculture. The pricing
system might be a good tool to control farmers’ behavior with respect to use water for the best benefit of their farming business.

4) Water rights—assign water rights to all sectors in a similar manner as a property right. This idea is to motivate people to care for their property.

This research has shown that the alternate flooding and drying water management treatment in rice culture reduces water use without reducing grain yield. The drying period in irrigated rice cultivation during the growing season is a major factor controlling amount of water used. Longer drying periods will save more water. However, too long drying period might cause grain yield reduction.

Even though pricing policy for water may appear to be reasonable for many scientists and policy makers, this idea is still far from practicable in many developing countries. Most farmers in poor countries might not be able to afford or be willing to buy water from sources once available free of charge. Thus, the pricing policy for water use by farmer might result in limiting rice production.
Recommended Future Research

This research was conducted on the silt loam soil at the Rice Research Station, Crowley, Louisiana. The dominant properties of silt loam soil is less water retention potential as compared to other heavy textural soils such as silty clay loam, clay loam, or clay. The silt loam soil quickly dried after the surface water was removed from the fields. As this point, farmers have to intensively manage and observe their rice fields to avoid water deficiency during the drying period.

Recent research showed that rice variety grown is also a major factor affecting the amount of water consumption. In this experiment, the Cocodrie variety, 110-days maturity, was employed. This variety is well known and is grown in a small specific area such as in the southern part of Louisiana. Therefore, Cocodrie might not be a variety representative for global rice production. Thus, the shorter maturity varieties might have potential to reduce water used greater than this variety.

Further research is needed to determine impact of environment factors such as soil types, rice varieties, duration for drying, and climate on water consumption as related to rice yield. Site-specific water management in irrigated rice farming should be studied worldwide in order to make a recommendation for water management practices. Optimistically, the results will be amplification for establishment of water use policy at the global scale.
References


Gately, D. 1995. Potential for international and national water conflicts is high in coming years according to research organization. Available online at: www.ifpri.org


Appendix A: Materials and Methods

(a) Greenhouse Experiment, 2002

A Crowley silt loam soil (Typic Albaqualf) collected from the LSU Agricultural Center, Rice Research Station at Crowley, Louisiana, was used in this study. Soil samples at 0-20 cm depth were air-dried, crushed and thoroughly mixed. The experiment was conducted.

Ten kilograms of soil was transferred to 3.5-gallon plastic pots. In order to imitate actual irrigated rice farming, which the amount of rice straw leftover after harvesting is usually varying from farm to farm. Rice straw was added in different rates for observing the interaction between amount of rice straw and water management practices.

Rice straw (ground using coffee grinder) was mixed with soil at rates of 0, 4, 8, and 16 t ha\(^{-1}\). A 2 x 4 factorial experiment was arranged in a split-plot design with two water management practices as main plot treatments, and four rates of rice straw incorporation as subplot treatments (0, 4, 8, and 16 t ha\(^{-1}\)), with four replications. Fertilizer application rates were applied in all pots of both water management treatments according to the recommendation of the Rice Research Center’s Technician, LSU AgCenter, Louisiana.

Water Management Treatments

The amount of water consumption was compared between the conventional flooding system (which is the most popular water management system in irrigated rice farming worldwide) and the alternate flooding and drying, which was set up as the alternative water management practices in this cultural system.
In the alternate flooding and drying treatment, the pots were keeping dried for one week period at the second and the fifth week after planting while the continuous flooding, the pots was keeping flooding entire the growing season.

Water-use Measurement

Water use in the pot experiment was measured the total amount of water loss from the pots. This amount of water was accounted for both evaporation and transpiration and then the average values from both water treatments were calculated, excepting during the drying period (2\(^{nd}\) and 5\(^{th}\) week) the amount of water use in the alternate flooding and drying treatment was not included.

Plant Growth and Rice Grain yield

The most powerful parameters (as related to this study) for comparing the efficiency of both water management practices were plant growth, grain yield, including economic. Without these parameters, it is too difficult to prove the effect of both water management treatments, particularly on the rice grain yield and income which are the major goal of the farmers. To compare as scientific basis, rice grain yield from both water management treatments were also compared by using statistical analysis.

(b) Field Experiment, 2003

The experiment was conducted at the LSU Agricultural Center, Rice Research Station, at Crowley, Louisiana during April to August 2003, to verify the results from the greenhouse experiment. All factors in the field experiment are remained same as done in the pot experiment, except for the application of rice straw rates. The experimental design was a 2 x 5 factorial experiment arranged in a split plot design with two water management practices as main plot treatments, alternate flooding and drying, and
pinpoint flooding (which most popular water management practices in the Southern part of Louisiana), five rates of rice straw incorporation as subplot treatment (0, 3, 6, 12, and 24 t ha$^{-1}$), with four replications. Plots size was 2.1 x 6 m.

Fertilizer application rates were also followed the recommendation of the Rice Research Station’s Technician. Nitrogen, phosphorus and potassium were applied to soil at rate of 100-75-75 kg ha$^{-1}$, respectively as pre-plant incorporation and second nitrogen application was applied at 85 kg ha$^{-1}$ (at sixth week after planting). Rice straw was incorporated to an approximately 15 cm depth at the assigned rates using a rotary tiller.

**Water-use Measurement**

The amount of water-use in the field experiment was too complicated to measure because it varied daily depends on several factors such as rainfall, sunlight, wind, soil properties, and growth stage of the rice plant. The amount of water use was directly obtained from the daily observation, except for the raining day. Then these values were calculated on daily basis for the entire season. To verify the data of water use in this experiment, these values were then double checked with the data from research report of previous experiments.

Energy consumptions were calculated basis on the energy use per hectare-cm of water that was pumped from the groundwater reservoir.

Rice growth and grain yields were collected from the experiment of Kongchum (2005) in both water treatments. These data were analyzed by IRRISTAT software (IRRI, 1992). The mean comparisons were obtained with Duncan’s Multiple Range Test (DMRT) for the results in ANOVA that showed significance.
Appendix B. Effect of Water Management Treatments on Above Ground Dry Matter Weight (t/ha).

<table>
<thead>
<tr>
<th>Year</th>
<th>Rice straw (t/ha)</th>
<th>Alt. Flooded and Drained</th>
<th>Continuously Flooded</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>0</td>
<td>8.13 c</td>
<td>7.66 b</td>
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<td></td>
<td>4</td>
<td>11.14 c</td>
<td>8.35 b</td>
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<td>14.29 a</td>
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<td>5.16</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>14.25 a</td>
<td>11.24 a</td>
<td>3.01</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>14.58 a</td>
<td>12.03 a</td>
<td>2.56</td>
</tr>
</tbody>
</table>

In a column under each year, means followed by a common letter are not significantly different at the 5% level by DMRT.
Appendix C. Effect of Water Management Treatments on Rice Grain Yield (t/ha) at 12 % Moisture Content.

<table>
<thead>
<tr>
<th>Year</th>
<th>Rice straw (t/ha)</th>
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<th>Continuously Flooded</th>
<th>Differences</th>
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<td></td>
<td></td>
<td>Alt. Flooded and Drained</td>
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<td>8</td>
<td>5.60 a</td>
<td>3.11 b</td>
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<tr>
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<td>16</td>
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<td>1.59</td>
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<td>6.42 a</td>
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</table>

In a column under each year, means followed by a common letter are not significantly different at the 5% level by DMRT.
Appendix D. Effect of Water Management Treatment on Agronomic Efficiency (Kg Grain per Kg N Applied).

<table>
<thead>
<tr>
<th>Year</th>
<th>Rice straw (t/ha)</th>
<th>Alt. Flooded and Drained</th>
<th>Continuously Flooded</th>
<th>Differences</th>
</tr>
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<tbody>
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<td>40.21 a</td>
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<td>9.90</td>
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<td>20.74 b</td>
<td>16.56</td>
</tr>
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<td></td>
<td>16</td>
<td>38.59 a</td>
<td>28.01 a</td>
<td>10.58</td>
</tr>
<tr>
<td>2003</td>
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<td>25.41 b</td>
<td>14.27</td>
</tr>
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<td>3</td>
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<td>13.24</td>
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<td>12</td>
<td>40.43 a</td>
<td>31.35 ab</td>
<td>9.08</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>42.97 a</td>
<td>34.70 a</td>
<td>8.27</td>
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</tbody>
</table>

In a column under each year, means followed by a common letter are not significantly different at the 5% level by DMRT.
Appendix E. Effect of Water Management Treatments on Nitrogen Use Efficiency (Kg Grain per Kg N of Above Ground Plant Tissue).

<table>
<thead>
<tr>
<th>Year</th>
<th>Rice straw (t/ha)</th>
<th>Alt. Flooded and Drained</th>
<th>Continuously Flooded</th>
<th>Differences</th>
</tr>
</thead>
<tbody>
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<td>2002</td>
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<td>60 ab</td>
<td>83 a</td>
<td>-23</td>
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<tr>
<td></td>
<td>4</td>
<td>73 a</td>
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<td>44 b</td>
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<td>16</td>
<td>41 c</td>
<td>32 b</td>
<td>9</td>
</tr>
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<td>2003</td>
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<td>39 a</td>
<td>41 a</td>
<td>-2</td>
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<tr>
<td></td>
<td>3</td>
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<td>24</td>
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<td>40 a</td>
<td>0</td>
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</tbody>
</table>

In a column under each year, means followed by a common letter are not significantly different at the 5% level by DMRT.
Vita

The author was born in Thailand in 1961. He received his Bachelor of Science in 1983 and Master of Science in 1986 from the faculty of agriculture, Khon Kaen University, Thailand, specializing in soil science both as undergraduate and graduate majors.

He worked for The International Rice Research Institute (IRRI) as a Researcher on “Site Specific Nutrient Management in Irrigated Rice Ecosystems” from 1987 to 2001. He started his doctoral program in the Department of Agronomy and Environmental Management in 2001, under the supervision of Dr. Ronald D. DeLaune. He majored in agronomy with emphasis on wetland soils management, and minored in environmental toxicology. Meanwhile, he is working for Master of Science degree in the Department of Environmental Studies, majoring in environmental planning and management.

He is a member of American Society of Agronomy (ASA), Soil Science Society of America (SSSA), Society of Wetland Scientists (SWS), and Louisiana Association of Agronomists (LAA). He has been serving as an Instructor in the Department of Agronomy and Environmental Management since June 2004.