Water saving technologies for rice production in the Asian region

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ABSTRACT

With increasing global water scarcity, water that is once diverted for agricultural production will be shifted to supply domestic and industrial sectors. Rice culture requires tremendous amount of water compared to other crops. Hence, there is a need to reduce water use in rice production. Several water saving technologies have been identified and developed depending on the availability of water and the stage of the rice production. During the land preparation period, large water losses were observed due to cracks formed after the fallow period. Straw mulching helped conserve moisture in the soil profile and reduced the mean crack width. It also reduced the soil saturation requirement but did not significantly reduce the amount of water input during land soaking. Shallow dry tillage formed soil aggregates which blocked the cracks and reduced total water input for land preparation by 31—34%. Other water saving techniques may be employed during the land preparation stage such as good field channels, good bund management.

Rice crop is established either by transplanting (conventional way) or by dry seeding (DS) or wet seeding (WS). Studies in the Muda Irrigation Scheme, Malaysia showed that land preparation duration was significantly reduced in DS and WS compared with TP, resulting to reduced total water input (rainfall and irrigation) before crop establishment. However, during the crop growth period in the main field, TP had a significantly shorter crop growth duration and lower total water input than DS and WS.

Alternate wetting and drying irrigation (AWD), which is a method of irrigation where water is allowed to dry before the next irrigation, can significantly reduce the amount of irrigation water input by as much as 35% without yield penalty. This technology employs a field water tube which is used to monitor the water level below the soil surface. When the soil dries, and the water level reaches 15 cm below the soil surface, then it is time to irrigate. This threshold level will not cause water stress to the plant and it is also called as “Safe AWD”. Chlorophyll meter based N-management can also be used under AWD conditions. With further decrease in water availability, aerobic rice technology may be employed. Aerobic rice, a production system in rice, is grown in well-drained, non-puddled, and non-saturated soils. With appropriate management, the system aims for yields of at least 4-6 tons per hectare. Compared with flooded lowland rice, aerobic rice requires 30-50% less water.

Dissemination of AWD and other water saving technologies is ongoing in many Asian countries such as the Philippines, Bangladesh, Vietnam, and other Asian countries. Adoption of water saving technologies is increasing in the irrigated ecosystems in the Asian region.

Keywords: Dry shallow tillage, Transplanting, Dry seeding. Wet seeding, Alternate Wetting and Drying (AWD), aerobic rice technology

INTRODUCTION

In 2025, two million ha of irrigated dry-season rice in India and 13 million ha of Asia’s irrigated wet-season rice may experience “physical water scarcity”, and most of the approximately 22 million ha of irrigated dry-season rice in South and Southeast Asia may suffer “economic water scarcity” (Bouman et al. 2005). Evidence of water scarcity at present already exists in some areas brought about by increasing competition among water sectors, which threatens the supply of water for agriculture. For example, in the Zhanghe irrigation scheme (in Hubei, China),...
in the 1960s water allocated for irrigation was 75% of the total water from the reservoir. However, in the ‘90s, only half was allocated for irrigation, in favor of hydropower, industry and municipal water demands. In Kaifeng City (in Hennan, China), water diverted from the Yellow River for irrigation declined by 20% in the 1990s compared with the 1960s (Loeve et al. 2004). In the Philippines’ Angat Reservoir, water is increasingly diverted to Manila for domestic and industrial use rather than for agriculture (Pingali et al. 1997, pp. 196-197).

Rice is known to be less water efficient than many other crops. To produce one kg of rice 3000-5000 liters of water is required. Water scarcity increases the pressure to produce more food and threatens food security of human population. Decreasing water availability for agriculture threatens the productivity of the irrigated rice ecosystem and ways must be sought to save water and increase the water productivity of rice (Guerra et al. 1998). Improving water-use efficiency of rice culture is a pre-requisite for food security in Asia. This paper describes the different methods of water saving in rice production and the dissemination of water saving technologies in Asia. Development and dissemination of Alternate Wetting and Drying (AWD) irrigation will be emphasized.

WATER USE IN RICE CULTURE

The water use in rice culture can be broken down into two phases: (1) the amount of water required to prepare the land for crop establishment (2) and the amount needed to meet the evapotranspiration (ET) requirement and to compensate for the seepage and percolation (S&P) during the crop growth period (Tuong & Bhuiyan, 1999). Among the components of water use in rice culture, only ET is beneficial for crop growth and development. The amount of water used for land preparation and losses to S&P are non-beneficial components, but, must be satisfied. Techniques or practices to reduce non-beneficial water losses are needed to reduce the water input in rice production.

WATER SAVING DURING LAND PREPARATION PERIOD (“GETTING THE BASICS RIGHT”)

High water losses occur during the land preparation stage under conventional tillage methods of puddling. High water losses during land preparation can be attributed to large amounts of water used during the land soaking period due to cracks which reach depths of 20-65 cm. Irrigation for land preparation of the next rice crop, thus, involves water application to cracked soils and results in bypass flow losses (water that flows through cracks to the subsoil) which accounted for 41-57% of the total water applied in the field during land soaking (Tuong et al. 1996). Water loss throughout the period of land preparation may be much greater than this, because cracks may not close after rewetting (Tuong et al. 1996), and bypass flows may continue until soil is re-puddled. This might explain the very high seepage and percolation losses during land preparation of up to 40% of the total water supplied for growing a rice crop (Wickham and Sen, 1978). Soil and water management and cultural practices which may be employed to reduce the losses and “getting the basics right” during the land preparation period are enumerated as follows:

Shallow dry tillage or “Crack plowing”

Employing shallow dry tillage forms small soil aggregates, which can block and impede water flow in the cracks and reduced the amount of water that recharged the groundwater via the bottom of the cracks and crack faces. Water is, therefore, retained better in the topsoil. Shallow dry tillage to fill the cracks before soaking can greatly reduce the amount of water used in wet land preparation. Shallow dry tillage or “Crack plowing” could reduce about 31-34% of the water input for land preparation (Cabangon et al. 2000).

Construction of field channels

In many irrigation systems, there are no field channels (or ‘tertiary’ irrigation or drainage channels) and water flows from one field into the other through breaches in the bunds. This is called “plot-to-plot” irrigation. The amount of water flowing in and out of a rice field can not be controlled and field-specific water management is not possible. This means that farmers may not be able to drain their fields before harvest because water keeps flowing in from other fields. The water that continuously flows through the rice fields may remove valuable (fertilizer) nutrients. Constructing separate channels to convey water for irrigation can hasten water delivery. Drainage channels from each field greatly improve the individual control of water, and are the recommended practice in any type of irrigation system. Alternatively, if field channels can not be constructed for individual fields, they should be constructed to serve a limited number of fields together.
Leveling

A well-leveled field is a prerequisite for good water management. When fields are not leveled, water is deep in the depressions while soil dries faster in higher parts. This results in uneven crop emergence and uneven early growth, uneven fertilizer distribution, and maybe extra weed problems which could lead to difficulty in managing the water.

Good puddling

Thorough puddling results in a good compacted plow sole that reduces the percolation rates throughout the crop growing period. The effectiveness of puddling in reducing percolation depends greatly on soil properties. Puddling may not be effective in coarse soils. On the other hand, puddling is very efficient in clay soils in creating the plow pan. Although puddling reduces percolation rates of the soil, the action of puddling itself consumes water, and there is a trade-off between the amount of water used for puddling and the amount of water “saved” during the crop growth period by reduced percolation rates.

Bund maintenance

Good bunds are a prerequisite to limit water losses by seepage and underbund flows. To limit seepage losses, bunds should be well compacted and any cracks or rat holes should be plastered with mud at the beginning of the crop season. Make bunds high enough (at least 20 cm) to avoid overbund flow during heavy rainfall. Researchers have used plastic sheets in bunds in field experiments to reduce seepage losses. Bouman et al. (2005) demonstrated a reduction of 450 mm in total water use in a rice field by lining the bunds with plastic. Although such measures are probably financially not attractive to farmers, the author has come upon a farmer in the Mekong delta in Vietnam who used old plastic sheets to block seepage through very leaky parts of his bunds.

Community seedbeds

Most lowland rice is established by transplanting rice seedlings from a seed bed into the main field. In large-scale irrigation systems, seed beds are often located in a portion of individual farmers’ fields dispersed in the area. If there are no field channels to separately irrigate the seed beds, the whole field is flooded while the rice plants grow in the seed bed. All water losses from the main field through evaporation, seepage, and percolation, are non-beneficial since no crop grows yet in the field. One solution is to construct field channels that bring water to the seed beds only to avoid flooding the main field. In this manner, the mainfield is soaked and puddled only a few days before transplanting. Seed beds are best located close to the main canals to avoid high conveyance losses. Community seed beds may be an option to concentrate the raising of seedlings in one place to use the irrigation water most efficiently. In some areas, private contractors produce seedlings that farmers can buy.

CROP ESTABLISHMENT (DIRECT WET SEEDING AND DIRECT DRY SEEDING)

Rice may be established by transplanting or by direct seeding methods. The seeds are sown in dry-tiled soil (dry seeding) or wet-puddled soil (wet seeding) Results showed similar yields among different crop establishment methods, but lower water input in direct seeding methods compared with transplanting (Tabbal et al. 2002). When preparing the land wet, as in puddling, the field should initially be worked dry and water added just before the puddling operation. Dry soil tillage helps reduce clod sizes, fills the soil cracks and reduces deep percolation of the water.

Rather than maintaining non-planted main fields flooded while the rice plants grow in the seed bed, pre-germinate seeds are sown on the puddled soil only a few days after puddling and leveling. In a study comparing 30-50 hectare irrigation blocks in the Muda Irrigation System in Malaysia, the total growing season (from land preparation to harvest) is shorter in direct-seeded than in transplanted systems and significantly reduced the water input for rice cultivation (Cabangon et al. 2002). However, when seed beds can be separately irrigated from main fields (i.e., community seedbed), a transplanted system will require less water than direct seeded rice since the total duration of the crop in the main field is shorter (and hence, less water needs to be delivered to the main field).

Large amounts of water (20–40% of total water use) are consumed during wet land preparation for puddled transplanted or wet-seeded rice. Farmers can reduce water use by shifting from puddled to non-puddled land preparation in a direct dry-seeded system. Dry land preparation does not require large amounts of irrigation water since it does not involve land soaking. Dry seeding can also increase the effective use of rainfall through early
crop establishment and hence reduce irrigation needs (Cabangon et al. 2002). However, dry seeding with subsequent flooding is only possible in heavy (clayey) soils with low permeability and poor internal drainage that do not require prolonged puddling to create an impermeable layer.

**WATER SAVING TECHNOLOGIES DURING CROP GROWTH PERIOD**

Several water-saving technologies during the crop growth stage include Alternate Wetting-and-Drying (AWD) and aerobic rice system. These water management strategies during the crop growth period specifically aim to reduce seepage and percolation in the field.

**Aerobic rice system**

A different approach to reduce water inputs in rice is to grow the crop like an irrigated upland crop, such as wheat or maize. Unlike (lowland) rice, upland crops are grown in non-puddled, non-saturated (i.e., “aerobic”) soil without ponded water. Irrigation is applied to bring the soil water content in the root zone up to field capacity after it has reached a certain lower threshold level (Bouman et al. 2005). In China, aerobic system is already being adopted by farmers mostly in the temperate zone using aerobic varieties (Wang, 2002). Though varieties suitable for the tropics are still being developed and tested, there are existing upland varieties that have been tested under tropics and under aerobic soil conditions which have relatively high potential yield. The potential water savings at the field level when rice can be grown under aerobic rice system (like an upland crop) are large (around 30-50% compared with CF), especially on soils with high seepage and percolation rates (Bouman and Tuong, 2001).

**Alternate Wetting and Drying (AWD)**

In Alternate Wetting and Drying (AWD), the field is allowed to dry for a certain period (for a number of days depending on the soil type) before the next irrigation is applied (Bouman and Tuong, 2001; Belder et al. 2004). Grain yields in AWD were reported to be maintained or even exceed continuous flooding (CF) in China (Li, 2001). However, other literatures elsewhere reported otherwise (Mishra et al. 1990; Tabbal et al. 2002). The differences could be due to the differences in specification of the AWD systems such as agro-hydrological conditions (e.g. frequency and duration of drying periods, groundwater table depth). In AWD, water depths are also shallow to reduce seepage and percolation losses by minimizing the hydrostatic pressure (Bouman and Tuong, 2001). In pot experiments, Anbumozhi (1998) described that rice plants exposed to deep ponding water depths of 18 cm cause leaf discoloration, lesser vigor in transplanting recovery and root decay. Plants grown under deep water levels also gave lower yields compared with shallow depths.

A practical way to implement AWD is to monitor the depth of ponded water on the field using a ‘field water tube’. After irrigation, the depth of ponded water will gradually decrease. When the ponded water has dropped to 15 cm below the surface of the soil (equivalent to a soil water potential of -10 kPa, see Fig. 1), irrigation should be applied to re-flood the field with 5 cm of ponded water. From one week before to one week after flowering, ponded water should always be kept at 5 cm depth. After flowering, the water level can drop again to 15 cm below the surface before re-irrigation. AWD can be started a few days after transplanting (or with a 10-cm tall crop in direct seeding). When many weeds are present, AWD can be postponed for 2-3 weeks until weeds have been suppressed by the ponded water. The threshold of 15 cm water depth (below the surface) before irrigation is called “Safe AWD” (Fig. 1) as this will not cause water stress and will not result to yield decline. In “Safe AWD”, water savings are in the order of 15-30%. For flooded rice, local fertilizer recommendations can be used. Moreover, studies showed that Site Specific N-Management (SSNM) can be used under AWD conditions similar to the way it is used under continuously flooded system. Cabangon et al. (2011) reported that there are no significant differences in the relationship between the N-content per unit leaf area and the SPAD readings between CF and AWD (Fig. 2). A SPAD value of 38 or a LCC reading of 3.5 was recommended (Cabangon et al. 2011).

The practice of midseason drainage and intermittent irrigation such as AWD can reduce methane emissions by over 40%. Midseason drainage or reduced water use also creates nearly saturated soil conditions, which may promote N2O production. There are conflicting reports on the net global warming potential (GWP) of midseason drainage, but there seems to be a growing consensus that this practice decreases the net GWP of paddy fields as long as nitrogen is applied in appropriate doses. Hosen In Bohol, Philippines, adoption of
Fig. 1. Soil water potential at different field water depths at IRRI (clay loam soil) and Huibei, China (silt loam soil). Source: Cabangon et al. (2008).

\[ y = 0.073x - 1.1 \quad R^2 = 0.74 \]
\[ y = 0.067x - 0.9 \quad R^2 = 0.70 \]
\[ y = 0.06x - 0.5 \quad R^2 = 0.61 \]
\[ y = 0.065x - 0.83 \quad R^2 = 0.66 \]

Fig. 2. Relationship between leaf N-content per unit leaf area and SPAD reading in continuous flooding (CF), Alternate wetting and drying (AWD low stress and AWD high stress) in 2004 dry season at IRRI. (Na is N-content per unit leaf area). Source: Cabangon et al. (2011).
AWD facilitated improved use of irrigation water and increased rice productivity. It also reduced methane emissions by almost 50% compared to rice produced under CF. The Bohol case is an example of new technologies that increase the income of poor farmers while decreasing GHG emissions. (Wassman et al. 2009).

Hosen (2012) reported that AWD water-saving technology has real potential to reduce the global warming impact of paddy fields to one-third (1/3) of the conventional continuously-flooded field water management. This result was based on a 8-season field experiment conducted at IRRI.

**CONCLUSION**

Farmers adopt technologies in response to conditions in their field or problems in the area, reduce cost of production and increase income, not necessarily due to the desire to save water. For instance, crop establishment methods such as dry seeding and wet seeding were adopted in Muda Irrigation system due to shortage of labor and high cost of labor for transplanting (Ho Nai Kin, 1996). Shallow tillage can be accomplished right after harvest when the soil is still moist for dry tillage. This additional tillage hastens the land preparation specifically the primary tillage plowing since the soil has already been tilled. Farmers can employ shallow tillage to incorporate straw and other organic matter to improve the soil physical and chemical properties. Alternate wetting and drying may be adopted if the water is scarce and farmers are forced to reduce the water supply. However, under normal conditions when water is adequate, it is a normal response for farmers to manage water with CF because it is the traditional practice. Training is an important activity for transferring the concepts, principles and practices behind a technology. Another point is “seeing is believing”. Farmers will likely adopt a technology if they actually see the technology and experience the technology or “learning by doing”. An example is the case study of technology transfer of AWD in a deep tube-well pump irrigation system and farmer-owned shallow tube-well irrigation in the Philippines (Lampayan, et al. 2003). Needs and opportunities assessment (NOA) was conducted which aims to assess the farmers’ problems and constraints, identify potential opportunities for improvement, to develop appropriate solutions to address the problems and educate researchers of farmers’ real problems (IRRI Knowledge Bank). Field demonstration plots comparing AWD and CF were set-up side by side and farmers were requested to manage both. All management practices except water management were similar, i.e. one plot is CF and another is AWD. Demonstration plots are also an opportunity where other farmers may see the performance of a technology versus their current practice. This demonstration plot also serves as a “lighthouse” or a source of information of the new technology which can radiate around its vicinity to many types of people. Farmers’ field schools may be set-up where farmers and researchers can exchange information and experiences on the technology. Harvest festivals may also be conducted for farmers to see the actual yield between the new technique and the current practice. Technology transfer is a complex process and definite details are site specific depending on the bio-physical properties, social orientation and cultural beliefs in the area.

At present, implementation of AWD is increasing in many Asian countries. For instance in the Philippines, technology demonstration plots and practical trainings are being conducted to disseminate AWD to technicians, extension workers and farmers (Lampayan et al. 2004) and in China’s Zhanghe Irrigation system (Loeve et al. 2004). Dissemination activities are also being conducted in other Asian countries such as Bangladesh, Vietnam, Laos, Indonesia, and Myanmar through the Irrigated Rice Research Consortium of IRRI (Lampayan, personal communication).

The extension process must be institutionalized with a strong policy support to hasten the dissemination process (IRRI, 2011). The issuance of A.O. no 25 in 2009 by the Philippines’ Department of Agriculture paved the way for the dissemination of water saving technologies. At present, about 80,000 farmers (covering more than 93,000 hectares) have been trained and have adopted AWD in the Philippines (Table 1). In Bangladesh, a similar ministerial order was passed by the Ministry of Agriculture to facilitate the dissemination of AWD nationwide. Adoption of AWD in Bangladesh has reached around 120,000 hectares. AWD adoption led to 20% reduction in the number of irrigations and a yield increase of about 10% (IRRI, 2011). In Vietnam, around 40,000 farmers have adopted AWD, which cover around 50,000 hectares (Table 2).

Acceptance of the above technologies for farmers depends on the type and level of water scarcity, on the irrigation facilities, and on the socioeconomics situation of their production system. Fig. 3 shows that applicability of different water saving technologies depending in water availability (Tuong et al. 2005). When water is
Table 1. Estimated no. of farmers adopting* AWD in the Philippines (as of May 2011)

<table>
<thead>
<tr>
<th>Region</th>
<th>AWD adoption</th>
<th>Number of farmers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area</td>
<td>Number of farmers</td>
<td></td>
</tr>
<tr>
<td>CAR</td>
<td>10,910</td>
<td>10,888</td>
</tr>
<tr>
<td>Region 1</td>
<td>4,099</td>
<td>10,102</td>
</tr>
<tr>
<td>Region 2</td>
<td>3,312</td>
<td>4,941</td>
</tr>
<tr>
<td>Region 3*</td>
<td>26,652</td>
<td>20,938</td>
</tr>
<tr>
<td>Region 6*</td>
<td>195</td>
<td>147</td>
</tr>
<tr>
<td>Region 7*</td>
<td>8,232</td>
<td>7,577</td>
</tr>
<tr>
<td>Region 11</td>
<td>27,853</td>
<td>17,294</td>
</tr>
<tr>
<td>Region 12</td>
<td>11,760</td>
<td>9,800</td>
</tr>
<tr>
<td>Total</td>
<td>93,014</td>
<td>81,687</td>
</tr>
</tbody>
</table>

* Estimates were taken from national irrigation systems with on-going widescale implementation of AWD, and with on-going demonstration trials and training activities.

Table 2. Estimated AWD adoption in An Giang Province, Vietnam (as of 2011 dry season)

<table>
<thead>
<tr>
<th>District</th>
<th>Total rice Area</th>
<th>Total rice farmers</th>
<th>AWD area (ha)</th>
<th>AWD rice farmers</th>
<th>% area adopting AWD</th>
<th>% farmers adopting AWD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Long Xuyen</td>
<td>5,433</td>
<td>8,117</td>
<td>4,882</td>
<td>7,003</td>
<td>90</td>
<td>86</td>
</tr>
<tr>
<td>2. Chau Doc</td>
<td>7,118</td>
<td>5,724</td>
<td>1,480</td>
<td>440</td>
<td>21</td>
<td>8</td>
</tr>
<tr>
<td>3. An Phu</td>
<td>15,182</td>
<td>-</td>
<td>3,290</td>
<td>-</td>
<td>22</td>
<td>-</td>
</tr>
<tr>
<td>4. Chau Tan</td>
<td>11,906</td>
<td>15,987</td>
<td>2,869</td>
<td>3,162</td>
<td>24</td>
<td>20</td>
</tr>
<tr>
<td>5. Phu Tan</td>
<td>22,387</td>
<td>27,671</td>
<td>4,830</td>
<td>5,788</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>6. Chau Phu</td>
<td>34,128</td>
<td>32,305</td>
<td>10,763</td>
<td>9,425</td>
<td>32</td>
<td>29</td>
</tr>
<tr>
<td>7. Chau Thanh</td>
<td>29,214</td>
<td>27,330</td>
<td>2,558</td>
<td>1,465</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>8. Thoi Son</td>
<td>36,599</td>
<td>30,829</td>
<td>5,106</td>
<td>3,160</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>9. Choi Moi</td>
<td>14,807</td>
<td>30,104</td>
<td>3,634</td>
<td>5,113</td>
<td>25</td>
<td>17</td>
</tr>
<tr>
<td>10. Tri Ton</td>
<td>40,015</td>
<td>13,899</td>
<td>6,987</td>
<td>3,422</td>
<td>17</td>
<td>25</td>
</tr>
<tr>
<td>11. Tinh Bien</td>
<td>16,407</td>
<td>13,728</td>
<td>3,431</td>
<td>1,710</td>
<td>21</td>
<td>12</td>
</tr>
<tr>
<td>TOTAL</td>
<td>233,196</td>
<td>205,694</td>
<td>49,829</td>
<td>40,688</td>
<td>27</td>
<td>23</td>
</tr>
</tbody>
</table>

plenty, farmers can practice CF in lowland rice and obtain the highest yields. But even with sufficient water available, by “Getting the basics right” (good land leveling, bund maintenance, construction of field channels, and thorough puddling in the case of puddled systems) will contribute to good crop growth and high yields. After crop establishment, continuous ponding of water generally provides the best growth environment for rice and will result in the highest yields.

After transplanting, water levels should be around 3 cm initially, and gradually increase to 5 cm with increasing plant height. With progressing water scarcity, establishment options alternative to transplanting can be considered if the turnaround time between soaking and transplanting is relatively large, such as in some large-scale irrigation systems (Cabangon et al. 2002). With community seedbeds,
less water will be consumed to get the crop established by transplanting. Large-scale raising of seedlings would ensure an efficient use of water during that period (main fields do not yet have to be soaked). Both direct wet and direct dry seeding are alternative options. With further increasing water scarcity, water management practices during the whole growing season need to be considered. Instead of keeping a 5–10 cm depth of ponded water during the growing season, the depth can be reduced to around 3 cm. This will reduce the hydrostatic pressure and minimize seepage and percolation losses. Around flowering, from 1 week before to 1 week after the peak of flowering, ponded water should best be kept at 5-cm depth to avoid any possible water stress that could result in spikelet sterility and severe yield loss. The practice of “Safe AWD” can reduce water losses by a small to considerable amount without a yield penalty. If water is getting so scarce that “safe AWD” is no longer possible, the periods between irrigation will have to become longer (letting the water in the field water tubes go deeper than 15 cm) and yield loss becomes inevitable. All forms of AWD require water control by the farmer. With own water sources, such as tubewells, this is not a problem. In community-based or large-scale irrigation systems, a communal approach to AWD is required in which delivery of water to groups of farmers is scheduled to realize a certain pattern of AWD.

Fig. 3. Schematic presentation of yield responses to water availability and soil condition in different rice production systems and their respective technologies to reduce water inputs. AWD = alternate wetting and drying, SSC = saturated soil culture, FC = field capacity, S = saturation point, ΔY = change in yield. Adapted from Tuong et al. (2005).

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