Productive water use in aerobic rice cultivation
(Penggunaan air secara produktif dalam penanaman padi aerob)

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Keywords: aerobic rice, water management, water productivity, yield response

Abstract
Studies were conducted to evaluate both lowland and aerobic rice performances under different irrigation methods and soil moisture regimes. Results showed that aerobic rice cultivated under overhead sprinkler irrigation required least amount of water but more susceptible to foliar diseases. With supplementary irrigation, grain yield obtained ranged from 2.2 to 3.6 t/ha and the seasonal field water requirement was between 442 and 763 mm. Light and frequent irrigation was better when compared to heavy and occasional irrigation to avoid unnecessary water stress that could cause yield reduction. As much as 50% yield reduction was recorded if water stress occurred during heading and early grain formation periods. Despite lower crop yield, studies showed that aerobic rice cultivation used much less water for production. This in turn improved water productivity from 0.4 to 0.6 kg/m³ compared to irrigated wetland rice. The reduction in the water used was mainly attributed to the reduced seepage and percolation losses, decrease in evaporation since there was no standing water in the field, and also water required during pre-saturation period for land puddling was completely discarded.

Introduction
Irrigated agriculture in Malaysia uses three-quarters of the total fresh water supply and more than 90% of that is devoted to lowland rice cultivation (Teh 1998). The traditional irrigated lowland rice production requires continuous flooding and needs high water inputs. It is a crucial move now to develop alternative cultivars and cultivation methods with high water use efficiency to sustain rice production when water catchment areas are dwindling and water supply is inadequate. Water resources are going to be vulnerable with climate change when there is an irregular rainfall for storage. Moreover, increased competition for water from growing industries and an expanding population only adds urgency to find an alternative system of growing rice with less water consumption.

Rice is the major consumer of irrigated water, particularly in the dry season. Lack of rainfall makes cropping impossible without irrigation. Farming communities just have to cope with this water scarcity scenario, by reducing irrigation water to their fields. To safeguard the food industry and conserve water, aerobic rice was introduced. It is fundamentally a different approach of rice cultivation where a high yielding rice is grown in non-puddled and non-saturated fields with supplementary irrigation and high
external inputs (Bouman et al. 2007). When rainfall is insufficient, irrigation is applied to replenish the soil water in the root zone after it has reached a pre-determined threshold level.

In Malaysia, upland rice is grown aerobically in upland environments such as in Sabah and Sarawak (Paul Vincent 2010). The upland rice can give stable but low yields in adverse environments where rainfall is low, irrigation is absent, soil texture is poor or toxic, weed infestation is high, farmers are too poor to supply high inputs and rice is grown as a subsistence crop. Furthermore, they are not responsive to external inputs such as fertilizer and water. Aerobic rice is the combination of both the characteristics of the upland and the high yielding lowland rice varieties (Tuong and Bouman 2003).

De Datta et al. (1973) reported that the cultivation of the high-yielding lowland rice variety (IR20) like an upland crop under furrow irrigation showed that total water savings was 56% and irrigation water savings 78% compared with growing the crop under flooded conditions. However, the yield was lower from 7.9 to 3.4 t/ha. Other studies on non-flooded irrigated rice using sprinkler irrigation and commercial lowland rice cultivars were conducted in Texas and Louisiana, USA (Westcott and Vines 1986; McCauley 1990). The studies showed irrigation water requirements were 20–50% less than in flooded conditions, depending on soil types, rainfall patterns and water management practices. However, the highest yielding cultivars (7–8 t/ha under flooded conditions) had yield reductions of 20–30%.

Experiments conducted in Changping, China reported that the total amount of water supplied during crop growing period ranged from 470–586 mm for aerobic rice and 1000–1500 mm for lowland rice and the yield ranged from 2.5–3.5 t/ha (Bouman et al. 2006). Again, in another field experiment in Guanzhuag, China, the yield of aerobic rice varied from 4.6–6.6 t/ha and was about 27% lower than lowland rice. In this case, total water input of aerobic rice was only 45% of the total water input of flooded rice (1350–1390 mm) (Bouman and Tuong 2001). The field water productivity (WP) values at the field level under typical lowland conditions ranged from 0.2–1.1 kg/m³ (Tuong 1999; Bouman and Tuong 2001). The wide range reflects the large variation in rice yield as well as in evapotranspiration (ET) caused by differences in environmental conditions where rice is grown. Wetland rice was relatively sensitive to water stress in generative stage after panicle initiation (PI) as yield dropped 47% when drought stress happened during that period. In aerobic rice, yield indicated little differences in sensitivity for water stress between before PI and after PI development stages (Bouman et al 2006).

In the Philippines, Atlin et al. (2006) reported aerobic rice yielded 3–4 t/ha using recently developed aerobic rice varieties in farmers’ fields under rainfed upland conditions. Bouman et al. (2005) and Peng et al. (2006) also showed that the tropical aerobic rice variety, Apo, yielded 4.0–5.7 t/ha under aerobic conditions, in the dry season. Evidence of feasible cultivation comes from Brazil and northern China. In Brazil, aerobic rice cultivars have outlined a 20-year breeding programme to improve upland rice with yields of 5–7 t/ha under sprinkler irrigation in farmers' fields (Tuong and Bouman 2003; Pinheiro et al. 2006). These varieties are grown commercially on 250,000 ha in the State of Mato Grosso. In Northern China, aerobic rice cultivars called Han Dao have been developed that yield up to 6.0–7.5 t/ha under flash irrigation in bunded fields (Wang and Tang 2000; Yang et al. 2005; Bouman et al. 2006). Recent research indicated that as little as 600–700 mm of water was needed on soils that have up to 75% sand and only 5% clay and with ground water tables more
than 2.5 m deep (Xue et al. 2008). It is estimated that Han Dao varieties are now being pioneered on some 120,000 ha in the Northern Chinese Plains.

The objectives of this study were to evaluate the crop water requirement for aerobic rice and to evaluate the effects on aerobic rice performance under various methods of irrigation.

Materials and methods
Sites description
The project was carried out at MARDI Seberang Perai Research Station in the northern part of Peninsular Malaysia from 2007 to 2010. Aerobic rice was planted in horticultural plots which were usually planted with grain maize or vegetables. Air temperatures range from 32 °C during the day to 22 °C during the night. Rainfall is common throughout the year averaging 2,400 mm per annum. The first wet season occurs from October to November and the second from April to May. The driest months are from January to February and again from June to July. The main textural class of the soil is sandy clay loam with sand, silt and clay content of 65, 8 and 37% respectively.

Open field experiments
The project was carried out in two phases. The first phase field trials were conducted over three seasons from 2007 to 2009. The first experiment employed split plot design with four replicates. Methods of irrigation were assigned to main plot, whereas different soil moisture regimes were assigned and randomized to subplots. Current high yield lowland rice variety MR 219 and MRQ 74 were used as the test crops and were planted on a plot size of half an acre. Grain yield was obtained using crop cutting test (CCT) of 1 m by 1 m. The harvested grains were dried, winnowed and weighed, then converted to per unit area crop yield based on 14% grain moisture content. For yield component parameters, two samples (25 cm by 25 cm quadrant) were taken from each plot. The performance parameters taken included amount of water applied, crop yield, plant height, panicle length, tiller number, dry matter above ground, filled-grain and empty-grain weights.

The foliar blast disease index was recorded 45 days after sowing following the International Rice Research Institute (IRRI) scoring scale as shown in Figure 1. The

![Foliar Blast Scoring Scale](image)

1–2 = Resistance; 3–4 = Moderately susceptible; 5–7 = Susceptible; 8–9 = Highly susceptible

*Figure 1. Foliar blast scoring scale (from IRRI)*
Water management of aerobic rice

scoring scale ranges from 1 to 9 where 1–2 = Resistance; 3–4 = Moderately susceptible; 5–7 = Susceptible; 8–9 = Highly susceptible. The scoring process starts from picking sampling plants randomly, the number of sampling plants depends on the size of the survey field, then score accordingly to IRRI scoring scale for each sampling point, and average out the scoring scale as the index for the treatment. In this case, 20 sampling plants were chosen for each treatment.

The main treatments were:
Method of water application
- M1 = Overhead sprinkler irrigation
- M2 = Basin irrigation
- M3 = Furrow irrigation

The sub-treatments were:
- T0 = Control (saturated soil condition throughout growing period)
- T1 = Soil moisture tension not more than 30 KPa (field capacity)
- T2 = Soil moisture tension not more than 60 KPa
- T3 = Rainfed after crop establishment
- T4 = Saturated soil condition throughout growing period except 2-week drought stress imposed beginning from heading

The second field experiment involved simpler trials to validate findings from the first field experiment over two seasons. Overhead sprinkler irrigation is used to irrigate the experimental plots. Randomized complete block design was employed with four replicates. Aerobic rice variety was used. Parameter and data recorded were the same as the previous trial. The treatments were:
- T0 = Soil moisture tension not more than 30 KPa
- T1 = Soil moisture tension not more than 60 KPa
- T2 = Rainfed after crop establishment

Glasshouse trials
The second phase involved conducting an experiment using fibre trough (dimension 120 cm wide x 240 cm long and 38 cm deep) in which soil was filled up to 30 cm deep under glasshouse condition. A total of five treatments using randomized complete block design (RCBD) with four replicates were employed. The experimental design and treatments were meant to evaluate the effect of drought stress at different stages of growth using aerobic variety and also to determine the crop ET. The treatments were:
- T0 = Control, (soil was kept above field capacity throughout growing period)
- T1 = 2-week drought stress imposed beginning 30 days after sowing (DAS)
- T2 = 2-week drought stress imposed beginning 44 DAS
- T3 = 2-week drought stress imposed beginning 58 DAS
- T4 = 2-week drought stress imposed beginning 72 DAS

Similar performance parameters as field experiment were taken including amount of water applied, crop yield, plant height, panicle length, tiller number, dry matter above ground, filled-grain and empty-grain weights.

Statistical analysis
All data collected were subjected to analysis of variance in accordance to the experimental design using Crop Stat program from International Rice Research Institute. The least significance difference (LSD) test was used to test differences between treatment means.

Results and discussion
Effects of irrigation methods and soil moisture levels on yield performance
Three field trials were conducted at MARDI Seberang Perai. The first trial was carried out in the off-season (OS) 2007 using wetland rice varieties MRQ 74. Analysis of variance (ANOVA) shows that the effects of soil moisture level on grain yield was significantly different. On the other hand, no
significant irrigation methods and interaction (irrigation method and soil moisture level) effects were obtained. This indicated that methods of water application will not affect the crop yield. However, crop under drought stress irrespective of irrigation methods would suffer yield reduction.

The results from the first trial showed that the yields obtained with different methods of water application were not significantly different from each other (Table 1). The average yield ranged from 2.26–2.99 t/ha.

The yields derived from sub-treatments T0, T1, T2, T3 and T4 in the off-season (OS) 2007 trial which had different soil moisture levels are also shown in Table 1.

Table 1. Grain yield performance with respect to irrigation methods and soil moisture levels at MARDI Seberang Perai in OS, 2007

<table>
<thead>
<tr>
<th>Irrigation methods</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead sprinkler</td>
<td>2.26a</td>
</tr>
<tr>
<td>Basin</td>
<td>2.99a</td>
</tr>
<tr>
<td>Furrow</td>
<td>2.77a</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil moisture levels</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>3.17a</td>
</tr>
<tr>
<td>T1</td>
<td>2.80ab</td>
</tr>
<tr>
<td>T2</td>
<td>2.61b</td>
</tr>
<tr>
<td>T3</td>
<td>1.95c</td>
</tr>
<tr>
<td>T4</td>
<td>2.86ab</td>
</tr>
<tr>
<td>Grand mean</td>
<td>2.67</td>
</tr>
<tr>
<td>5% LSD</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Means followed by a common letter are not significantly different at \( p \leq 0.05 \) level

\[\text{cv (b)} = 10.9 \%\]; interaction = not significant

[cv (b) measures the precision of the sub-plot treatment (soil moisture levels) and interaction effects]

Yields produced from treatments T2 and T3 were significantly lower than treatment T0. Treatments T1 and T4 though yielded lower compared to T0 but not significantly lower. This showed that wetland rice variety is sensitive to drought stress and must maintain the wet soil regime at least between field capacity to saturation to avoid any significant yield reduction. The trend also indicated that decreasing soil moisture content tends to reduce yield. Crop grown under rainfed environment performed badly even though quite significant amounts of rainfall of 750 mm was obtained during the growing period. When drought stress was imposed on treatment T4, the frequent rains nullified the treatment effects and as a result crop performance remained normal.

The second trial was conducted in OS 2008 using aerobic rice variety (RU 9732). ANOVA showed that the yield obtained from rainfed crop was significantly lower compared to T0 (Table 2). Again, yield responses derived from the third trial in OS 2009 further confirmed the results obtained in the preceding two trials (Table 2). Grain yield was still significantly lower for rainfed crops even though aerobic rice is supposed to be more tolerant to drought stresses. Despite that, the crop performed much better under aerobic soil conditions whereas wetland rice always needs saturated soil conditions.

**Effects of irrigation methods on foliar diseases**

While conducting the first field trial to evaluate crop performance, infestations of foliar diseases on different irrigation treatments were also recorded. Likewise,

Table 2. Aerobic rice (RU 9732) performance under different soil moisture levels

<table>
<thead>
<tr>
<th>Soil moisture levels</th>
<th>Grain yield (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Off-season 2008</td>
<td>Off-season 2009</td>
</tr>
<tr>
<td>T0 = Soil moisture tension not more than 30 KPa</td>
<td>3.1a</td>
</tr>
<tr>
<td>T1 = Soil moisture tension not more than 60 KPa</td>
<td>2.8a</td>
</tr>
<tr>
<td>T2 = Rainfed after crop establishment</td>
<td>1.6b</td>
</tr>
</tbody>
</table>

Means with same letters are not significantly different at \( p < 0.05 \) level
ANOVA showed that the effects of irrigation methods on foliar disease were significant at 5% level for OS 2007 crop and also main season (MS) 2007/08 crop to further confirm the study. On the other hand, no significant effect on soil moisture levels and interaction were obtained.

The blast disease index for sprinkler irrigation were significantly higher than surface irrigation (furrow and basin) as shown in Table 3. Between the two surface irrigation methods, crop irrigated using basin irrigation (flooding) was slightly more susceptible to blast disease. Overhead supplementary irrigation showed the most vulnerable to blast disease which might be due to the high humidity growing environment which was conducive to disease development. The overall effects of irrigation methods and soil moisture levels on disease susceptibility are shown in Figure 2.

**Effects of water stress on crop performance**

Short term drought stress experiments were laid out under rain shelter to avoid rain interference while imposing stress treatments. Aerobic rice variety (RU 9732) was used in the trials and started in MS 2008/09 and then continued to the second trial in OS 2009 and again the third season in MS 2009/10. The effects observed would therefore be solely attributed to the stress treatments. The results for the three seasons are shown in Table 4.

Yield responses obtained from three trials in the rain shelter showed that two-week drought stress treatment during heading period (58–71 DAS) consistently caused significant yield reduction compared

### Table 3. Susceptibility of foliar disease to different methods of irrigation

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th>Treatment mean OS 2007 (disease index)</th>
<th>Treatment mean MS 2007/08 (disease index)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead sprinkler</td>
<td>4.3a</td>
<td>4.3a</td>
</tr>
<tr>
<td>Basin</td>
<td>2.4b</td>
<td>2.8b</td>
</tr>
<tr>
<td>Furrow</td>
<td>1.8b</td>
<td>2.4b</td>
</tr>
</tbody>
</table>

Means followed by a common letter are not significantly different at $p \leq 0.05$ level

Disease index: 1–2 = Resistance; 3–5 = Moderate resistance; 5–7 = Moderate susceptible; 8–9 = Susceptible

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**Figure 2. Effects of irrigation methods and soil moisture levels on disease susceptibility**
Table 4. Aerobic rice yield response to two-week drought stress

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (g)</th>
<th>MS 2008/09</th>
<th>OS 2009</th>
<th>MS 2009/10</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0</td>
<td>91.7a</td>
<td>107.6a</td>
<td>100.5a</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>90.3a</td>
<td>111.3a</td>
<td>126.0a</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>62.0b</td>
<td>100.0a</td>
<td>111.0a</td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>56.3b</td>
<td>49.3b</td>
<td>39.7b</td>
<td></td>
</tr>
<tr>
<td>T4</td>
<td>87.3a</td>
<td>83.0a</td>
<td>92.7a</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by a common letter are not significantly different at $p \leq 0.05$

Two-week drought stress treatments during vegetative stage did not affect crop performance. In fact, the treatment crop (T1) yielded marginally higher than the control (Figure 3). Adequate water for the whole growing period is a basic requirement for healthy crop growth and achieving potential yield. In general, when moisture content of the soil decreases, rice yields begin to decline except during vegetative period (30–43 DAS). The most sensitive periods to water deficit is during the early heading period (58–71 DAS) followed by panicle initiation period (44–57 DAS) as shown in treatment T3 which had a 50% yield reduction when drought stress occurred during early heading period.

Field water requirements

Field water requirement studies were conducted at MARDI Seberang Perai in OS 2007. The results showed that the total amount of water required for aerobic rice production ranged from 442 to 763 mm (Table 5). Among the three methods, overhead irrigation was the most efficient method which required only 189 mm from irrigation supply to supplement the rainfall of 253 mm and total amounted to 442 mm for the growing period. Nevertheless, crop under overhead irrigation had disadvantage of disease susceptibility as described earlier. This showed that a large amount of water can be saved from aerobic rice cultivation compared to wetland paddy cultivation which typically requires 1200 mm depth of water (Chan and Chong 2009). The amount of water saved was attributed to exclusion...
Table 5. Field crop water requirements based on different methods of irrigation

<table>
<thead>
<tr>
<th>Irrigation method</th>
<th>Seasonal field crop water requirement (mm)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Irrigation supply</td>
<td>Effective rainfall</td>
</tr>
<tr>
<td>Overhead sprinkler</td>
<td>189</td>
<td>253</td>
</tr>
<tr>
<td>Basin</td>
<td>510</td>
<td>253</td>
</tr>
<tr>
<td>Furrow</td>
<td>398</td>
<td>253</td>
</tr>
</tbody>
</table>

Table 6. Water productivities of wetland and aerobic rice in Malaysia

<table>
<thead>
<tr>
<th>Water requirement (mm/season)</th>
<th>Lowland rice</th>
<th>Aerobic rice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1100–1300</td>
<td>440–760</td>
<td></td>
</tr>
<tr>
<td>1200 (Avg)</td>
<td>560 (Avg)</td>
<td></td>
</tr>
<tr>
<td>Yield (t/ha)</td>
<td>5–7</td>
<td></td>
</tr>
<tr>
<td>6.0 (Avg)</td>
<td>2.2–3.6</td>
<td></td>
</tr>
<tr>
<td>Method of water application</td>
<td>Continuous flooding, Overhead sprinkler &amp; surface irrigation</td>
<td></td>
</tr>
<tr>
<td>Water productivity Index (kg/m³)</td>
<td>0.39</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.57</td>
<td></td>
</tr>
</tbody>
</table>

of pre-saturation for puddling, reduction of deep percolation from flooded field and also evaporation from free water surface.

Seasonal average crop water requirements for aerobic rice and wetland rice are 560 and 1200 mm respectively. Average yield are at 3.2 and 6.0 t/ha respectively. This in turn gives rise to water productivity index (WPI) of 0.6 and 0.4 kg/m³ for aerobic and wetland rice (Table 6). There is a 50% water saving to produce every kilogram of paddy. Even so, the WPI for aerobic rice is still far less than maize which was reported as high as 1.81 kg/m³ (Toung et al. 2005).

This has shown that by growing crop varieties that can tolerate water stress and adopt improved water management practices, farmers can reduce the risk of crop failure from drought and other adverse weather conditions. This in turn will allow them to increase production on marginal land and to cope with short term and long term water deficits under both irrigated and rainfed conditions and at last enhancing food security and improving livelihoods of the farmers.

To obtain a good crop establishment in a dry tilth field for aerobic rice, initial irrigation is a must unless rainfall comes in time soon after sowing. Light and frequent irrigation is better when compared to heavy and occasional irrigation to prevent any unnecessary water stress. A 40 mm depth of water per irrigation in 4 to 5 days interval is shown to be sufficient during active vegetative stages. A shorter interval is needed after panicle initiation until yield formation where the crop reaches its highest ET rate. Based on the schedule, the soil moisture tension can be kept below 30 KPa to avoid any unnecessary water stress that can cause adverse effects on yield.

Under conditions where rainfall is low and irrigation water supply is restricted, irrigation scheduling should be based on avoiding water deficits during the grain formation period followed by panicle initiation to minimize yield reduction.

Conclusion
The current lowland high-yielding rice varieties can certainly be grown under aerobic conditions with supplementary irrigation. Our studies have shown aerobic
rice cultivation saves water, but to a certain extend of yield penalty. On the other hand, adopted aerobic rice varieties that exhibit drought tolerant characteristics with shorter maturation period have shown promising results but the yield is still below wetland rice. Nevertheless, in areas where water is relatively scarce, the best way to maximize total rice production is by growing aerobic rice. At the moment, overhead sprinkler and alternate wetting and drying irrigations are the two supplementary irrigation methods suitable for aerobic rice cultivation.

The choice to determine the most suitable irrigation method depends on field topography, water source, land use, pest and disease incidence, and cultural practices. Research results showed that the overhead irrigation uses lesser amount of water compared to alternate wetting and drying, but the overhead method made the crop more susceptible to disease infestation due to moist crop environment. The two methods produced comparable yield results. Seasonal crop water requirement in off-season 2007 amounted to 560 mm with crop yield around 3.2 t/ha. This was translated to water productivity index of 0.57 kg/m³ which compared favourably to wetland rice of around 0.42 kg/m³. The potential of growing aerobic rice is good when it can be grown as upland crops such as maize and vegetable. The targeted areas can be water-short single cropping lowland rice areas, abandoned paddy fields or even rotational cropping farms near the fringes of rice granary areas. The realization of water savings combined with high yields in aerobic rice depends on good water and soil management, basic understanding of crop-water relationships and irrigation management.

References
Water management of aerobic rice


**Abstrak**

Kajian telah dijalankan dengan menilai prestasi padi aerob dan padi sawah bertakung pada rejim pengairan dan suhu tanah yang berbeza. Hasil kajian menunjukkan tanaman secara aerob dengan bantuan pengairan renjis memerlukan jumlah air yang sedikit tetapi mudah dijangkiti penyakit karah daun. Dengan bantuan pengairan, prestasi hasil yang diperoleh ialah 2.2–3.6 t/ha dan keperluan air mengikut musim penanaman ialah 442–763 mm. Pembekalan air yang sikit dan kerap adalah lebih baik berbanding dengan pengairan sekali sekala yang banyak untuk mengelakkan tanaman mengalami stres akibat tekanan air yang menyebabkan kemerosotan hasil. Sebanyak 50% kemerosotan hasil direkodkan akibat daripada tekanan air terhadap tanaman pada peringkat pengeluaran tangkai buah dan pengisian biji. Walaupun pengeluaran hasil yang rendah, kajian menunjukkan bahawa pertumbuhan tanaman padi aerob menggunakan air yang sedikit. Situasi ini menunjukkan peningkatan produktif penggunaan air antara 0.4–0.6 kg/m³ berbanding dengan sawah bertakung. Pengurangan penggunaan air disebabkan kurangnya ketirisan, kehilangan akibat penyerapan dan penyejatan memandangkan tiada lapisan air yang bertakung dan juga penjimatan air yang diperlukan untuk memenuhi sawah bertakung.

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