Aerobic rice in China: opportunities and challenges

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Abstract

Aerobic rice is a production system in which especially developed rice varieties are grown in nonsaturated soils without ponded water just like wheat or maize. The target environments are areas where water is not enough to grow conventional lowland rice. In northern China, breeders have developed “aerobic rice” varieties since the mid-eighties; these are grown on an estimated 80,000 ha. However, there is little knowledge on obtainable yields and water requirements to assist farmers in improving their management. We present results from field experiments with aerobic rice variety HD297 in 2001-06. The ORYZA2000 model was used to extrapolate the experimental results to different weather conditions, irrigation management, groundwater depths, and soil types. The highest experimental yields were 5-5.6 t ha⁻¹ with 600-700 mm total irrigation plus rainfall water. Yields were 2.5-4.3 t ha⁻¹ with 450-550 mm water input. Low yields (down to 0.5 t ha⁻¹) were obtained with dry soil (water tension > 100 kPa) around flowering because of high spikelet sterility. The average seasonal evapotranspiration requirement was about 600 mm. Simulation modeling suggests that yields can go up to 7-8 t ha⁻¹. To further increase yield and productivity of aerobic rice in the North China Plain, we suggest increasing yield through improved crop management practices and develop varieties with increased yield potential. We conclude that aerobic rice holds promise for farmers in water-short irrigated or rainfed environments where water availability is too low or too expensive to grow flooded lowland rice.

Media summary

Aerobic rice provides an option to farmers to grow rice with less water.

Key words

Aerobic rice, ORYZA2000, water scarcity, North China Plain

Introduction

China annually produces about 176 million t of rice, which is produced on 29 million ha of mostly irrigated lowlands (Maclean et al., 2002; FAOSTAT, 205). Lowland rice fields have relatively high water requirements and their sustainability is threatened by increasing water scarcity (Bouman and Tuong, 2001). Water is especially scarce in the North China Plain that contains 26% of China’s cultivated land and produces 24% of all China’s grains (Geng et al., 2001). Rainfall is barely sufficient to support a one-season crop and grain production relies heavily on surface and groundwater resources. However, both water resources are being over-drafted to satisfy the increasing demands of agriculture, industry, and domestic use (Geng et al., 2001). New technologies need to be developed to assist farmers to cope with water shortages in rice production. The project “Developing a system of temperate and tropical aerobic rice in Asia (STAR)” undertook strategic research to develop sustainable aerobic rice systems for water-scarce irrigation and rainfed environments in Asia. Aerobic rice is a production system in which specially developed rice varieties are grown in well-drained, nonpuddled, and nonsaturated soils without ponded water. Evidence of feasibility comes from northern China, where breeders have produced first-generation (temperate) aerobic rice varieties that use only 50% of the water used in lowland rice. However, sustainable crop-soil-water management recommendations are lacking. This paper presents the results of a number of experiments with aerobic rice variety HD297 in 2001-06. The findings provide insights into key processes of water and nutrient dynamics, key sustainability issues, and target domains for aerobic rice system.
**Methods**

The research methodologies adopted in the aerobic rice project in China included on-farm field experiments, participatory varietal selection trials, simulation modeling, Geographic Information System, and farmer surveys. Water and nutrient dynamics were studied in on-farm field experiments and with simulation modeling. In China, results of water and nitrogen (N) experiments done in two locations near Beijing (Changping and Shangzhuang) were synthesized for the period 2001-06. In all these experiments, aerobic rice variety HD297 was direct dry-seeded, with 3-5 irrigation water treatments aiming at different amounts applied and distribution over the cropping season. Full experimental details of the Beijing experiments are given by Yang et al. (2005), Bouman et al. (2006), Xue et al. (2007), and Zhang et al (2008). We used the crop growth simulation model ORYZA2000 (Bouman et al., 2001) to extrapolate experimental findings to wider environments (soil, weather, hydrology) and compute irrigation water requirements and yield levels under different irrigation management scenarios. Two studies were done in China: one extrapolating experimental data from Kaifeng and another extrapolating experimental data from Beijing to soils of the Yellow River Basin. The Kaifeng study was reported by Feng et al. (2007) and Bouman et al. (2007). Here, a summary of the simulation study using the Beijing data is presented, adapted from Xue et al. (2008).

**Results**

A large number of aerobic rice varieties were identified for northern China, depending on local climate and cropping systems. Between 1986 and 2005, 58 aerobic rice varieties have been released. In our experiments, yields of up to 6 t ha\(^{-1}\) were obtained with HD502 and HD297 in aerobic soil with soil water potentials at 20 cm depth going beyond 100 kPa.

Table 1 presents the results of the irrigation experiments. The experiments in 2001-02 were discussed by Yang et al. (2005) and Bouman et al. (2006); the experiments in 2003-04 are analyzed by Xue et al. (2007), and those in 2005-07 by Zhang et al (in prep 2008). Here, we only present major highlights. At Changping (2001-04), with sandy soil and deep groundwater table, soil water tensions varied between 10 kPa (field capacity) and beyond 90-100 kPa, which was the upper limit of the tensiometers. The highest amount of water applied (irrigation plus rainfall) was 769 mm in W0 in 2001; the lowest was 469 mm in W4 in 2002 (Table 1). The highest amount of water applied was 668 mm in W1 in 2005 and the lowest was 450 mm in W3 in 2006.

Our yield levels (Table 1) compared well with other reports for aerobic rice HD297 in northern China. At another site close to Beijing, Tao et al. (2006) reported yields of 5.7-6.1 t ha\(^{-1}\) with irrigation applied when soil water tension at 15 cm depth exceeded 15 kPa, resulting in around 1400 mm total water input. In field experiments near Kaifeng (34° 82’ N, 114° 51’ E; 69 m asl), Feng et al. (2007) obtained relatively lower yields of 2.4-3.6 t ha\(^{-1}\) with 750-1,000 mm total water input. In the same area, however, Bouman et al. (2007) reported farmers’ yields of HD297 up to 5.5 t ha\(^{-1}\) with sometimes as little as 566 mm total water input but with groundwater depth varying between 20 and 200 cm. In our experiments, highest yields of 5.3-5.6 t ha\(^{-1}\) were obtained at Changping despite the drier soil conditions there, whereas the yields at Shangzhuang (with wetter soil conditions) were not higher than 5.1 t ha\(^{-1}\) (Table 1). Even with low amounts of total water input, yields were still higher than 2.5 t ha\(^{-1}\) in all years, except in 2003, where yield declined to 0.5 t ha\(^{-1}\) in W4. The low yields in 2003 were mainly caused by very low grain filling realized in all treatments, but especially so in W3 and W4. Around the time of flowering, from 77 to 97 d after emergence (DAE), less than 10 mm rainfall was recorded, with only 40 mm irrigation applied in W1 and W2, and no irrigation in W3 and W4. Rice was very sensitive to drought around flowering, which led to increased spikelet sterility and decreased grain filling.

Using the crop growth simulation ORYZA2000 to extrapolate the experimental results to different weather conditions, irrigation management, and soil types, we quantified yields, water inputs, water use, and water productivities. Average maximum simulated yields were 6.8-7.5 t ha\(^{-1}\) with soil water potentials in the root zone staying between 0 and 100 kPa. Water productivity with respect to total water input was 0.89-1.05 g grain kg\(^{-1}\) water, and that with respect to evapotranspiration was 1.28-1.42 g grain kg\(^{-1}\) water.
Figure 1 shows the cross-over points in terms of water availability where aerobic rice gives higher yields than flooded lowland in Changping field experiments (Yang et al. 2005). Two aerobic rice varieties (HD297 and HD502) and one lowland variety (JD305) were grown under flooded conditions and under aerobic soil conditions with different amounts of total water input ( irrigation and rainfall). Under flooded conditions with 1,300-1,400 mm water input at the right-hand side of the horizontal (water) axis, lowland variety JD305 gave highest yields of 8-9 t ha$^{-1}$. The yield of JD305, however, quickly declined with increasing water shortage and aerobic soil conditions. With less than 900 mm water input and under aerobic soil conditions, aerobic rice varieties HD297 and HD502 outperformed the lowland variety.

Table 1. Amounts of water inputs by irrigation plus rainfall (mm) and yield HD297 (averaged over N levels) for 5 water treatments at Changping, 2001-2004 and Shangzhuang, 2005-2006.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Total water input (mm)</th>
<th>Average yield (t ha$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W0</td>
<td>644</td>
<td>769</td>
</tr>
<tr>
<td>W1</td>
<td>577</td>
<td>708</td>
</tr>
<tr>
<td>W2</td>
<td>586</td>
<td>620</td>
</tr>
<tr>
<td>W3</td>
<td>519</td>
<td>695</td>
</tr>
<tr>
<td>W4</td>
<td>469</td>
<td>547</td>
</tr>
</tbody>
</table>

Figure 1. Yield of aerobic rice varieties (black diamonds) and a lowland variety (open diamonds) under flooded and aerobic soil conditions, Changping, 2001-04 (data from Yang et al, 2005).

Conclusions

In China, maximum aerobic rice yields of HD297 in controlled field experiments were 5-5.6 t ha$^{-1}$ with 600-700 mm total irrigation plus rainfall water. Yields were 2.5-4.3 t ha$^{-1}$ with 450-550 mm water input, while yields dropped to 0.5 t ha$^{-1}$ in very dry soil (water tension higher than 100 kPa) around flowering, which increased spikelet sterility. Irrigation is essential at flowering time if there is no rain. The average seasonal evapotranspiration (ET) requirement was 600 mm. With shallow groundwater, capillary rise can meet most of the ET and there may be no need to irrigate. With deep groundwater tables, the net irrigation needs are 167 mm in a typical ‘wet rainfall year’ (two times irrigation), 246 mm in a typical “average rainfall year” (three times irrigation), and 395 mm in a typical “dry rainfall year” (four to five times). Simulations and field experiments showed that, on typical freely draining soils, aerobic rice yields with HD297 can reach 6 t ha$^{-1}$ with 477 mm rainfall and 112-320 mm irrigation water. In northern China, the target areas are where water availability (rainfall with or without supplementary irrigation) is 400-900 mm during the cropping season. In the central part
of the Yellow River Basin (Kaifeng area), and in most of the North China Plain, attainable yields of 5-6 t ha\(^{-1}\) are possible with 0-220 mm irrigation application (in average rainfall years; groundwater 2 m deep or less).

References

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