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Aerobic rice, a water-saving rice production system, and the risk of yield failure – a case study from the Philippines

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Abstract

Aerobic rice is a water-saving rice production system for water-short environments with favorable soils where adapted, potentially high yielding varieties are dry seeded into fields that are maintained at aerobic non-submerged conditions. Supplementary irrigation is applied as necessary. In the Philippines, wet season yields were 4 to more than 5 t ha^{-1}. In the dry season (DS), however, yields ranged from more than 6 t ha^{-1} to complete failures of yield. The possible reasons are low soil moisture itself, nutritional problems associated with aerobic soil conditions, and soil health problems such as parasitic nematodes, pathogenic fungi or allelopathy. Dap Dap, a location with sandy loam soil in Luzon, the Philippines, where such a collapse of yield occurred in previous experiments was selected for a case study. As in those earlier trials, root-knot nematodes were observed in high numbers, and these were suspected to be the main problem. Two treatments were implemented in the DS 2006 and 2007 at four replications in a randomized complete block design using the improved upland variety Apo: a) control of direct dry seeded rice and aerobic soil conditions b) as control but with biocide application (Dazomet at 50 g ai m^{-2}, incorporated in 15 cm depth) to eliminate biotic stresses. Irrigation was applied regularly to avoid severe water stress; irrigation amounts were recorded as well as soil moisture tensions. Yield, and at crucial crop growth stages biomass development was measured and root-knot nematodes counted. The status of root health was assessed from biweekly root samples, using a grading scale from 1 to 9, and from an examination and isolation for root pathogens of these samples. Plant samples from mid-tillering and panicle initiation stages were analyzed for nutrient deficiencies and the effect of biocide application on soil nitrate and ammonium was assessed through KCl-extractable N from soil samples collected at different crop growth stages. In this poster, 2 year's results and their analysis will be presented.

Introduction

Aerobic rice is a water-saving rice production system in which potentially high yielding, fertilizer responsive adapted rice varieties are grown in fertile aerobic soils that are non-puddled and have no standing water. Supplementary irrigation, however, can be supplied in the same way as to any other upland cereal crop (Wang et al., 2002; Bouman et al., 2005). In temperate areas in northern China about 140 000 ha are already cultivated with aerobic rice using "Han Dao" varieties that are especially adapted to the aerobic soil conditions. The yields that can be obtained here range from 4.5 to 6.5 t ha^{-1} (Wang et al., 2002). For the tropics, the aerobic rice system is still under development. But also here, high yields can be obtained; in transplanted aerobic rice, e.g. up to 6 t ha^{-1} (Bouman et al., 2005); but even though yields remained generally greater than 3 tha^{-1}, a gradual yield decline was observed under continuous cultivation. The incidence of very variable yield and complete yield failure were observed in the dry season (DS) in the Philippines. Yield decline or failure is often associated with “soil sickness”; a “reduction in growth and yield by continuous monocropping of the same land is called soil sickness, which is a general term that does not specify causal agents. Yield decline in continuous cropping may result from interwoven factors including build-up of soil-borne pathogens, depletion of mineral nutrients, and accumulation of toxic substances (allelopathy)” (Ventura et al., 1984). Yield decline has also been reported from aerobic rice systems in Brazil (Fageria and Baligar, 2003; Pinheiro et al., 2006) where this phenomenon has been attributed to “autotoxicity”. Other possible reasons for declining yields or even complete failures are soil borne pests and diseases. Prot et al. (1994) identified root knot nematodes (RKN) (*Meloidogyne graminicola*) as a potential threat in upland rice systems and intermittent irrigation systems in the Philippines. One example for a complete yield loss is a water by N experiment at Dap Dap on Luzon island for which water-shortage or N limitation was unlikely the cause of yield failure as the trial included low water-stress and high N level treatments. RKN, however, were observed in high numbers. For crop management practices, the identification of the major cause to limited crop growth is important. A first step would be a rough division into abiotic and biotic factors. Therefore, we conducted this case study to verify if biotic factors, especially RKN, were the main cause for the previous yield collapses.

Material and Methods

The experiment was conducted during the DS 2006 and 2007 at Dap Dap in Tarlac province in Central Luzon, The Philippines, at a site with loamy sand (71% sand, 22% silt, and 7% clay). Four main treatments of which 2 are presented here were implemented in a randomized complete block design with 4 replications: Control: un-treated soil and direct seeding of the improved upland variety Apo, and Biocide: as Control but pretreatment of the soil with the biocide Dazomet at 50 g ai m^{-2} and incorporated to 15 cm depth. Apo was direct dry seeded in rows of 25 cm spacing at 60 kg ha^{-1} at 2-3 cm depth after dry land preparation. 120 kg N ha^{-1} were split applied as urea in 3 equal doses at 10-14 days after emergence (DAE), mid-tillering (MT) and panicle initiation (PI), 60 kg P ha^{-1}, and 60 kg K ha^{-1} were given as Solophos and KCl in two equal splits as basal application and at MT, also 20 kg $ZnSO_4$ ha $^{-1}$ were basally applied. Fertilizer rates for 2006 were 26 kg P ha $^{-1}$, 50 kg K ha^{-1} and 20 kg Zn ha^{-1} as in the previous water by N trial. The field was kept free of weeds by the pre-emergence herbicide Butachlor and hand weeding as necessary. Irrigation was applied at regular intervals to keep the field at medium water stress levels. Agronomic yield was estimated from 6 m^{-2} located in the centre of each plot. Sequential biomass samples were collected at crucial crop growth stages (10-14DAE, MT, PI, half way between PI and flowering (½ Fl), Fl, and physiological maturity (PM)) from 2 x 0.75 m row segments for biomass measurement. For plant nutrient analysis Y-leaves were collected from 2 x 0.5 m row segments at MT, PI and Fl. Soil samples were collected before fertilizer applications in two sets, one for mineral N determination and one for air drying and pH determination (H_2O), before seeding (BS), at 10-14 DAE, MT, PI, FL and PM (air drying only) from 0-15 cm next to plant rows. Mineral N was analyzed by an auto analyzer, (Bran+Luebbe Auto Analyzer III) after KCl extraction. Root knot nematodes (RKN) were assed at MT, PI, Fl and harvest as second stage juveniles (J2) per gram dry root after an incubation period, and by a severity rating of root galling on a scale of 0 = no galls to 5 = > 75 % galls. In 2007, the sample was stratified per plot into selection of apparently healthy plants (4) and sick (stunted, yellowing) plants (4) at MT, PI, Fl and harvest. Root health was evaluated initially on a weekly and later a bi-weekly basis until Fl from root samples collected with an auger of 10 cm diameter to a depth

of 10 cm within plant rows at 3 replicates per plot. Roots were evaluated according to a grading scale from 1 to 9, where grades of 1 – 3 indicate healthy roots, higher grades indicate increasing degree of root discoloration, lesions and decay (adapted from (CIAT, 1987). Soil water tensions were read daily from 2 tensiometers installed at 15 cm depth in each plot.
An additional pot experiment was conducted in 2007. From one plot with a patch of severe yellowing of seedlings about three weeks after emergence, soil was collected in two sets from patches with good plant growth and those with poor, yellowing plants. Apo was grown for 6 weeks in about 250 cm³ of aerobic soil in two sets per soil type: water logged and drained. Fifty mg N (as urea) per pot was applied in 2 splits.

Results and Discussion

The crop in Control developed the same symptoms as in the previous trials: crop growth was initially fairly good until about PI, except for patches of yellowing plants which increased over the season to cover up to the whole plot. Additionally, during the later season patches of plants with drying and browning of leaves developed. The severity and extent in the formation of yellowing patches was much more severe in 2007. Yield in Control failed in both years. Crop growth in Biocide was very good but also here the plants appeared to suffer increasing stress from about PI onwards. Yield in both years was more than 2 t ha^{-1} (Table 1). By comparison the best DS yields of Apo at this location were 5.7 and 3.2 t ha^{-1} (Vermeulen, 2007). Soil moisture tensions became relatively high in 2006 with seasonal average values of 12 and 25 kPa in Control and Biocide respectively, where peak values were more than 70 kPa. In 2007, tensions remained, with 8 and 12 kPa, close to field capacity and peak values were less than 30 kPa in Biocide.

Table1. Agronomic yield at 14% moisture [t ha^{-1}] and total biomass dry weight [t ha^{-1}] in 2006 and 2007.

	2006				2007			
	Yield	sd	Biomass	sd	Yield	sd	Biomass	sd
Control	0.2 a	0.2	4.3 a	2.3	0.0a	0.0	2.2 a	0.7
Biocide	2.2 b	0.2	8.2 b	2.5	2.4b	0.8	8.9 b	1.5

Figures in columns followed by the same letter are not statistically significant (P=0.05); sd = standard deviation

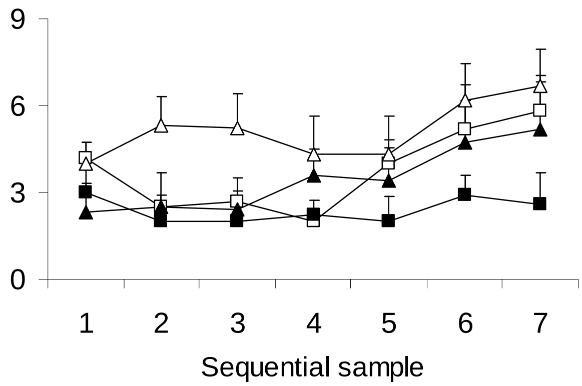

Figure1. Grading for root health on a scale of 0-9 for seven sequential root samples over the cropping season at Dap Dap (Tarlac, Philippines) in 2006 and 2007. Filled symbols: Biocide; open symbols: Control; squares: 2006; triangles: 2007; error bars indicate the standard deviation.

Root health tended to be improved in Biocide. In Control root grades became worse over the season with a widening gap towards Biocide in 2006. In 2007, root health also deteriorated towards the end of the season in Biocide and the gap in grades towards Control tended to be larger during the first half of the season (Figure 1). For pathogenic fungi, however, there was only little evidence. Although 3 potentially pathogenic fungi were isolated, *Pythium*, *Fusarium* and a *Rhizoctonia*-like species, they were found only infrequently in the sequential root samples and not related to specific treatments. In 2007, *Pythium* was detected at almost all sampling events, except for the very early stages.

The biocide treatment did not completely eradicate the RKN but strongly reduced infestation in 2006 when the highest rating was less than 1 at harvest. In 2007, sampling for RKN was stratified according to "healthy" and "sick" plants. For Biocide, "sick" plants were only identified from Fl onwards. Even though rates for the "healthy" plants also started with almost 0 galling at MT, they then increased to a level of almost 3 at harvest. In Control, rates started at 1 and 2 and went up to 3 and almost 5 at Fl and harvest in 2006 and 2007, respectively (Figure 2). Root galling and grading correlated well with a significant r value of 0.9 when both years and treatments, and all crop stages were considered: with increasing gall rates root health deteriorated. The count of J2 was low until Fl and reached about 2000 at harvest in Control but remained low in Biocide in 2006. In 2007, counts were high at Fl and harvest, and only at the first sampling at MT counts were almost 0 in Biocide. Rooting depth as a possible consequence of RKN damage (Diomande, 1984) was impaired in Control as at a 20 to 30 cm only in 2 or 3 samples roots were present, while in Biocide this was still the case in half or more than half of the samples in 2006 and 2007 respectively.

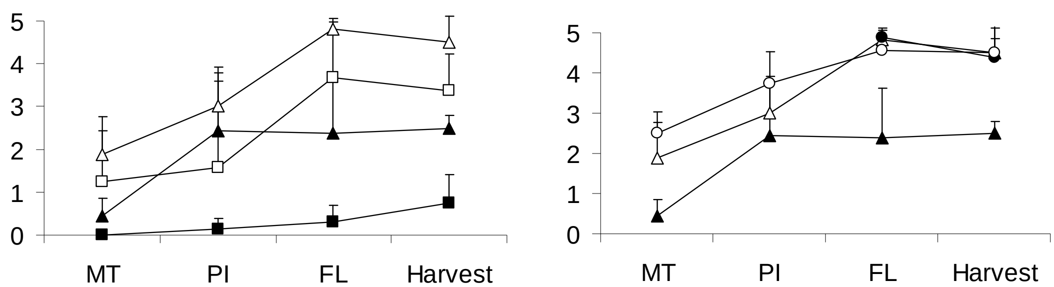

Figure2. Galling of roots caused by RKN on a scale of 0 to 5 in 2006 and 2007 at Dap Dap (Tarlac, Philippines) for "healthy" plants (left) and for the comparison of "healthy" and "sick" plants in 2007 (right). Filled symbols: Biocide; open symbols: Control; squares: 2006; triangles: 2007; circles: "sick" plants; error bars indicate the standard deviation.

When comparing the rate for healthy and sick plants in Control, rates were only slightly higher in the sick plants. In Biocide, on the contrary, when sick plants were observed at Fl and harvest a wide gap of 2 units between sick and healthy plants existed. This may indicate that high galling at Fl and harvest caused the ill appearance of the plants in Biocide, however in Control at early growth stages when gall rating was low the sick looking plants may also be indicative of an additional constraint related to the severe patch formation of yellowing plants. The pot experiment supported this: the soil pH of patches of good plant growth was 6.5 and of that of dying plants significantly increased to 7.1. Rice seedlings grew well in the low pH soil and water logging improved growth still further. In the high pH soil plants remained small and water logging did not improve plant growth but on the contrary led to a slight yellowing of leaves. Gall rating was not affected by the different soil types and roots remained quite healthy but grades were significantly higher in the high pH soil. From Brazilian Oxisols an increase in Fe deficiency has been reported due to liming of the soil to pH values of 6 and 6.5 (Fageria, 2001).

The biocide increased total mineral N in the top soil from 16 mg kg^{-1} in Control to 28 mg kg^{-1} in Biocide at BS and from 10 to 18 mg kg^{-1} at 10-14DAE in 2007. Because of the data variability these differences were not significant. For 2006, data for BS and 10 – 14 DAE were not available, but from MT onwards there was no treatment difference. Biocide also led to a reduction in soil pH. The gap between Biocide and Control decreased over the season in both years and it closed completely at PI in 2006. Over the cropping season and the years, the soil pH increased in both treatments. It can therefore be assumed that the crop in Biocide not only benefited from at least the initial absence of parasites and pathogens but that the crop was also boosted by the improved mineral N and possibly also a higher availability of pH sensitive nutrients like Fe, Mn and Zn, especially as the pH in Control increased from 6.5 BS in 2006 to 8.0 in 2007 at PM. Consequently, at MT, Biocide tended to have higher tissue concentrations in some nutrients, especially Zn (2007 at MT) and Mn. For Mn there was no significance in the direct comparison of the two treatments as the data ranged from 59 to 489 mg kg^{-1} (Biocide at MT in 2007). However, at the same time Control (32 to 48 mg kg^{-1}) reached deficiency levels (Table 2). At PI, levels for Zn and Fe became low as well and at Fl both treatments showed deficiencies for P.

Table2. Tissue concentrations of N, P, and K [%] and Mn, Zn and Fe [mg kg^{-1}] during the cropping season 2006 and 2007.

	2006					2007					
	N	P	K	Mn	Zn	N	P	K	Mn	Zn	Fe
MT											
Control	3.7a	0.18a	2.2a	95a	66a	3.1a	0.20a	2.4a	40a	26b	91a
Biocide	3.8a	0.23a	2.0a	302a	68a	3.4a	0.24a	2.4a	207a	41a	98a
PI											
Control	3.6a	0.17a	2.0a	57a	43a	3.0a	0.17a	2.4a	33a	23a	73a
Biocide	3.8a	0.19a	2.1a	205a	53a	3.1a	0.21a	2.1a	80a	29a	87a
Fl											
Control	2.3b	0.21a	2.0a			2.1a	0.18a	1.8a			
Biocide	2.9a	0.22a	1.7a			2.3a	0.14a	1.5a			
1)	<2.5	<0.10	<1.5	<40	<20						<70

Figures in columns followed by the same letter are not statistically significant (P=0.05);
1) Critical deficiency levels for irrigated lowland rice of the Y-leaf at tillering stage (Dobermann and Fairhurst, 2000).

Conclusion

Of the initially suspected biotic factors evidence was found for RKN which were present in both years and caused a higher level of infestation in 2007. Also potentially pathogenic fungi were isolated, but with no clear treatment relationship. The general assessment of root health showed that root health deteriorated towards the end of the season, except for Biocide in 2006, probably following the increasing galling. The Biocide treatment created favorable soil conditions through an increase in mineral N during the early crop growth stages and a decrease in soil pH as well as a reduction of RKN especially during the early growth stages. RKN were a major factor in Control where they were present at higher levels than in Biocide: roots were already galled early on in the season and galling increased to moderate to high levels at Fl and harvest. However, the situation was likely aggravated by nutritional problems as indicated by low tissue Mn levels and the severe seedling yellowing in 2007.

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