Growth and yield performance of aerobic rice varieties under varying nitrogen levels and drought imposed at critical growth stages

Rictibert C. Pamunag
Department of Agriculture Region-IX, Ipil, Zamboanga Sibugay, Mindanao, Philippines
Corresponding author: rictipamunag@gmail.com

ABSTRACT

A field experiment using the split-split-plot design was conducted in Sanito, Ipil, Zamboanga Sibugay (7°47’24.19”N, 122°35’37.78”E) to determine the performance of four aerobic rice varieties under varying nitrogen (N) levels and drought imposed at critical growth stages. Four selected rice varieties (NSIC Rc222, PSB Rc18, PSB Rc98, and NSIC Rc418) applied with varying N levels (no N application, 50, 100 and 150 kg N ha⁻¹) grown under four water management (well-watered conditions, no irrigation for 1-30, 31-60 and 61-90 days after sowing) were utilized in the study. Growth and yield performance of aerobic rice varieties were evaluated by determining the growth parameters (tillers per hill, leaf area index, total dry matter, crop growth rate, net assimilation rate, chlorophyll content, relative water leaf content, harvest index), grain yield and yield components (panicle per hill, number of filled and unfilled spikelets, the weight of 1000 grains). Results showed that the application of N (50-150 kg N ha⁻¹) under well-watered conditions significantly increased grain yield by as high as 18% compared to no N application. Well-watered conditions at all growth stages produced the highest grain yield (2,926.42 kg ha⁻¹) of about 13% higher as compared to rice crops subjected to water stress at different growth stages. Specifically, water stress at the early reproductive stage affected panicle initiation and flowering that resulted in a reduced number of spikelets per panicle, a number of fertile spikelets, and grain weight. PSB Rc98 and NSIC Rc418 are the two best performing varieties, having comparable higher grain yield as compared to other varieties.

Keywords: agricultural biotechnology, split-split-plot design, nitrogen levels, water stress, Ipil, Zamboanga Sibugay
INTRODUCTION

Rice is the most vital food crop in the world and in the Philippines, becoming crucial in ensuring food security and alleviating poverty (BASF, 2020). More than 90% of the Philippine households consider rice as the staple food item and takes up a quarter (25%) of the household total food budget. Relatively, it accounts for 17.4% of Gross Value Added in Agriculture and 3.5% of the Gross Domestic Product in terms of the Philippine’s political economy, and provides a source of income to its extensive chain of stakeholders on the demand and supply side (Intal & Garcia, 2005).

Meanwhile, one of the most critical concerns observed in the decrease of rice production in recent years is the abiotic stresses (drought, poor soils), which are characterized by much uncertainty, particularly about the timing, duration, and intensity of rainfall (Menelly, 2016). Water stress affects plant growth and development and, ultimately, reduces grain yield of rice. The reduction in yield may depend on the developmental stage of the crop. In the Philippines, some regions were affected by drought from 2007 to 2010. Zamboanga Peninsula experienced drought in 2010, which reduced rice production by 9% (BAS, 2012).

Several water-saving technologies during crop growth stage include Alternate Wetting-and-Drying (AWD) and aerobic rice system. Water productivity (grain yield over water inputs by irrigation and rainfall) with aerobic rice was higher than with flooded rice, suggesting that aerobic rice is a viable option to “produce more rice with less water” in a situation where water is more scarce than land (Bouman & Tuong, 2000). The selection of appropriate varieties is a success component in the aerobic rice system. However, the development of the aerobic rice system is still in its infancy, and more research is needed to develop varieties and management systems that increase yield to satisfy the always growing demand for rice (Peng et al., 2006).

On the other hand, nitrogen (N) occupies a conspicuous place in plant metabolism. Consequently, to get more crop production, N application is indispensable and unavoidable (Massignam et al., 2009). Thus, this study was conceptualized, which generally aimed to determine the growth and yield of four aerobic rice varieties under varying N levels and drought imposed at critical growth stages.

METHODS

Site Characteristics

The study was conducted in the Experimental Area of DA-RFO IX Research Division in Sanito, Ipil, Zamboanga Sibugay (7°47’24.19” N, 122°35’37.78” E). The experimental area had a silty clay loam texture with a strong acidic pH of 4.9 (Table 1). The soil was considered less fertile with low organic matter content of 1.37% and low nitrogen (N) content (0.09%). Available phosphorus (P) was 1.0 ppm and exchangeable potassium (K) was 0.34 cmolc/kg⁻¹ soil.
Table 1. Soil chemical properties of the experimental site (Rice Research Area, DA-RFO IX, Sanito, Ipil, Zamboanga Sibugay).

<table>
<thead>
<tr>
<th>Soil Property</th>
<th>Method</th>
<th>Value</th>
<th>Critical Level Range*</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>Potentiometric</td>
<td>4.90</td>
<td>5.50-6.50</td>
</tr>
<tr>
<td>Organic Matter (%)</td>
<td>Walkley-Black</td>
<td>1.37</td>
<td>2.00-3.00</td>
</tr>
<tr>
<td>Percent N</td>
<td>Modified Kjeldahl</td>
<td>0.09</td>
<td>0.10-0.15</td>
</tr>
<tr>
<td>P (ppm)</td>
<td>Bray no. 2</td>
<td>1.00</td>
<td>5.00-25.00</td>
</tr>
<tr>
<td>Exchangeable K (cmolc/kg⁻¹)</td>
<td>Flame Photometer</td>
<td>0.34</td>
<td>0.05-0.20</td>
</tr>
</tbody>
</table>

*Source: Analytical Service Laboratory, Agricultural Systems Cluster, UPLB.

Lay-out of the Experiments

This experiment was laid out in split-split-plot based on Randomized Complete Block Design with three replications. The main plot contained four water management (drought-imposed at critical growth stages) treatments. Under well-watered conditions, surface irrigation was done to maintain soil moisture. Soil moisture content was determined by following the gravimetric method (IRRI, 1980). Subplot contained four N levels while four varieties in sub-subplot.

Crop Establishment

The field was plowed and harrowed to mix the soil and incorporate plant residues. Main canals dividing the replications were constructed before the final harrowing, while inner canals dividing the treatments were built after planting.

Registered seeds of NSIC Rc222, PSB Rc18, PSB Rc98, and NSIC Rc418 were sown manually at 60 kg ha⁻¹ per variety at 25 cm between rows and 20 cm between hills of 2-3 cm depth. The seeds were covered with soil to promote seed-soil contact and to protect them from birds. Weeds were controlled by the application of 2,4-D B 500, a post-emergence herbicide following the company’s recommended rate and timing.

Growth Parameters

Counting of tillers from 10 designated hills was done starting 30 DAS and subsequently at 30-day intervals until harvest. The Leaf Area Index (LAI) was measured from plants that were used in determining dry matter yield at 30, 60, 90 days after sowing (DAS) and at harvest. Samples for leaf area were obtained from 4 hills per plot. Sample plants were cut close to the ground. From each selected hill, the tillers were counted, and the topmost tiller was used for LAI measurement. The length and width of the individual leaf of the tiller sample were measured manually. A correlation factor (k) of 0.75 at all other growth stages, except harvest wherein the value of 0.725 was used (Yoshida et al., 1978). The LAI was calculated using the following formula:

\[
\text{Leaf area} = K \times \text{length} \times \text{width}
\]

\[
\text{Leaf area/hill} = \text{total leaf area of the middle leaf} \times \text{total number of tillers}
\]

\[
\text{LAI} = \frac{\text{Sum of green leaf area x Area (cm)}}{\text{Hill}} \times \text{Total number of hill x Total number of hills}
\]

\[
\text{Area of land covers by the sampled hills}
\]
The Total Dry Matter (TDM), which includes the total biological yield (leaves, sheath + culms) and the economically valuable part (grains), was obtained from 4 hills per plot. Samples were cleaned by tap water and separated into leaves and sheaths, culm + roots (during vegetative stage), and panicles (during the reproductive stage). Plants sample were oven-dried at \( 70^\circ C \) for 72 h and weighed. Sampling for DMY was done at 30, 60, 90 DAS, and harvest. Meanwhile, the Crop Growth Rate (CGR) was measured at 30, 60, 90 DAS, and harvest. The crop growth rate was calculated using the formula:

\[
\text{CGR} = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{1}{G_A}
\]

Where:
- \( W_2 - W_1 \) - change in weight (g)
- \( T_2 - T_1 \) - change in time (d)
- \( G_A \) - change in time (m²)

The Net Assimilation Rate (NAR) was measured at 30, 60, 90 DAS, and harvest using the samples that were used in the determination of TDM. Net assimilation rate was calculated using the formula:

\[
\text{NAR} = \frac{(W_2 - W_1) (\ln LA_2 - \ln LA_1)}{(LA_2 - LA_1) (T_2 - T_1)}
\]

Where:
- \( W_2 - W_1 \) - change in weight (g)
- \( LA_2 - LA_1 \) - change in leaf area (m²)
- \( T_2 - T_1 \) - change in time (d)

Meanwhile, the LCC reading was done by selecting the topmost, youngest, fully-expanded leaf. The middle part of the leaf was placed on the LCC and compared its color with color panels. This sample was measured at the end of the water stress imposition. For the Relative Leaf Water Content (RLWC), fully-expanded young leaves were weighed for the fresh weight (FW) and were soaked in distilled water for 24 h in the dark to obtain a steady turgid weight (TW). Afterward, the leaf was oven-dried at \( 85^\circ C \) until constant Dry Weight (DW) was achieved. The sample was measured at the end of the water stress imposition. The RLWC was computed based on Lafitte (2002):

\[
\text{RLWC} = \frac{FW-DW}{TW-DW} \times 100
\]

Harvest Index (HI) was determined from the grain yield samples (2.5 m x 2 m). Straw and grain weight measurements were taken, and HI was computed as:

\[
\text{HI} = \frac{\text{Economic yield (kg)}}{\text{Biological yield (kg)}} \times 100
\]
Grain Yield and Yield Components

Panicle per hill was determined by counting all the panicles in 10 randomly selected sample hills per plot during harvest. In contrast, the weight of 1000 grains (g) was determined by measuring the weight of 1000 grains from each sample plot after harvest. The weight was adjusted to 14% moisture content (MC). At the same time, the number of filled and unfilled spikelets was determined by counting all filled and unfilled spikelets and was obtained from the same samples that were used in the determination of other yield components. Percent filled spikelets were calculated using the formula:

\[
\text{Percent filled spikelet} = \frac{\text{Number of filled spikelets}}{\text{Total number of spikelets}} \times 100
\]

RESULTS AND DISCUSSION

Agronomic characteristics

Agronomic characteristics of four aerobic rice varieties are shown in Table 2. The number of tillers and LAI value peaked at 90 DAS. It was observed that tiller and LAI increased with increasing N fertilizer application. Application of 150 kg ha\(^{-1}\) of N produced the highest number of tillers (28 tillers/hill), although comparable to 50 and 100 kg N ha\(^{-1}\) applications (27 tillers/hill and 28 tillers/hill, respectively). Crops without N application had the lowest number of tillers (24 tillers/hill). Increased in N level could be considered as a significant factor in the tiller. This result conforms with several studies that N application is the most common and effective way to enhance the tiller population (Sakakibara et al., 2006 and Liu et al., 2011). NSIC Rc418 produced the highest number of tillers (28 tillers/hill), although comparable to NSIC Rc222 and NSIC Rc18 (23 tillers/hill and 23 tillers/hill, respectively) while PSB Rc98 had the least number of tillers (25 tillers/hill). The results indicated that the tillering pattern of test varieties differed in the present study and could be attributed to the genetic potentiality of each variety.

Meanwhile, crops applied with 150 kg N ha\(^{-1}\) produced the highest LAI (5.28) followed by crops used with 50 and 100 kg N ha\(^{-1}\) (4.43 and 4.73, respectively), while lowest LAI was observed in crops with no N application (3.85). The results can be attributed to the positive effect of N on leaf development and tillering. Likewise, the increase could be attributed to the duration of leaf photosynthetic activity (Fageria & Baligar, 2005; Fageria, 2007).
At 60-90 DAS, the highest NAR was attained by NSIC Rc222 (5.62 g m⁻² d⁻¹), NSIC Rc418 (5.45 g m⁻² d⁻¹), and NSIC Rc18 (5.19 g m⁻² d⁻¹). These varieties had the highest NAR due to the number of tillers and leaves per unit area. Meanwhile, an increasing CGR with increasing N levels was observed across growth stages. At 60-90 DAS period, significant differences in varying N levels x variety interaction were observed wherein 150 kg N ha⁻¹ applied to NSIC Rc418 had the highest CGR (26.92 g m⁻² d⁻¹) although comparable to PSB Rc98. PSB Rc18 and NSIC Rc222 (26.00 g m⁻² d⁻¹, 21.65 g m⁻² d⁻¹ and 20.87 g m⁻² d⁻¹, respectively). These growth periods coincide with the reproductive stage. Also, a significant increase in CGR could be attributed to higher TDM production. Among varieties, significant differences in CGR at all growth stages from vegetative to maturity were observed; this could be due to inherent varietal characteristics in terms of growth duration. At 30-60 DAS, NSIC Rc418 had the highest CGR (1.77 g m⁻² d⁻¹) until 60-90 DAS (21.68 g m⁻² d⁻¹) while at 90 DAS to harvest, PSB Rc98 had the highest CGR (15.77 g m⁻² d⁻¹). Generally, CGR declined at the maturity stage.

Rice applied with 150 kg N ha⁻¹ consistently had the highest chlorophyll content from reproductive to maturity stage (0.63, 0.65, 0.69, and 0.65 LCC units, respectively). At 90 DAS, significant differences in water management x N levels x varieties interaction were observed. Under well-watered conditions with 150 kg N ha⁻¹ application, PSB Rc98 and PSB Rc18 had the highest chlorophyll content (0.77 and 0.72 LCC unit). When water stress was imposed at 1-30 DAS, PSB Rc98 and NSIC Rc418 applied with 150 kg N ha⁻¹ had the highest LAI (0.77 and 0.72 LCC units), while NSIC Rc222 and PSB Rc18 had the lowest chlorophyll content (0.63 LCC units, respectively). It was observed that regardless of varying levels, N application had affected the chlorophyll content of aerobic rice varieties. Chlorophyll gives an indirect estimation of the nutrient status because much of leaf nitrogen is incorporated in chlorophyll. However, rice plants can exhibit varietal differences in terms of a water stress response. The high tillering varieties (NSIC Rc222, PSB Rc18, and NSIC Rc418) are observed to be more sensitive to water stress.
Meanwhile, significantly higher RLWC was observed under well-watered treatment from 30, 60, and 90 DAS (63.81%, 62.51%, and 68.21%, respectively). This result suggests that during the water stress period, the water available to the root zone of the plants of water-stressed treatments was limited. As a result, the water-stressed plants were unable to absorb water as compared to the control plants (well-watered condition). Meanwhile, PSB Rc98 had the highest RLWC during 30, 60 DAS, and maturity (62.34%, 61.99%, and 71.48%, respectively), while at 90 DAS; PSB Rc18 had the highest RLWC (65.95%). This result indicates that various varieties could resist drought differently. Drought-tolerant varieties can maintain the water status in their leaves, which demonstrates their ability to cope with drought stress (Nguyen et al., 1997).

Total dry matter production increased significantly with increasing N fertilizer application at all the growth stages of the crop that peaked at harvest. Highest TDM was obtained from crops under 150 kg N ha\(^{-1}\) (12,592.53 kg ha\(^{-1}\)), followed by crops fertilized with 50 and 100 kg N ha\(^{-1}\) (10,829.01 and 9,912.65 kg ha\(^{-1}\), respectively), while crops obtained lowest TDM production without N application (9,407.60 kg ha\(^{-1}\)). Chaturved (2005), in his research, presented that dry matter accumulation increased significantly with N fertilizer application in rice at all the growth stages of the crop. PSB Rc98 got the highest TDM during harvest (13,477.37 kg ha\(^{-1}\)). TDM production increased at a slow rate up to 30 DAS, and after that grew at a faster rate up to harvest.

On the other hand, aerobic rice applied with 150 kg N ha\(^{-1}\) had the highest HI (0.51), although comparable to those crops used with 50 and 100 kg N ha\(^{-1}\) (0.49, respectively), while those crops obtained lowest HI without N application (0.41). The increased grain and straw yield due to increase N supply were precisely due to yield attributing characters under increased N supply. Among four aerobic rice varieties, PSB Rc98 had the highest HI (0.59), followed by NSIC Rc418, PSB Rc18, and NSIC Rc222 (0.59, 0.41, and 0.38, respectively). Fageria et al. (2006) reported that an efficient partitioning of photosynthates and assimilation to the grains, particularly during the grain filling stage, is an important trait associated with the remarkable yield increase in rice.

**Grain yield and yield components**

Grain yield and yield components of four aerobic rice varieties are shown in Table 3. It was observed that as N level was increased, the number of panicles and spikelets and 1000-grain weight increased. The number of panicles increased from 17 panicles per hill under no N application to 21 panicles per hill under crops with 150 kg N ha\(^{-1}\) application. The highest number of spikelets per panicle was obtained in rice crops applied with 150 kg N ha\(^{-1}\) fertilizer (120 spikelets), although comparable with those rice crops used with 100 kg N ha\(^{-1}\) fertilizer (116 spikelets). This result was followed by those rice crops applied with 50 kg N ha\(^{-1}\) and those rice crops without N fertilizer application (107 spikelets and 106 spikelets, respectively). The N content of a leaf can influence the leaf’s photosynthetic ability; that is, an increase in the N content can strengthen the source ability of assimilates. Also, the application of 150 kg N ha\(^{-1}\) fertilizer had the highest 1000-grain weight (27.19 g).

In contrast, the lowest 1000-grain weight was obtained by those crops without N application (24.36 g) although comparable with 50 and 100 kg N ha\(^{-1}\) (24.91 and 25.43 g, respectively). Therefore, it seems that the importance of the adequate supply of N could enhance leaves’ initiation and flowering capacity resulting in increased grain weight. Among four aerobic rice varieties tested, PSB Rc98 produced the highest number of panicle per hill (20 panicles per hill), the highest number of spikelets per panicle (132 spikelets), and highest 1000-grain weight (28 g) while PSB Rc18 produced the highest percent filled spikelets (78%), although comparable
to NSIC Rc222 and PSB Rc98 (75% and 74%, respectively). Generally, PSB Rc98 and PSB Rc18 had the larger leaf area among the four aerobic rice varieties resulting in the development of more number of spikelets. Sheehy et al. (2001) reported that the leaf area is an essential factor influencing the source ability for panicle development. The variation among four aerobic rice varieties could be explained by differences in leaf characters related to photosynthetic ability and resulting capacity of tillers to support spikelet growth. Table 3 shows the yield components of four aerobic rice varieties as influenced by varying levels of nitrogen and different water management.

**Table 3.** Yield components of four aerobic rice varieties as influenced by varying levels of nitrogen and different water management.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Yield Parameters</th>
<th>Yield (t ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Panicle/hill</td>
<td>Spikelets per Panicle</td>
</tr>
<tr>
<td>Water Management</td>
<td>ns</td>
<td>*</td>
</tr>
<tr>
<td>Well-Watered</td>
<td>19</td>
<td>109</td>
</tr>
<tr>
<td>No Irrigation for 1-30 DAS</td>
<td>19</td>
<td>112</td>
</tr>
<tr>
<td>No Irrigation for 31-60 DAS</td>
<td>19</td>
<td>114</td>
</tr>
<tr>
<td>No Irrigation for 61-90 DAS</td>
<td>19</td>
<td>116</td>
</tr>
<tr>
<td>Nitrogen Level</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>No Nitrogen Application</td>
<td>17 c</td>
<td>106 b</td>
</tr>
<tr>
<td>50 kg/ha of N</td>
<td>19 ab</td>
<td>107 b</td>
</tr>
<tr>
<td>100 kg/ha of N</td>
<td>19 b</td>
<td>116 a</td>
</tr>
<tr>
<td>150 kg/ha of N</td>
<td>21 a</td>
<td>120 a</td>
</tr>
<tr>
<td>Varieties</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>NSIC Rc222</td>
<td>17 b</td>
<td>94 b</td>
</tr>
<tr>
<td>PSB Rc18</td>
<td>17 b</td>
<td>95 b</td>
</tr>
<tr>
<td>PSB Rc98</td>
<td>20 a</td>
<td>132 a</td>
</tr>
<tr>
<td>NSIC Rc418</td>
<td>20 a</td>
<td>126 a</td>
</tr>
</tbody>
</table>

* In a column, means followed by the same letter are not significantly different at 5% level of significance by LSD. (DAS = Days After Sowing).

Aerobic rice in well-watered condition obtained the highest grain yield (2.93 t ha\(^{-1}\)), while crops under water stress for 61-90 DAS had the lowest grain yield (2.37 t ha\(^{-1}\)) although comparable to crop under water stress from 1-30 and 31-60 DAS (2.53 and 2.45 t ha\(^{-1}\), respectively). It was observed that the reduction in percent-filled spikelets was more pronounced when aerobic rice was subjected to water stress at the reproductive stage (61-90 DAS) than the vegetative stage. The result suggests that water stress at different growth stages is known to reduce rice yield. According to Saragih et al. (2013), drought or water stress at the early reproductive stage significantly affects the grain yield of rice. This effect might be due to a decrease in translocation of assimilates towards reproductive organs. Significant differences were observed under varying nitrogen levels. Application of 150 kg N ha\(^{-1}\) fertilizer produced the highest yield (2.81 t ha\(^{-1}\)) although comparable to rice applied with 50 and 100 kg N ha\(^{-1}\) fertilizer (2.52 t ha\(^{-1}\) and 2.67 t ha\(^{-1}\), respectively). The probable reason might be due to vigorous and enhanced plant growth, and continuous and synchronized supply of nutrients throughout the growth stages of rice. Grain yield obtained with N fertilization was significantly higher than control or no N application indicating the evaluated N levels positively affected grain yield. PSB Rc98 got the highest grain yield (2.94 t ha\(^{-1}\)) although comparable to NSIC Rc418 (2.89 t ha\(^{-1}\)), while PSB Rc18 and NSIC Rc222 had the lowest yield (2.29 t ha\(^{-1}\) and 2.14 t ha\(^{-1}\), respectively). This result was probably due to the higher number of panicles per hill, spikelets per panicle, and
higher 1000 grain weight obtained by PSB Rc98. Hence, PSB Rc98 had the broadest range of adaptability, as indicated by its high grain yield across different water stress and nitrogen levels.

CONCLUSION AND RECOMMENDATION

Water stress imposed at different critical rice crop growth stages and varying N levels influenced growth, yield components, and grain yield of four aerobic rice varieties. Water stress at different growth stages is known to reduce rice yield. Generally, a relative increase in terms of growth parameters with increasing N fertilizer level was observed. Among four aerobic rice varieties, PSB Rc98 and NSIC Rc418 were the best performing varieties with the highest yield of 2.94 t ha\(^{-1}\) and 2.89 t ha\(^{-1}\), respectively. Therefore, based on this study, under Zamboanga Sibugay conditions, PSB Rc98 and NSIC Rc418 are the best performing and most adaptable varieties under aerobic conditions. These varieties appeared to perform well when applied with 50-150 kg N ha\(^{-1}\) and planted in a well-watered state.

REFERENCES


