Yield-contributing Factors in Lowland Irrigated Rice as Affected by Variety, Water Management and Fertilizer Rate in Agusan Soil

Jehru C. Magahud* and Princess Anne B. Padios

R&D Division, Philippine Rice Research Institute–Agusan, Basilisa, Remedios T. Romualdez 8611 Agusan del Norte, Philippines

Rice grain yields in irrigated areas of Agusan del Norte/Sur provinces ranged at only 3.3–3.8 t/ha in 2010–2019 – hence the need to study the yield potential of varieties, appropriate water management, and optimum fertilizer rates to improve such yields. This study assessed the effects of rice varieties, water management, and fertilizer rates on grain yield and agronomic parameters. It also recommended variety, water management, and fertilizer rate for improving grain yields in Agusan soil. Screenhouse experiment was done using lowland rice soils collected from Remedios T. Romualdez, Agusan del Norte, Philippines. The experiment was laid out in unbalanced randomized complete block design with three factors: [1] PSB Rc 18, NSIC Rc 122, and PSB Rc 82 for the variety factor; [2] continuous submergence (CS) and alternate wetting and drying (AWD) for the water management factor; and [3] PalayCheck (PFR) and farmers’ fertilizer rates (FFR) for the fertilizer rate factor. Three replications each for PSB Rc 18+CS+PFR, PSB Rc 18+CS+FFR, PSB Rc 18+AWD+FRR, NSIC Rc 122+CS+FFR, NSIC Rc 122+AWD+FRR, PSB Rc 82+CS+PFR, PSB Rc 82+CS+FFR, and PSB Rc 82+AWD+FRR plus four replications each for PSB Rc 18+AWD+PFR, NSIC Rc 122+CS+PFR, NSIC Rc 122+AWD+PFR, and PSB Rc 82+AWD+PFR were employed. Data on chlorophyll (chl) levels, plant height, tiller count, and number of healthy and unhealthy leaves were gathered weekly. Yield component data, including panicle lengths and dry weight of all filled grains or grain yields, were determined before and after harvesting. Dry weight of straw and roots were also assessed. Compared with PSB Rc 82, PSB Rc 18 had a significantly higher grain yield by 9% due to enhanced protection of chloroplast structure, leading to longer leaf area duration and higher chl contents across growth stages (GSs). These contributed to an improved “sink” or significantly greater number of grains per panicle by 19% and enhanced “source” or better health status of leaves. Improved “source” increased the grain filling efficiency, resulting in a significantly higher number of filled grains per panicle by 18%, grain weight per panicle by 21%, and harvest index by 6%. In contrast with AWD, CS had a significantly higher grain yield by 7% due to higher soil nitrogen availability leading to better yield-contributing plant traits. These traits include a significantly longer vegetative stage by 3%, greater straw biomass by 9%, higher leaf chl levels, and better health status of leaves from grain filling until harvesting. Moreover, the lower number of small, unproductive tillers in CS allowed more plant resources to be used for improving the health of large, panicle-bearing tillers. Compared with FFR, PFR had a significantly higher grain yield by 18% due to a closer-to-the-optimum fertilizer rate leading to an improved “source.” Improved “source” includes the

*Corresponding author: jcmagahud@gmail.com
following statistically significant parameters: [1] higher number of tillers by 7–18%, greater number of healthy leaves, and higher total number of leaves throughout GSs; [2] greater biomass by 15%; [3] higher chl content from booting until grain filling stage; and [4] better health status of leaves from booting until harvesting. The closer-to-the-optimum fertilizer rate also improved the “sink,” which was the significantly higher number of productive panicles by 16% and longer panicles by 2%. The study implies that certain management practices – employing a more adapted variety, CS or PFR in Agusan soil – provides a better genetic or environmental factor, which enhances plant traits and improves grain yields. Management recommendations are as follows: [1] PSB Rc 18 should be selected over PSB Rc 82 because it is more adapted in Agusan soil, [2] CS should be preferred over AWD in a non-zinc-deficient Agusan soil, and [3] the 74-28-43-24 kg N-P₂O₅-K₂O-S/ha PFR should be selected over the 42.0-4.5-10.5-3.8 kg N-P₂O₅-K₂O-S/ha FFR. Variety, water management, and fertilizer rate do not have significant two- and three-way interaction effects on grain yield; hence, no specific combination of the three factors can be recommended.

Keywords: Agusan soil, continuous submergence, grain yield, lowland rice, PalayCheck fertilizer rate, PSB Rc 18

INTRODUCTION

In 2010–2019, rice grain yields in irrigated areas of Agusan del Norte/Sur provinces ranged at only 3.3–3.8 t/ha, 10.5–24.3% lower than the annual grain yields in the Philippines for nine out of 10 years (PhilRice-SED 2021a). Frequent rainfall, poor soil drainage, the occurrence of soil nutrient deficiencies, and inappropriate soil nutrient management (Mabayag et al. 2004a) are major constraints in improving rice growth and yields in Agusan. The major poorly drained lowland soil in Agusan is the Butuan soil series, which developed from older alluvial terraces along many sections of the Agusan River. Butuan loam comprises 74,010 ha in the two Agusan provinces (Mojica et al. 1967).

Genetic (G), environmental (E), and G x E factors determine the grain yield of lowland rice. The genetic contribution depends on the yield potential of the variety planted. The environment’s suitability to rice production, including water and fertilizer management being employed, also determines growth and yield. Furthermore, rice varieties will respond differently to the kind of environment they are exposed to. Hence – in Agusan – the yield potential of varieties, appropriate water management, and optimum fertilizer rates was studied in the past to improve yields of lowland rice in the area.

Previous field experiments showed that PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are well-adapted in Agusan del Norte/Sur. PSB Rc 18 yields 5.9–6.1 in the July–December season and 4.0–6.7 t/ha in the January–June season (Mabayag et al. 2004b, 2012; Jimenez et al. 2015a; Sobrevilla and Mabayag 2013). NSIC Rc 122, popularly known as “Angelica,” yields 5.8–6.8 t/ha in the July–December season and 4.3 t/ha in the January–June season (Berganio et al. 2004; Jimenez et al. 2015a). It out-yielded four popular rice varieties in a recent technology demonstration (Reyes et al. 2020); it is relatively tolerant to white stem borer, bacterial leaf blight, sheath blight, and lodging (Berganio et al. 2004). PSB Rc 82 yields 5.4–6.8 t/ha in the July–December season and 3.7–6.1 t/ha in the January–June season (Jimenez et al. 2015a, b, d; Mabayag et al. 2004b). It has moderate resistance to bacterial leaf blight (Burdeos and Batay-an 2012) and intermediate tolerance to zinc deficiency (Jimenez and Estoy 2013).

It was reported in China and Bangladesh that, compared to CS, exposure of lowland rice to alternate wetting and moderate soil drying resulted in either significantly or numerically higher growth (Rahman and Bulbul 2014; Ye et al. 2013), yields (Zhang H et al. 2009a; Yang et al. 2009), and water use efficiency (Zhang H et al. 2009a; Ye et al. 2013; Rahman and Bulbul 2014). Meanwhile, Agusan farmers usually flood their fields by continuously allowing irrigation water to enter and exit their fields. A study found that, compared to CS, exposure of Agusan soil to AWD worsened the soil nitrogen (N) status but improved the soil phosphorus (P), potassium (K), sulfur (S), zinc (Zn), and copper status (Magahud et al. 2019). The same study also observed that, until 59 days after transplanting (DAT), AWD resulted in better growth in most fertilizer treatments but lower chl levels in minus N and no fertilizer treatments.

Farmers in Agusan employed the following fertilizer rates: 33–49 kg N, 7–14 kg P₂O₅, and 9–20 kg K₂O in January–June cropping season and 35–61 kg N, 5–9 kg P₂O₅, and 6–14 kg K₂O in July–December season (PhilRice-SED 2021b). Since these FFRs were associated with low grain
yields, improved fertilizer rates were studied to increase such yields: 98-28-28 kg N-P₂O₅-K₂O/ha produced 5.6 and 6.3 t/ha (Estoy 2019), 90-0-30-24-20 kg N-P₂O₅-K₂O-S-Zn/ha yielded 5.0–6.0 t/ha (Escañan and Nemeño 2013b), and 53-30-60 kg N-P₂O₅-K₂O/ha produced 4.9 t/ha (Escañan and Nemeño 2013a).

Fertilizer rates were recommended based on soil status and plant uptake of nutrients in Agusan. 51 and 72 kg K₂O/ha were suggested to augment the K deficiency indicated by the soil’s indigenous K supply (Cruz et al. 2004). 53-7-37 kg N-P₂O₅-K₂O/ha or lower rates were recommended since these increase soil availability and plant uptake of NPK (Nemeño et al. 2019). Using the PalayCheck platform, the 28-28-43-24 kg N-P₂O₅-K₂O-S/ha plus leaf color chart (LCC) based N fertilizer applications were suggested to achieve 5.0 t/ha yield (Magahud et al. 2019; PhilRice 2007). PalayCheck recommendation varies on the kind of nutrient deficient in the area. Soil test-based fertilizer rate, at 70-7-37 kg N-P₂O₅-K₂O/ha, was recently suggested since it increased N and K uptake plus attained the highest yield and net income (Rollon et al. 2021).

In Agusan, a multitude of experiments on the yield potential of varieties and yield improvements in response to various fertilizer rates were already done. CS and AWD soils were compared, but only the soil nutrient status and rice growth differences up to 59 DAT were studied. The differences of CS and AWD in terms of grain yield and the contributions of growth parameters to grain yield were not yet documented and analyzed. Furthermore, in our knowledge, there were no or very limited findings on variety x water management, variety x fertilizer rate, water management x fertilizer rate, and variety x water management x fertilizer rate interactions. Only the following results on interactions were reported: [1] yields of rice varieties differ with planting dates (Mabayag et al. 2012); [2] PSB Rc 82 is more responsive to N application than NSIC Rc 160 (Nemeño and Siclay 2010); and [3] reactions of rice varieties to Zn treatments, Zn vs. no Zn amendments (Corton et al. 1999; Jimenez et al. 2015c; Jimenez and Estoy 2013), and organic vs. no organic fertilizer treatments (Sobrevilla and Mabayag 2013) vary. This, despite the fact that the main and interaction effects of variety, water management, and fertilizer rate can greatly increase grain yields of lowland rice in the low-yielding area of Agusan.

This study assessed the effects of three Agusan-adapted varieties, two water management, and two fertilizer rates on grain yields and agronomic parameters. It also recommended variety, water management, and fertilizer rate for improving grain yields in Agusan soil.

MATERIALS AND METHODS

Medium for Growing Rice and Crop Establishment

The Agusan soil used for this study was collected from the plowed layer or 0–25-cm depth of a rice farm in Remedios T. Romualdez, Agusan del Norte (09.06788889°N, 125.58861111°E). This was the same soil used by Magahud et al. (2019) in their screenhouse experiment. The soil was added with irrigation water to manually disaggregate soil particles, mixed thoroughly, and passed through a fine mesh to remove undecomposed plant materials.

The soil had the following characteristics based on chemical laboratory analyses: silt loam texture, pH 6.5, 5.3% organic matter, 0.29% total N, 18 mg/kg Olsen available P, and 0.32 cmol/kg exchangeable K (Magahud et al. 2019). Based on the replicated minus-one-element technique (Azhiri-Sigari et al. 2003; Sigari et al. 2003) conducted from 11 Jan–18 Mar 2018, it had the following nutrient status: deficient N and K but sufficient P, S, Cu, and Zn (Magahud et al. 2019).

Under the experiment in a screenhouse of PhilRice Agusan from 15 Mar 2018 until 13 and 27 Jun 2018, 8 kg of homogenized soil was transferred into black plastic pails (23-cm height, 27-cm top diameter, and 20-cm bottom diameter). The 8-kg soil represents the soil volume for a hill of rice based on the following computations:

\[
10,000 \text{ m}^2 \text{ farm area/} (0.2 \text{ m} \times 0.2 \text{ m}) \text{ planting distance for transplanted rice} = 250,000 \text{ rice hills/ha}
\]

Assuming that 1-ha furrow slice = 2,000,000 kg soil

Each pail was planted with five 12-d-old rice seedlings. Each pail was thinned when seedlings were fully established, the two most vigorous of which were retained.

Experimental Treatments

The experiment had three factors: variety, water management, and fertilizer rate. Three varieties suitable in the locality – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – were planted. These varieties were bred by the International Rice Research Institute for irrigated lowland ecosystems and were approved in 1994, 2003, and 2000, respectively. Their average grain yields are 5.1, 4.7, and 5.4 t/ha; maximum grain yields are 8.1, 8.9, and 12.0 t/ha. Maturities are 123, 121, and 110 d after seeding; heights are 102, 106, and 100 cm; number of tillers are 15, 14, and 15 (PhilRice 2011).

Two water management treatments were tested: CS and AWD (Table 1). Water levels in first, second, and third fertilizer applications are 1.0, 2.5, and 4.0 cm for CS pails
Table 1. Water management of pails under CS and AWD.

<table>
<thead>
<tr>
<th>Rice growth stage</th>
<th>DAT</th>
<th>Water level, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>From transplanting until a day before third fertilizer application</td>
<td>0–47</td>
<td>1.0–3.0</td>
</tr>
<tr>
<td>From third fertilizer application until the earliest heading</td>
<td>48–54</td>
<td>3.0–4.0</td>
</tr>
<tr>
<td>From heading until harvesting</td>
<td>54–104 for PSB Rc 18 and NSIC Rc 122; 54–90 for PSB Rc 82</td>
<td>4.0–6.0</td>
</tr>
</tbody>
</table>

and 1.0, 2.5, and 2.5 for AWD pails. Transparent plastics were used as roof of the screenhouse experiment to prevent rainwater from the pails.

Two fertilizer rates were tested: PFR and FFR. PFR is based on 74-28-43-24 kg N-P$_2$O$_5$-K$_2$O-S/ha fertilizer rate (PhilRice 2007; Magahud et al. 2019), assuming below-critical LCC values at mid-tillering and early panicle initiation stages. Such rate is equivalent to the following fertilizers applied in each pail: 0.80 g 14-14-14-12S and 0.10 g 0-0-60 at the early stage (7 DAT) plus 0.20 g urea each at mid-tillering (36 DAT) and early panicle initiation (48 DAT). Urea application was based on weekly LCC values.

FFR is based on the 42.0-4.5-10.5-3.8 kg N-P$_2$O$_5$-K$_2$O-S/ha fertilizer rate, which represents farmers’ applications in Agusan at 33–49 kg N, 7–14 kg P$_2$O$_5$, and 9–20 kg K$_2$O/ha in January–June cropping season and 35–61 kg N, 5–9 kg P$_2$O$_5$, and 6–14 kg K$_2$O/ha in July–December season (PhilRice-SED 2021b). Such rate is equivalent to the following fertilizers applied in each pail: 0.13 g 14-14-14-12S and 0.04 g 0-0-60 at 7 DAT plus 0.16 g urea each at 36 and 48 DAT. Application timing and fertilizer materials used in FFR were adjusted so that PFR and FFR will only differ in N-P$_2$O$_5$-K$_2$O-S rates.

Gathering of Data on Yield-contributing Plant Factors

Chl levels of the top most expanded or flag leaf of every pail were measured. Quantitative readings (SPAD value) were done on the top, middle, and bottom portions of the leaf using a chl meter (SPAD 502 plus, Konica Minolta) at 08:00–08:15 AM weekly from 22–86 DAT. The average of the three readings for every leaf was reported as the SPAD value. Qualitative measurements (LCC value) using four-panel LCC were done at 07:30–08:30 AM weekly from 14–98 DAT.

The following data were gathered weekly for every pail: plant height (cm) from 19–96 DAT, number of tillers from 19–54 DAT, and number of healthy and unhealthy leaves from 14–98 DAT. Unhealthy leaves are those with at least 50% of their surface area covered with dots or withered (Figure 1).

![Healthy leaf (A), leaf with dots (B), and withered leaf (C)](adopted from Magahud et al. 2019).

The number of days from transplanting to heading and flowering was noted for each pail. The number of days until three panicles in a pail are ≥80% golden yellow and until half the number of panicles in a pail are ≥80% golden yellow were recorded.

The number of tillers and productive panicles in every pail was recorded before harvesting. Six (6) representative panicles from each pail were selected and tagged then used to determine panicle lengths (cm), number of filled and unfilled grains, and grain weight (g). Furthermore, all panicles in every pail were harvested, air-dried, and threshed. Filled grains were separated from unfilled grains and oven-dried until constant weight to determine their oven-dry biomass or the grain yield (g).

Rice straw was harvested by cutting it from the roots. Roots were carefully washed with water to remove attached soil particles. Straw and roots were air or sun-dried to remove any dripping water and oven-dried until constant weight to determine their oven-dry biomass or the grain yield (g). The harvest index was computed from grain yield and straw biomass.
Experimental Design, Data Analyses, Interpretation, and Presentation

The experiment was arranged in a $3 \times 2 \times 2$ factorial set-up using an unbalanced randomized complete block design with three replications each for PSB Rc 18+CS+PFR, PSB Rc 18+CS+FFR, PSB Rc 18+AWD+FFR, NSIC Rc 122+CS+FFR, NSIC Rc 122+AWD+FFR, PSB Rc 82+CS+PFR, PSB Rc 82+CS+FFR, and PSB Rc 82+AWD+FFR plus four replications each for PSB Rc 18+AWD+PFR, NSIC Rc 122+CS+PFR, NSIC Rc 122+AWD+PFR, and PSB Rc 82+AWD+PFR.

Since light intensity was noted to differ on various portions of the screenhouse, the experiment was blocked, with portions of each block receiving the same light intensity. The first, second, and third blocks contained all 12 factor combinations, whereas the fourth block had only four factor combinations: [1] PSB Rc 18+AWD+PFR, [2] NSIC Rc 122+CS+PFR, [3] NSIC Rc 122+AWD+PFR, and [4] PSB Rc 82+AWD+PFR.

The main and interaction effects of experimental factors – variety, water management, and fertilizer – on grain yield and plant traits were determined using the three-way analysis of variance (ANOVA) test. Before subjecting to ANOVA test, non-normal or skewed data were first transformed as follows: LCC at 77 DAT; plant height at 19 DAT; % healthy leaves at 14 DAT; % withered leaves at 14, 28, 35, and 49 DAT; number of filled and unfilled grains; and grain weight per panicle. Tukey’s test was used to analyze the mean differences among the three varieties.

Results of the tests are presented in tables. Significant results were related to literature; mechanisms for the differences in grain yields were explained using the yield-determining factors.

RESULTS AND DISCUSSION

Climatic Data

Figure 2 presents the data on temperature (°C) and relative humidity (%), which were recorded daily at 08:00 AM and 02:00 PM using a portable thermometer with dry and wet bulbs. The 08:00 AM temperature did not markedly differ, at 24.2–26.4 °C, from 1–70 DAT. It decreased to 20.3–20.7 °C at 71-84 DAT and, again, increased to 27.1-28.0 °C at 85–104 DAT. The 02:00 PM temperature did not significantly change, at 25.9–31.9 °C, from 1–70 DAT. It dropped to 21.3 °C at 71–77 DAT and, again, rose to 25.3–31.1 °C at 78–104 DAT.

The 08:00 AM relative humidity did not markedly change, at 77.6–77.9%, from 1–14 DAT. It decreased to 72% at 15–21 DAT; from there on, it did not significantly change, at 71.4–75.0%, until 77 DAT. It rose to 82% at 78–84 DAT, dropped to 73.3% at 85–91 DAT; from there on, it did not markedly differ, at 73.3–76.0%, until 104 DAT.

The 02:00 PM relative humidity dropped from 71.4 to 63.7% from 1–21 DAT; from there on, it increased up to 77% until 35 DAT. Then, it fluctuated at 63.0–77.6% until 77 DAT. It decreased to 66.7% until 91 DAT; from there on, it increased to 71.8% until 104 DAT.

Main Effects of Variety, Water Management, and Fertilizer Rate on Grain Yield and Yield Component Parameters

Significant main effects were observed: variety on grain yield and all yield component parameters, water management on grain yield, and fertilizer rate on grain yield and some yield component parameters (Table 2).
Comparison for Yield-contributing Factors in PSB Rc 18 vs. NSIC Rc 122 vs. PSB Rc 82

PSB Rc 18 was statistically significant in the following parameters: 9% greater grain yield at 33.4 g/pail, 17% higher number of tillers per pail at 27 tillers, 18% greater total number of grains per panicle at 118 grains, 18–29% higher number of filled grains per panicle at 93 grains, and 21–33% greater grain weight per panicle at 2.1g (Table 3a). NSIC Rc 122 was significantly greater in the number of tillers by 19%, the number of productive panicles by 14%, and panicle length by 4%. PSB Rc 82 was significantly lower in grain yield and all yield component parameters. These results conform with field experiments in the past. In organic farms in Negros Occidental and Oriental Mindoro, average yields of PSB Rc 18 were highest at 3.7 t/ha, followed by NSIC Rc 122 at 3.4 t/ha, and PSB Rc 82 at 2.9 t/ha (Manigbas et al. 2018a). In Nueva Ecija, grain yields of PSB Rc 18 were superior to PSB Rc 82 under organic fertilizer application in wet and dry seasons, as well as inorganic fertilizer application in the wet season (Manigbas et al. 2018b). In Agusan del Norte, PSB Rc 18 had yields greater than NSIC Rc 122 and PSB Rc 82 across six planting dates (Mabayag et al. 2012).

Straw biomass of PSB Rc 82, at 36.6 g/pail, was significantly greater than NSIC Rc 122 by 9% (Table 3b). Root biomass of NSIC Rc 122, at 16.5 g/pail, was significantly higher than PSB Rc 18 and PSB Rc 82 by 39–41%. Harvest index of PSB Rc 18 and NSIC Rc 122, at 0.48 and 0.49, were significantly greater than PSB Rc 82 by 6–7%.

Chl levels of the top-most expanded leaf during the grain filling stage were higher in PSB Rc 18, followed by NSIC Rc 122, and lastly by PSB Rc 82. Significant differences in LCC values were observed: higher for one GS in PSB Rc 18; lower for one GS in PSB Rc 82 (Table 3c). Significant differences in SPAD values during the grain filling stage were noted: higher for two GS in PSB Rc 18, higher for one GS in NSIC Rc 122, and lower for two GS in PSB Rc 82 (Table 3d).

Plant height before and after heading was tallest in PSB Rc 18 at 83–113 cm, followed by NSIC Rc 122 at 79–103 cm, and lastly by PSB Rc 82 at 81–101 cm. Plant heights among and between varieties were statistically different: taller for three GS in PSB Rc 18, taller for four GS and shorter for three GS in NSIC Rc 122, and shorter for four GS in PSB Rc 82 (Table 3e).

Chl levels of the top-most expanded leaf across GS of varieties were higher in PSB Rc 18 and lower in PSB Rc 82 and NSIC Rc 122. LCC values among and between varieties were statistically different: higher for seven GS in PSB Rc 18, higher for three GS and lower for four GS in PSB Rc 82, and higher for one GS and lower for seven GS in NSIC Rc 122 (Figure 3a). SPAD values among and between varieties were also significantly different: higher for nine GS in PSB Rc 18, higher for three GS and lower for five GS in NSIC Rc 122, and lower for nine GS in PSB Rc 82 (Figure 3b).

The number of tillers at the vegetative stage was significantly greatest in NSIC Rc 122 at 13–35 tillers, followed by PSB Rc 18 at 11–31 tillers, and lastly by PSB Rc 82 at 11–25 tillers (Figure 3c).

The health status of leaves (Magahud et al. 2019) was better in NSIC Rc 122, followed by PSB Rc 18, and lastly by PSB Rc 82. Percentage healthy leaves among and between varieties were statistically different: higher for
Table 3a. Average grain yield and yield component parameters of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Grain yield, g/pail</th>
<th>Yield component parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of tillers per pail</td>
<td>Number of productive panicles per pail</td>
</tr>
<tr>
<td>PSB Rc 18</td>
<td>33.37a</td>
<td>26.62a</td>
</tr>
<tr>
<td>NSIC Rc 122</td>
<td>31.67ab</td>
<td>27.07a</td>
</tr>
<tr>
<td>PSB Rc 82</td>
<td>30.48b</td>
<td>22.69b</td>
</tr>
</tbody>
</table>

Different letters on a particular column denote that – using the ANOVA and Tukey’s tests – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P2O5-K2O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P2O5-K2O-S/ha)

Table 3b. Average oven-dry straw biomass, root biomass, and harvest index of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Straw biomass, g/pail</th>
<th>Root biomass, g/pail</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSB Rc 18</td>
<td>35.78ab</td>
<td>11.83b</td>
<td>0.483a</td>
</tr>
<tr>
<td>NSIC Rc 122</td>
<td>33.52b</td>
<td>16.49a</td>
<td>0.485a</td>
</tr>
<tr>
<td>PSB Rc 82</td>
<td>36.56a</td>
<td>11.71b</td>
<td>0.454b</td>
</tr>
</tbody>
</table>

Different letters on a particular column denote that – using the ANOVA and Tukey’s tests – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P2O5-K2O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P2O5-K2O-S/ha)

Table 3c. Average LCC values of flag leaf at grain filling stage of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate.

<table>
<thead>
<tr>
<th>Variety</th>
<th>LCC values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2–5 d after flowering</td>
</tr>
<tr>
<td>PSB Rc 18</td>
<td>3.42a</td>
</tr>
<tr>
<td>NSIC Rc 122</td>
<td>3.39a</td>
</tr>
<tr>
<td>PSB Rc 82</td>
<td>3.27a</td>
</tr>
</tbody>
</table>

Different letters on a particular column denote that – using the ANOVA and Tukey’s tests – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P2O5-K2O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P2O5-K2O-S/ha)

Table 3d. Average chl (SPAD) meter values of flag leaf at grain filling stage of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate.

<table>
<thead>
<tr>
<th>Variety</th>
<th>SPAD values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3–6 days after flowering</td>
</tr>
<tr>
<td>PSB Rc 18</td>
<td>38.80a</td>
</tr>
<tr>
<td>NSIC Rc 122</td>
<td>38.32a</td>
</tr>
<tr>
<td>PSB Rc 82</td>
<td>36.06b</td>
</tr>
</tbody>
</table>

Different letters on a particular column denote that – using the ANOVA and Tukey’s tests – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P2O5-K2O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P2O5-K2O-S/ha)

Table 3e. Average plant height at various days before and after flowering of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Plant height, cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2–5 d before heading</td>
</tr>
<tr>
<td>PSB Rc 18</td>
<td>83.04a</td>
</tr>
<tr>
<td>NSIC Rc 122</td>
<td>79.21a</td>
</tr>
<tr>
<td>PSB Rc 82</td>
<td>81.15a</td>
</tr>
</tbody>
</table>

Different letters on a particular column denote that, using the ANOVA and Tukey’s tests – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P2O5-K2O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P2O5-K2O-S/ha)
Figure 3a. LCC values of top-most expanded leaf at various DAT of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate. Different letters on a particular DAT denote that – using the ANOVA and Tukey’s tests – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P$_2$O$_5$-K$_2$O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P$_2$O$_5$-K$_2$O-S/ha).

Figure 3b. chl (SPAD) meter values of top-most expanded leaf at various DAT of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate. Different letters on a particular DAT denote that, using the ANOVA and Tukey’s tests, PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P$_2$O$_5$-K$_2$O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P$_2$O$_5$-K$_2$O-S/ha).
three GS in NSIC Rc 122, higher for three GS and lower for one GS in PSB Rc 18, higher for one GS, and lower for three GS in PSB Rc 82 (Figure 3d). Percentage leaves with dots among and between varieties were statistically different: lower for four GS in PSB Rc 82, lower for two GS and higher for four GS in PSB Rc 18, and higher for five GS in NSIC Rc 122. Percentage withered leaves among and between varieties were statistically different: lower for ten GS in NSIC Rc 122, lower for seven GS and higher for two GS in PSB Rc 18, and higher for eight GS in PSB Rc 82.

**Mechanisms for Differences in Grain Yields for PSB Rc 18 vs. NSIC Rc 122 vs. PSB Rc 82**

The significantly higher grain yield in PSB Rc 18 than PSB Rc 82 (Table 3a) can be due to higher antioxidant enzyme activity and photosynthetic transport (Zhang et al. 2010; El-Esawi and Alayafi 2019; Nahakpam 2017), which enhanced the protection of chloroplast structure. This enhanced protection could have been responsible for the longer leaf area duration (Figure 3d) and, possibly, the better functional stay-green trait (Zhang et al. 2010) of PSB Rc 18 than PSB Rc 82. Such traits possibly prolonged the period of chloroplasts to produce chl, hence the increased total time to assemble the other reagents for photosynthesis (PS) such as solar radiation, carbon dioxide, and water. This extended PS time (Jeon et al. 2011) and increased total PS (Kumagai et al. 2009) in PSB Rc 18.

Compared to PSB Rc 82, the enhanced protection of chloroplast structure could be the reason for higher chl content in PSB Rc 18 across GS (Figures 3a and b), including grain filling (Tables 3c and d), leading to a more efficient PS and PS-related processes and higher net PS (Ullah et al. 2011; Huang et al. 2016; Kumagai et al. 2009). This resulted in a higher crop growth rate (CGR) (Mondal et al. 2013); higher net PS and CGR contributed to an improved “source” or better health status of leaves in PSB Rc 18 than PSB Rc 82 (Figure 3d). Higher total PS, net PS, and CGR plus an improved “source” also contributed to an enhanced “sink” (Takai et al. 2006), hence the significantly greater number of grains per panicle in PSB Rc 18 than PSB Rc 82 (Table 3a).

An improved “source” and higher net PS during grain filling increased the non-structural carbohydrates (NSCs) in culms and leaves, resulting in hastened translocation of NSCs to panicles or grains (Takai et al. 2006; Zhang et al. 2010) – hence the significantly greater number of filled grains per panicle, grain weight per panicle (Table 3a), and harvest index (Table 3b) in PSB Rc 18 than PSB Rc 82. The improved “sink” (Zhang Y et al. 2009; Zhang H et al. 2009b; Yang et al. 2007) and grain filling efficiency resulted in significantly superior grain yields in PSB Rc 18 than PSB Rc 82.
Figure 3d. Percentage (%) healthy leaves, leaves with dots, and withered leaves at various DAT of three rice varieties – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 – across two levels each of water management and fertilizer rate. Different letters on a particular DAT denote that – using the ANOVA and Tukey’s tests – PSB Rc 18, NSIC Rc 122, and PSB Rc 82 are different at 5% level of significance; water management are CS and AWD; fertilizer rates are PFR (74-28-43-24 kg N-P₂O₅-K₂O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P₂O₅-K₂O-S/ha).
Comparison for Yield-contributing Factors in Rice under CS vs. AWD

In contrast with AWD, grain yield in CS – at 33.0 g/pail – was significantly higher by 7% (Table 4a). In earlier field experiments, higher grain yields were also noted in CS than the following variations of AWD: irrigation when water levels were 10, 20, and 30 cm below the soil surface (Oliver et al. 2008); irrigation if water level reached 15 cm below the soil surface (Thant et al. 2018); and irrigation at 10-d intervals with 1–2-cm water during the wet period (Chapagain and Yamaji 2010). Furthermore, in a greenhouse experiment, CS had a higher grain yield than those irrigated when water tensions reached 10, 20, and 40 kPa (Parveen et al. 2017).

Straw biomass in CS, at 36.8 g/pail, was significantly higher by 9% (Table 4b). In their greenhouse experiment in January–March 2018 using the same soil sample in this study, Magahud et al. (2019) also observed greater shoot biomass of CS than AWD in no fertilizer and minus nitrogen (N) treatments. In a field experiment, CS also had a significantly higher straw yield than those exposed to irrigation when water levels were 10, 20, and 30 cm below the soil surface (Oliver et al. 2008). In a greenhouse experiment, CS had a higher straw yield than those irrigated when water tensions reached 20 and 40 kPa (Parveen et al. 2017).

This study has noted that the numbers of days from transplanting to heading and flowering in CS, at 68.3 and 70.3 days, were significantly longer in CS by 3% (Table 4c). This translates to a significantly longer vegetative stage in CS.

Chl levels of the top-most expanded leaf were generally higher in CS than AWD. LCC values were significantly higher in CS at 35 and 91 DAT by 7–17% (Figure 4a). SPAD values were significantly greater in CS at 29, 36, and 43 DAT by 3–10% – significantly lower in CS at 57 DAT by 4% (Figure 4b). The higher SPAD and LCC values

---

**Table 4a.** Average grain yield and yield component parameters of two water management, CS vs. AWD, across three rice varieties and two fertilizer rates.

<table>
<thead>
<tr>
<th>Water management</th>
<th>Grain yield, g/pail</th>
<th>Yield component parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of tillers per pail</td>
<td>Number of productive panicles per pail</td>
</tr>
<tr>
<td>CS</td>
<td>32.98a</td>
<td>25.74a</td>
</tr>
<tr>
<td>AWD</td>
<td>30.80b</td>
<td>25.29a</td>
</tr>
</tbody>
</table>

Different letters denote that – using the ANOVA test – CS and AWD are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; fertilizer rates are PFR (74-28-43-24 kg N-P₂O₅-K₂O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P₂O₅-K₂O-S/ha).

**Table 4b.** Average oven-dry straw biomass, root biomass, and harvest index of two water management, CS vs. AWD, across three rice varieties and two fertilizer rates.

<table>
<thead>
<tr>
<th>Water management</th>
<th>Straw biomass, g/pail</th>
<th>Root biomass, g/pail</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS</td>
<td>36.80a</td>
<td>14.39a</td>
<td>0.472a</td>
</tr>
<tr>
<td>AWD</td>
<td>33.84b</td>
<td>12.54a</td>
<td>0.476a</td>
</tr>
</tbody>
</table>

Different letters denote that – using the ANOVA test – CS and AWD are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; fertilizer rates are PFR (74-28-43-24 kg N-P₂O₅-K₂O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P₂O₅-K₂O-S/ha).

**Table 4c.** Average number of days from transplanting to heading, flowering, and grain maturity of two water management, CS vs. AWD, across three rice varieties and two fertilizer rates.

<table>
<thead>
<tr>
<th>Water management</th>
<th>Number of days from transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>To heading</td>
</tr>
<tr>
<td>CS</td>
<td>68.26a</td>
</tr>
<tr>
<td>AWD</td>
<td>66.43b</td>
</tr>
</tbody>
</table>

Different letters denote that – using the ANOVA test – CS and AWD are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; fertilizer rates are PFR (74-28-43-24 kg N-P₂O₅-K₂O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P₂O₅-K₂O-S/ha).
in CS pails coincide with the time when the drying and wetting processes were done in AWD pails at 0–54 DAT. In their screenhouse experiment, Magahud et al. (2019) also noted higher SPAD and LCC values in CS than AWD in three fertilizer treatments. Likewise, previous studies indicated that CS rice exhibited either significantly or numerically higher chl levels than AWD rice for four crop stages (Khairi et al. 2015a, b). Plants were generally shorter in CS than AWD. In CS, plants were significantly shorter by 2–5% at 26, 75, and 82 DAT and significantly taller by 3–5% at 33 and 40 DAT (Figure 4c). In their screenhouse experiment, Magahud et al. (2019) also noted shorter CS plants in complete and minus potassium (K) fertilizer treatments. Similar results were reported from active tillering until physiological maturity (Sarker et al. 2017). Furthermore,
Plants exposed to CS were observed to be shorter than those irrigated when water levels reached 5 and 15 cm below the soil surface and those irrigated 3 d after the disappearance of water (Boruah et al. 2018).

The number of tillers was significantly lower in CS by 10–14% from 19–54 DAT (Figure 4d). During harvesting, however, the number of tillers was not significantly different between CS and AWD (Table 4a). We observed that, from 19–54 DAT, the number of large tillers in CS and AWD were almost the same, whereas the number of small tillers was lower in CS. This indicates that AWD enhanced the production of small tillers. Under both water management, large tillers produced panicles and were retained until harvesting; small tillers did not produce panicles and became withered before harvesting.
Earlier studies support the present results on the number of tillers. A significantly lower number of tillers was found in CS for 59 DAT (Magahud et al. 2019), during the panicle initiation stage (Ishfaq et al. 2020), and from early until harvesting stages (Mboyerwa et al. 2021). Under the same past experiments, the following information was also gathered: [1] number of large tillers in CS and AWD were almost the same, whereas the number of small tillers was lower in CS (Magahud et al., pers. comm.); [2] as the number of tillers decrease for both CS and AWD towards crop maturity, the gap between CS and AWD became increasingly closer from panicle initiation to heading and from heading to panicle maturity (Ishfaq et al. 2020); hence, it is likely that AWD had a higher number of small tillers, which became withered towards crop maturity; and [3] the number of tillers that had degenerated or died from maximum tillering to crop maturity was lower in CS (Mboyerwa et al. 2021).

Compared with AWD, CS had better health status of leaves from grain filling to harvesting stages but inferior during tillering stage (Figure 4e). The following were observed to be statistically significant under CS: [1] the number of healthy leaves was higher by 8–32% at 77, 84, and 98 DAT and lower by 13–17% at 21 and 28 DAT; [2] the percentage of healthy leaves was higher by 1% at 91 DAT and lower by 8% at 28 DAT; [3] the percentage of leaves with dots was lower by 1% at 98 DAT and greater by 4–6% at 21 and 28 DAT; and [4] the percentage of withered leaves was lower by 4% at 84 DAT and higher by 1–3% at 28–49 DAT.

Mechanisms for Differences in Grain Yields for CS vs. AWD

The significantly superior grain yield in CS than AWD (Table 4a) can be due to the higher soil N availability leading to better yield-contributing plant traits. The same soil sample used in this study was earlier found to exhibit higher N availability if exposed to CS (Magahud et al. 2019). This higher soil N availability was also noted in rice soils from other areas (Khairi et al. 2015a; Shao et al. 2015). Greater N availability in CS soil can be explained by lower aerial N losses through volatilization (Dong et al. 2012; Xu et al. 2012) and nitrification-denitrification (Dong et al. 2012; Tuyogon 2014; Xu et al. 2013).

More available N in CS soil allowed root absorption and plant translocation of more N, which resulted in a significantly longer vegetative stage (Table 4c), a better
health status of leaves from grain filling until harvesting (Figure 4e), and higher leaf chl levels (Figures 4a and b) of CS plants. This longer vegetative stage gave the plants more time to assemble the reagents for PS and to perform PS, which possibly led to higher total PS in CS than AWD throughout the plant’s duration. Greater leaf chl levels possibly allowed the plants to gather more reagents for PS and perform more PS per unit time, which resulted in a more efficient PS process. Longer vegetative stage and better PS performance resulted in significantly greater straw yield (Table 4b).

Superior health status of leaves during grain filling (Figure 4e), better PS performance, and higher straw yield (Table 4b) is an improvement in “source,” allowing the transfer of more photosynthates to grains, resulting in higher grain yield in CS than AWD.

In this study, the duration when the drying and wetting processes were done in AWD pails at 0–54 DAT corresponds to higher SPAD and LCC values in CS pails. This can be explained by lower aerial N losses from the soil of CS pails at this time.

Similar results were observed in screenhouse experiments in Malaysia, where grain yields, filled grains per panicle, grains per panicle, and the number of panicles were significantly higher in two CS treatments compared to AWD treatment (Khairi et al. 2015a, b). This was coupled by significantly higher soil ammonium concentration on the seventh week (Khairi et al. 2015a), significantly higher chl contents and fluorescence, and quantum yield of photosystem II of CS than AWD treatments for 2–3 wk (Khairi et al. 2015a, b). Photosynthetic active radiation, net PS rate, transpiration rate, and stomatal conductance were also greater in CS than AWD treatments (Khairi et al. 2015b).

Liebig’s law of minimum states that the level of plant production or yield can be no greater than that allowed by the most limiting essential growth factor. Among the essential nutrients absorbed from the soil, N was the most deficient in the Agusan soil used in this study (Magahud et al. 2019). As such, the slightly better N availability in CS than in AWD soil used (Magahud et al. 2019) explains the significantly higher yield in CS.

The number of small, unproductive tillers was lower in CS than AWD during vegetative and reproductive stages (Figure 4d; Table 4a). Thus, the nutrients, water, and photosynthates for synthesizing and maintaining the small tillers were – instead – used for improving the health of the large, productive tillers, and for filling in their panicles or grains. This contributed to the superior yield in CS.

**Comparison for Yield-contributing Factors in Rice under PFR vs. FFR**

Compared with FFR (42.0-4.5-10.5-3.8 kg N-P$_2$O$_5$-K$_2$O-S/ha), PFR (74-28-43-24 kg N-P$_2$O$_5$-K$_2$O-S/ha) was statistically significant in the following parameters: 18% greater grain yield at 34.1 g/pail, 18% higher number of tillers per pail at 27 tillers, 16% higher number of productive panicles per pail at 23 panicles, 2% greater panicle length at 23.7cm (Table 5a), and 15% higher straw biomass at 37.4 g/pail (Table 5b). The number of days from transplanting to heading, flowering, and grain maturity were numerically higher in PFR (Table 5c).

Chl levels of the top-most expanded leaf were higher in PFR than FFR from booting until grain filling stages. LCC values were significantly greater in PFR by 5–11% at 70, 77, and 84 DAT (Figure 5a). SPAD values were significantly greater in PFR by 4–5% at 64 and 78 DAT but significantly lower in PFR by 3% at 36 DAT (Figure 5b).

Plants were significantly taller in PFR by 3–5% for seven GS, ranging from 47 DAT until harvest (Figure 4c). The number of tillers was significantly higher in PFR by 7–18% from 19 until 54 DAT and upon the harvest of rice (Figure 4d; Table 5a).

PFR had better health status of leaves than FFR. The number of healthy leaves was significantly higher in PFR by 6–58% for 11 GS, ranging from 21 DAT until harvest (Figure 4e). The percentage of healthy leaves was significantly greater in PFR by 5–11% at 21, 70, and 98 DAT but significantly lower in PFR by 4% at 14 DAT. The percentage of withered leaves was significantly lower in PFR by 1–6% from 63–84 DAT but significantly higher in PFR by 4% at 14 DAT. Two field experiments, employing the same FFR (42.0-4.5-10.5 kg/ha) and PFR (74-28-43 kg/ha) N-P$_2$O$_5$-K$_2$O rates used in this present study, also found that – compared to FFR – PFR produced either significantly or numerically higher grain yields, number of tillers, number of productive panicles, panicle length, chl levels, straw biomass, and plant height (Jehru C. Magahud, pers. comm.). Such experiments were done in July–October 2019 and January–April 2020 cropping seasons in Remedios T. Romualdez, a few hundred meters from this experiment’s soil collection site.

**Mechanisms for Differences in Grain Yields for PFR vs. FFR**

In this experiment, the PFR is either the optimum or near optimum N-P$_2$O$_5$-K$_2$O-S/ha rates for lowland rice grown in Agusan soil; the FFR, on the other hand, is below the optimum. Field equivalent of this study’s PFR (74-28-43-24 kg N-P$_2$O$_5$-K$_2$O-S/ha) are the exact rates recommended producing 5.0 t/ha yield in Agusan (Magahud et al. 2019), with near or within the optimum ranges (60-70
Table 5a. Average grain yield and yield component parameters of two fertilizer rates – PFR (74-28-34-24 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) – across three rice varieties and two water management.

<table>
<thead>
<tr>
<th>Fertilizer rate</th>
<th>Grain yield, g/pail</th>
<th>Number of tillers per pail</th>
<th>Number of productive panicles per pail</th>
<th>Panicle length, cm</th>
<th>Total number of grains per panicle</th>
<th>Number of filled grains per panicle</th>
<th>Number of unfilled grains per panicle</th>
<th>Grain weight per panicle, g</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFR</td>
<td>34.14a</td>
<td>27.36a</td>
<td>23.41a</td>
<td>23.66a</td>
<td>103.98a</td>
<td>80.50a</td>
<td>23.48a</td>
<td>1.78a</td>
</tr>
<tr>
<td>FFR</td>
<td>29.02b</td>
<td>23.22b</td>
<td>20.17b</td>
<td>23.28b</td>
<td>101.76a</td>
<td>78.38a</td>
<td>23.38a</td>
<td>1.75a</td>
</tr>
</tbody>
</table>

Different letters denote that – using the ANOVA test – PFR and FFR are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; water management are CS and AWD.

Table 5b. Average oven-dry straw biomass, root biomass, and harvest index of two fertilizer rates – PFR (74-28-34-24 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) – across three rice varieties and two water management.

<table>
<thead>
<tr>
<th>Fertilizer rate</th>
<th>Straw biomass, g/pail</th>
<th>Root biomass, g/pail</th>
<th>Harvest index</th>
</tr>
</thead>
<tbody>
<tr>
<td>PFR</td>
<td>37.44a</td>
<td>14.49a</td>
<td>0.477a</td>
</tr>
<tr>
<td>FFR</td>
<td>32.56b</td>
<td>12.11a</td>
<td>0.471a</td>
</tr>
</tbody>
</table>

Different letters denote that – using the ANOVA test – PFR and FFR are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; water management are CS and AWD.

Table 5c. Average number of days from transplanting to heading, flowering, and grain maturity of two fertilizer rates – PFR (74-28-34-24 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) – across three rice varieties and two water management.

<table>
<thead>
<tr>
<th>Fertilizer rate</th>
<th>Number of days from transplanting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>To heading</td>
</tr>
<tr>
<td>PFR</td>
<td>67.41a</td>
</tr>
<tr>
<td>FFR</td>
<td>67.17a</td>
</tr>
</tbody>
</table>

Different letters denote that – using the ANOVA test – PFR and FFR are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; water management are CS and AWD.

Figure 5a. LCC values of top most expanded leaf at various DAT of two fertilizer rates – PFR (74-28-34-24 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg \(N\)-P\(_2\)O\(_5\)-K\(_2\)O-S/ha) – across three rice varieties and two water management. Asterisk (*) on a particular DAT denotes that – using the ANOVA test – PFR and FFR are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; water management are CS and AWD.
N, 14-30 P₂O₅, and 60-90 K₂O kg/ha) (Mabayag et al. 2015) to attain a relatively higher yield in the province. Yields of irrigated rice in Agusan del Norte/Sur ranged at only 3.3–3.8 t/ha in 2010–2019 (PhilRice-SED 2021a). Meanwhile, FFR used in this experiment is lower in N and at least 3.5x lower in P₂O₅ and K₂O than the recommended and optimum fertilizer rates for the province.

Similar results were noted in field experiments in Jabonga, Agusan del Norte for two cropping seasons of 2018, where grain yields were higher in fertilizer rates of Rice Crop Manager (RCM) treatments than those of farmers’ practice. The average N-P₂O₅-K₂O rates and yields of three treatments in 8–10 farms are as follows: 82-21-21 kg / ha produced 6.2 t/ha for RCM 1, 59-22-22 kg/ha yielded 6.2 t/ha for RCM 2, and 19-8-8 kg/ha produced 5.3 t/ha
for farmer’s practice. In contrast with farmers’ practice, RCM added more nitrogen-phosphorus-potassium (NPK) to satisfy the insufficient amounts in soil and reach the optimum or near-the-optimum NPK levels (Caryl S. Agting, pers. comm.). Furthermore, in field experiments at Remedious T. Romualdez in Agusan del Norte, grain yields were higher in two RCM treatments than farmers’ practice in two cropping seasons of 2018. Compared with farmers’ practice, RCM added more N and P to satisfy the insufficient amounts in soil and reach the optimum or near-the-optimum NPK levels (Caryl S. Agting, pers. comm.).

Carbon dioxide, water, and sunlight can be the non-limiting essential growth and yield factors for rice employed with PFR and FFR. Moreover, PFR added more nitrogen-phosphorus-potassium-sulfur (NPKS) to the existing indigenous nutrients in Agusan soil – leading to optimum or near-the-optimum rice NPKS levels and, consequently, higher rice growth and yield (Table 5a). Meanwhile, FFR added less NPKS to the existing indigenous soil nutrients – resulting in lower-than-optimum rice NPKS levels and, thus, lower rice growth and yield.

More NPKS absorbed by roots of rice in PFR provided more nutrients for producing structural carbohydrates and NSCs, resulting in improved “source” throughout plant GS and “sink” during the reproductive stage. Improved “source” was the [1] significantly higher number of tillers (Figure 5d; Table 5a), number of healthy leaves (Figure 5e), and total number of leaves in PFR throughout plant GS; and [2] significantly higher straw biomass (Table 5b). These indicated more sites where the reagents for PS were assembled and PS occurred. This may have resulted in higher total PS and more photosynthates.

More NPKS absorbed by roots of rice in PFR may have resulted in more nutrients for synthesizing chl, hence the significantly higher chl content noted in PFR from booting until grain filling stages (Figures 5a and b). Greater chl content may have increased the net PS (Hou et al. 2018; Pan et al. 2016; Wang et al. 2008) – producing more photosynthates, which improved the “source” and “sink.” Enhanced “source” was the better health status of leaves in PFR from booting until harvesting (Figure 5e).

Improved “sink” was the significantly higher number and longer panicles noted in PFR (Table 5a). More photosynthates and improved “sink” may have resulted in a more efficient grain filling process, hence the superior grain yield of PFR than FFR.

**Interaction Effects of Variety, Water Management, and Fertilizer Rate on Grain Yield and Yield Component Parameters**

No significant interaction effects of the three factors on grain yield were observed. However, the following interaction effects were significant on most yield component parameters: variety x water management, variety x fertilizer rate, and variety x water management x fertilizer rate (Table 2). This can be due to the different responses of varieties to the varying water management and fertilizer rates employed. The soil sample used in this study

---

**Figure 5d.** Number of tillers at various DAT of two fertilizer rates –PFR (74-28-43-24 kg N-P₂O₅-K₂O-S/ha) and FFR (42.0-4.5-10.5-3.8 kg N-P₂O₅-K₂O-S/ha) – across three rice varieties and two water management. Asterisk (*) on a particular DAT denotes that – using the ANOVA test – PFR and FFR are different at 5% level of significance; varieties are PSB Rc 18, NSIC Rc 122, and PSB Rc 82; water management are CS and AWD.
is Zn-sufficient if exposed to AWD but nearly Zn-deficient if continuously submerged (Magahud et al. 2019). Since the varieties used may differ in their tolerance to Zn deficiency (Corton et al. 1999; Jimenez et al. 2015c; Jimenez and Estoy 2013), their yield components vary with different water management. Furthermore, varieties have different nutrient use efficiencies (Nemeño and Siclay 2010); hence, their yield components change with varying fertilizer rates.

Recommendations on Variety, Water Management, and Fertilizer Rate for Improving Grain Yields in Agusan Soil

PSB Rc 18 should be selected over PSB Rc 82 because it is more adapted in Agusan soil.

CS should be preferred over AWD in non-zinc-deficient Agusan soil, such as the one used in this study. CS can also be employed in Zn-deficient rice areas but coupled with Zn application (Corton et al. 1999; Mabayag et al. 2015; PhilRice 2007). AWD recorded a significantly lower grain yield; hence, it should be employed only in areas with limited water supply.

The 74-28-43-24 kg N-P₂O₅-K₂O-S/ha PFR should be selected over the 42.0-4.5-10.5-3.8 kg N-P₂O₅-K₂O-S/ha FFR. Moreover, the following fertilizer rates can also be considered: [1] RCM-based recommendation and [2] recommendations from recent studies in Agusan such as 53-7-37 kg N-P₂O₅-K₂O/ha (Nemeño et al. 2019) and 70-7-37 kg N-P₂O₅-K₂O/ha (Rollon et al. 2021).

No specific combination of variety, water management, and fertilizer rate can be recommended since these three factors did not have significant two and three-way interaction effects on grain yield.

CONCLUSIONS AND RECOMMENDATIONS

Compared with PSB Rc 82, PSB Rc 18 had a significantly higher grain yield by 9% due to the enhanced protection of chloroplast structure, leading to longer leaf area duration and higher chl contents across GSs. These contributed to an improved “sink” or significantly greater number of grains per panicle by 19%, as well as enhanced “source” or better health status of leaves. Improved “source” increased the grain filling efficiency, resulting in a significantly higher number of filled grains...
per panicle by 18%, grain weight per panicle by 21%, and harvest index by 6%.

In contrast with AWD, CS had a significantly higher grain yield by 7% due to higher soil N availability, leading to better plant traits. These traits include a significantly longer vegetative stage by 3%, greater straw biomass by 9%, higher leaf chl levels, and better health status of leaves from grain filling until harvesting. Moreover, the lower number of small, unproductive tillers in CS allowed more plant resources to be used for improving the health of large, panicle-bearing tillers.

Compared with FFR, PFR had a significantly higher grain yield by 18% due to a closer-to-the-optimum fertilizer rate leading to an improved “source.” Improved “source” includes the following statistically significant parameters: [1] higher number of tillers by 7–18%, greater number of healthy leaves, and higher total number of leaves throughout GSs; [2] greater biomass by 15%; [3] higher chl content from booting until grain filling stage; and [4] better health status of leaves from booting until harvesting. The closer-to-the-optimum fertilizer rate also improved the “sink,” which was the significantly higher number of productive panicles by 16% and longer panicles by 2%.

The study implies that certain management practices – employing a more adapted variety, CS or PFR in Agusan soil – provides a better genetic or environmental factor, which enhances plant traits and improves grain yields. The following are the management options recommended by the study: [1] PSB Rc 18 should be selected over PSB Rc 82 because it is more adapted in Agusan soil, [2] CS should be preferred over AWD in a non-zinc-deficient Agusan soil, and [3] the 74-28-43-24 kg N-P2O5-K2O-S/ha PFR should be selected over the 42.0-4.5-10.5-3.8 kg N-P2O5-K2O-S/ha FFR. Variety, water management, and fertilizer rate do not have significant two and three-way interaction effects on grain yield; hence, no specific combination of the three factors can be recommended.

Results of the study, particularly on CS vs. AWD, should be confirmed in experimental and farmers’ fields, where the feasibility and efficiency of these management options are affected by current field practices on water management of pests. Furthermore, recently-released varieties recommended for Agusan can be tested. The need for Zn application on Zn-deficient rice fields under AWD should also be studied since soil Zn deficiency is very common in Agusan.

ACKNOWLEDGMENTS

The Philippine Rice Research Institute funded the research. Sheena Lourdes P. Dalumpines and Agapito E. Lincuna Jr. participated in conceiving, designing, and performing the experiments. Warrien A. Vitor and Julius Paul B. Guquib conducted portions of the experiments.

REFERENCES


ESCAÑAN DL, NEMEÑO GA. 2013a. Improvement of diagnostic method and correction of soil fertility constraints to yield of irrigated lowland rice in Mindanao.


RAHMAN MD, BULBUL SH. 2014. Effect of alternate wetting and drying (AWD) irrigation for Boro rice cultivation in Bangladesh. Agric For Fish 3(2): 86–92.


