Interactive Effect of Weeding Regimes, Rice Cultivars, and Seeding Rates Influence the Rice-Weed Competition under Dry Direct-Seeded Condition

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Abstract: Dry direct-seeded rice (Oryza sativa L.), a climate-smart and resource-efficient (labor and water) rice production technology is gaining popularity in many parts of Asian countries; however, weeds are the major constraints for its early establishment and optimum productivity. Chemical weed management is effective, rapid, and also decreases weed management costs in dry direct-seeded rice (DSR) system; however, chemical use for weed management have a negative effect on the environment and also have human health hazards. Therefore, integrated weed management (IWM) is the best option for the sustainability of rice production under the DSR system. Improving competitiveness against weeds, weed-competitive rice cultivars, and high seeding rates were found to be the most promising IWM strategies in DSR. In this context, a field study was conducted to evaluate the weed competitiveness of rice cultivars and seeding rates on the performance of aus rice in dry direct-seeded systems in Bangladesh. Three inbred rice cultivars (CV), namely “BRRI dhan26”, “BRRI dhan48”, and “BRRI dhan55”, and one hybrid cultivar, “Arize” were tested in a seeding rate (SR) of 20, 40, and 80 kg ha⁻¹ under two weeding regimes (WR) of weed-free and partially-weedy. Rice grain yield was strongly affected (p < 0.01) by the interactions of WR, CV, and SR. In weed-free conditions, the yield of all three inbred cultivars was increased up to SR of 40 kg ha⁻¹ and for the hybrid cultivar, up to SR of 20 kg ha⁻¹, and with further increment of SR, there was no yield advantage. Conversely, under partially weedy conditions, the yield of three inbred cultivars increased up to SR of 80 kg ha⁻¹; however, for the hybrid cultivar, this increment was up to SR of 40 kg ha⁻¹ and thereafter, no yield gain. In weedy conditions, the higher SR compensates for the yield losses by increasing the competitiveness of rice with weeds. Across SR, the hybrid cultivar had a significantly (p < 0.01) higher weed competitive index (WCI) than all the inbred cultivars and the highest SR always had a higher WCI.

Keywords: weed management; hybrid rice; early-vigor; competitiveness; resources conservation; climate-smart production
1. Introduction

Rice (*Oryza sativa* L.) is a major crop in the food security and livelihood of the people of South Asian (SA) countries. Ending hunger and malnutrition in SA is essential to achieve sustainable development goals and rice plays a crucial role [1]. The common rice production method in SA is transplanting the rice seedling into puddled soil [2]. Puddling and transplanting operations consumed a huge amount of water, approximately 30% of the total water requirement for rice cultivation of a season [3]. The alternative rice production method, which is dry direct seeding (DSR), is becoming popular in SA countries where irrigation water is scarce and the wage rate of agricultural labor is high [4,5]. Moreover, due to the development of better technology (e.g., mechanized line sowing seed drill, mechanical weeder, and improved herbicides) in the last decades, DSR has become more contented than the transplanted rice [6–8].

Bangladesh is the fourth largest rice-producing country in the world and second in SA, and around 67% of the country’s cultivated land area is used for rice production [9,10]. Rice grows here throughout the year and there are three distinct growing seasons popularly known as *aus* (April–August), *aman* (June–December), and *boro* (November–May), covered by 9, 49, and 42% area, respectively [10]. Rice in *aus* and *aman* are considered mainly rainfed but significant partial irrigations are needed depending on rainfall variability and land conditions. *Boro* is completely irrigated rice and more than 80% of irrigated areas depend on groundwater. Sources of groundwater are decreasing over time due to unregulated use, leading to a scarcity of irrigation water across a large part of the country at the end of the *boro* season. Irrigation cost in Bangladesh is increasing over time, therefore, the profitability of *boro* rice is decreasing. In the wet season, *aman* rice is the main crop in the field and there are only a few options for another non-rice crop during this time due to frequent and heavy rains and waterlogging conditions.

With the increasing population, Bangladesh also needs to increase the production of other non-rice crops such as pulses, oilseed, vegetables, and spices. Those crops are mostly grown during the dry season in Bangladesh and this is also the *boro* rice cultivation period. If we examine the rice production statistics in Bangladesh from 1970 to 2018, we find a decreasing trend in *aus* areas from 1970 to 2010 and thereafter, an increasing trend [11]. *Aman* areas from 1970 to 2018 were almost static and *boro* areas had an increasing trend from 1970 to 2010 and thereafter almost static [11]. Increasing the cultivation of non-rice crops during the dry season (*boro*) would save groundwater as well as the production of other nutritious crops for the growing population, but this could reduce the total volume of rice production (national production). In this situation, to minimize rice shortages, *aus* yield and area need to be increased. Considering the important contribution of *aus* rice to Bangladesh’s rice production levels, the government is also trying to increase the *aus* rice areas. *Aus* season usually starts at the end of a couple of months of dry spell and just before the start of the wet season; therefore, it is difficult for farmers to manage this large volume of water for puddling and transplanting, and this is one of the main reasons that many areas suitable for *aus* remain fallow.

Therefore, dry direct seeding (DSR) is the alternate option for the successful cultivation of *aus* rice where irrigation water is scarce and the wage rate of agricultural labor is high [4,5]. However, the success of DSR mostly depends on efficient and economic weed management [12,13]. Weed infestation in DSR systems is usually higher than the puddled transplanted rice; because of this, there is no size advantage of rice plants at the time of emergence, which is usually present in transplanted systems [2,14]. A DSR field remains mostly aerobic as opposed to the continuous standing water in puddled and transplanted rice, another important reason why weed grows more in DSR systems [15]. Weed management currently is almost herbicide-dependent and sequential application of pre-and post-emergence herbicides [16] or tank mixtures of different post-emergence herbicides [17] was found effective in controlling weed in DSR systems. However, weed management currently is not cost-effective without herbicides and injudicious use of herbicides may adversely affect the environment and help to develop resistant weed biotypes [18]. Therefore,
weed management in DSR needs integration of different practices such as preventive measures, cultural methods, mechanical and manual weeding, etc., that could reduce farmers’ dependence on herbicides and offer the best sustainable weed management [19].

Competitive rice cultivar (CV) is a component of integrated weed management (IWM) and an attractive option to suppress weed growth where there is no need to incur any additional costs [20]. Competitive CV suppresses weeds by its quick canopy coverage or CV may be more capable of reducing the ability of a weed species through competition for limited resources, or cultivars may produce chemical exudates that reduce the growth of weeds [21]. Although rice is generally a weak competitor against weeds, the identification of superior weed competitive rice cultivars could play an important role in reducing herbicide load in the agro-ecosystem by reducing its use and enhancing the performance of herbicides [22–24].

Seed rate (SR) is an important factor in DSR crop establishment which determines the adequate plant population for optimum yield. In the DSR system, low plant population and high gaps encourage the growth of weeds [15]. On the other hand, high plant density produces less productive tillers, greater chance of disease and insect infestation, increases crop lodging, and requires higher nitrogen application [4]. High SR is encouraging in DSR system for compensating for poor crop establishment in where weed problem is higher, the chance of bird and rodent damage, and seed rotting due to too much rain shortly after sowing, or seedling death due to submergence [25–27]. Therefore, there will likely be an interaction between cultivar choice and seed rate on the yield of rice, especially in dry-seeded conditions. A few similar types of studies were conducted in SA, Southeast Asian countries [19,22,28], and in Bangladesh to evaluate the weed competitiveness of boro rice cultivars [29,30]; however, no single work so far in aus rice in DSR conditions. The objectives of the current study are to evaluate the yield performance and weed competitiveness of aus rice cultivars including hybrid and inbred at different SR and weeding regimes in dry direct-seeded systems.

2. Materials and Methods

2.1. Experimental Site

The field trial was established during the pre-monsoon season called aus rice (Oryza sativa L.) in 2015 at the regional station of Bangladesh Agricultural Research Institute, Jashore (23°18’ N, 89°19’ E, 19 m MSL), Bangladesh. The trial site was located in the High Ganges River Floodplain under the agro-ecological zone (AEZ 11), which is relatively high and medium high land. The cropping system in the area is extremely diverse and intensive with a range of rabi crops such as wheat (Triticum aestivum L.), maize (Zea mays L.), pulses, mustard (Brassica sp.), potatoes (Solanum tuberosum L.), vegetables, and boro (rice, etc.) are grown in the dry season. The aman rice is the only option in monsoon season; however, during the early monsoon season, farmers usually practice either jute (Corchorus capsularis) or aus rice. The soil (0–15 cm) of the trial field is a clay loam (sand 29%, silt 34%, and clay 36%) with a bulk density of 1.58 Mg m⁻³, pH of 7.6, and organic carbon less than 1%. The experimental field had been following a wheat-mungbean (Vigna radiata L.)-fallow cropping system for several years prior to the establishment of the trial.

2.2. Experimental Treatments and Design

The trial included two weed management regimes (weed-free and partial-weedy), four rice cultivars (“BRRI dhan26”, “BRRI dhan48”, “BRRI dhan55”, and a hybrid rice cultivar, “Arize”) including both inbred and hybrid, and three rice seed rates (20, 40, and 80 kg ha⁻¹). The experimental design was a split-plot in a randomized complete block arrangement with three replications. The main plots were arranged with two weeding regimes and sub-plots were arranged with four rice cultivars and three seed rates. The sub-plot size was 3 m × 2 m and between sub-plots, 0.5 m was buffer space without any bund. The main plot was separated with a buffer space of 0.75 m. The weed-free treatment plots were weed-free by application of a pre-emergence herbicide (Pendimethalin 1000 g ai ha⁻1 mix
with 350 L clean water and applied at two days after sowing and irrigation) followed by three times manual weeding (at 15, 30, and 50 days after sowing (DAS)) using niri. In partially weedy treatment, one manual weeding was done at 30 DAS. Before and after this weeding, the plots were kept in competition with weeds. We considered partially weedy instead of full weedy because in dry direct-seeding conditions there is a chance of complete yield loss due to weed competition. The three inbred rice cultivars, i.e., “BRRI dhan26”, “BRRI dhan48”, and “BRRI dhan55” were released by Bangladesh Rice Research Institute and recommended for aus season (http://knowledgebank-brri.org/brri-rice-varieties/) and hybrid rice “Arize” was collected from a private company (Bayer Crop Science Ltd., Monheim am Rhein, Germany), which is very much popular in the study area.

2.3. Crop Management

The experiment field was dry cultivated using a power tiller operated seeder (PTOS) machine (2 passes) which provided a friable seed bed. Dry seeds were sown manually with a row spacing of 20 cm in shallow furrows made by a hand-drawn single tyne furrower. The seeds were weighed separately according to the respective seed rate and for each line to facilitate desirable plant population in each treatment. The seeds were sown on 15 April 2015 at a depth of around 2 cm and then covered using loose soil. Fertilizer was applied at the rate of 100-10-40-10-2.2 kg ha\(^{-1}\) of nitrogen, phosphorus, potassium, sulfur, and zinc in the form of urea, triple superphosphate (TSP), muriate of potash (MoP), gypsum, and zinc sulphate, respectively. All TSP, MoP, gypsum, and zinc sulphate were applied immediately before making the seed furrows. Urea fertilizer was applied as top-dressing (three equal splits) at 10 days after sowing (DAS), at the early tillering (20 DAS), and maximum tillering (35 DAS). Immediately after sowing the field was lightly irrigated, and succeeding irrigations were arranged based on a soil water tension threshold (15 kPa at 15 cm soil depth) which was found to be the safe threshold for rice [31]. Once seedling was established, for irrigation at each time water, was added to the plots until the depth of water on the soil surface reached around 5 cm (40–50 mm water).

2.4. Observations

Rice stand establishment (plants m\(^{-2}\)) was determined at 12 DAS by counting the number of plants in five randomly selected 1 m row lengths in each sub-plot. To determine the weed competitiveness, weed density and biomass were measured at 30 and 60 DAS. Two quadrats measuring 40 cm by 40 cm were placed randomly in each plot during every sampling time; then weeds were collected from each quadrat. Collected weeds were clustered by a group of grasses, broadleaf, and sedges. After removing the roots of all weeds, these weeds were placed in paper bags for oven drying at 70 °C for determination of actual biomass for each treatment [4]. During weed sampling (on the same date and the same quadrats), all rice plants were also cut from the base of soil and the number of rice tillers and rice dry biomass were determined. The days to 50% flowering (FL) were measured from five randomly selected 1 m row lengths in each sub-plot by daily counts of the number of rice tillers in which anthesis had commenced.

The crop was harvested at physiological maturity stage and grain yield was determined by harvesting a 2.25 m\(^2\) (1.5 m by 1.5 m) area in the center of each plot. Immediately after harvesting, grains were mechanically threshed and cleaned well and then fresh grain weight was determined. At the time of weighing a grain moisture meter (GMK-303RS) was used for grain moisture content determination. Fresh grain weight was converted to grain yield (t ha\(^{-1}\)) at 14% moisture content. Immediately before harvest, the number of panicles was counted from five randomly placed 1 m row lengths in each sub-plot. The number of florets per panicle (unfilled and filled) was counted from 20 randomly selected panicles per sub-plot. Floret fertility was calculated as the percentage of filled grains to the total number of florets per panicle.
2.5. Weed Competitive Index

The weed competitive index (WCI) was calculated to find the most weed competitive cultivar using the following formula [32].

\[
WCI = \left[ \frac{GYi}{GYm} \right] - \left[ \frac{WBi}{WBm} \right]
\]

(1)

where \( Gyi \) is the yield of individual cultivar across seed rate in terms of weed infestation. The \( GYM \) is the mean yield of all cultivars across seed rate in terms of weed infestation. \( Wbi \) is the weed biomass of individual cultivar across seed rate, and \( WBm \) is the mean weed biomass of all cultivars across seed rate. In the partial weedy plot, the weed biomass was measured two times—once before an hand weeding (HW) and once at anthesis. To calculate WCI, the sum of the total biomass of the two samplings was used.

2.6. Rainfall and Temperature

Daily weather data such as rainfall and minimum and maximum temperatures during the trial period were recorded from the weather station at the Regional Agricultural Research Station, Bangladesh Agricultural Research Institute, Jashore, about 150 m from the trial field (Figure 1).

![Figure 1. Temperatures, solar radiation, and rainfall during the trial period.](image)

2.7. Statistical Analysis

The data were tested for normality and homogeneity of variance before analyzing variance (ANOVA). Weed data were not normally distributed, therefore, Box–Cox transformations, which provide a value of \( \lambda \) (lambda sign) that maximizes a log-likelihood function, were used to find the best transformation [33] and based on the \( \lambda \) value either log or square root transformed. The rice plant stand, rice density and biomass, weed density and biomass, yield and yield components, and transformed weed data were analyzed using a statistical software JMP 13 (SAS Institute, San Francisco, CA, USA). Tukey’s honestly significant difference (HSD) test was used at the \( p \leq 0.05 \) level to test the differences between the treatment means. Regression analysis was done to determine relationships between rice biomass and weed biomass using software SigmaPlot 14.0 (Systat Software, Inc., Point Richmond, CA, USA). Weeds were absent in the weed-free plots, therefore, weeding regimes were not included as a factor in the ANOVA analysis of weed data.
3. Results

3.1. Rice Stand Establishment, Tiller Density, and Tiller Biomass

Rice plant density at 12 DAS was not affected by the WR or any of the interaction but was affected ($p < 0.001$) by the CV and SR (Table 1). Across WR and SR, the highest plant density (181 plants m$^{-2}$) was recorded from the cultivar “BRRI dhan26” followed by “BRRI dhan48” and hybrid “Arize”. Plant density (140 plants m$^{-2}$) was lowest for the cultivar “BRRI dhan55”. Across WR and CV, plant density increased with the increase of SR from 20 to 80 kg ha$^{-1}$. Rice tiller density at 30 and 60 DAS was significantly ($p < 0.001$) affected by the WR, CV, SR, and CV $\times$ SR at 30 DAS and WR $\times$ SR at 60 DAS (Table 1).

Table 1. Effect of weeding regimes, rice cultivars, and seeding rates on rice plant stand establishment, rice tiller density, and biomass (dry weight basis) in dry direct-seeded aus rice.

| Variables | Rice Plant Count (no. m$^{-2}$) at 12 DAS | Rice Tiller Density (no. m$^{-2}$) at 30 DAS | Rice Tiller Biomass (g m$^{-2}$) at 30 DAS | Rice Tiller Density (no. m$^{-2}$) at 60 DAS | Rice Tiller Biomass (g m$^{-2}$) at 60 DAS |
|-----------|----------------------------------------|---------------------------------------------|------------------------------------------|---------------------------------------------|------------------------------------------|
| Weeding regimes (WR) | | | | | |
| Weed-free | 157 | 399 a | 46 a | 432 a | 655 a |
| Partial-weedy | 162 | 273 b | 30 b | 292 b | 399 b |
| Rice cultivars (CV) | | | | | |
| Hybrid Arize | 155 bc | 367 a | 51 a | 411 a | 600 a |
| BRRI dhan26 | 181 a | 365 a | 38 b | 367 b | 550 ab |
| BRRI dhan48 | 162 ab | 306 b | 32 b | 340 c | 495 b |
| BRRI dhan55 | 140 c | 309 b | 31 b | 330 c | 462 b |
| Seeding rate (SR) kg ha$^{-1}$ | | | | | |
| 20 | 78 c | 193 c | 19 c | 283 c | 418 c |
| 40 | 150 b | 320 b | 38 b | 365 b | 538 b |
| 80 | 250 a | 497 a | 57 a | 438 a | 625 a |
| $P < F$ | | | | | |
| WR | 0.85 ns | 130.0 *** | 43.9 *** | 425.9 *** | 115.5 *** |
| CV | 10.3 *** | 9.4 *** | 14.9 *** | 27.8 *** | 6.5 *** |
| SR | 351.9 *** | 256.3 *** | 85.1 *** | 172.9 *** | 25.4 *** |
| WR $\times$ CV | 0.57 ns | 0.53 ns | 0.77 ns | 1.54 ns | 0.93 ns |
| WR $\times$ SR | 1.7 ns | 0.68 ns | 0.58 ns | 7.2 *** | 0.39 ns |
| CV $\times$ SR | 1.9 ns | 2.71 ** | 0.56 ns | 0.38 ns | 0.98 ns |
| WR $\times$ CV $\times$ SR | 0.58 ns | 0.56 ns | 0.94 ns | 0.79 ns | 0.94 ns |

Means in a column (for weeding regimes, rice cultivars, and seeding rates) followed by the same small letter are not significantly different according to Tukey’s honestly significant difference (HSD) at alpha = 0.05. *** and ** indicates significance at $p < 0.001$ and 0.01. ns, indicates non-significance; DAS indicates days after sowing.

Across CV and SR, compared to the weed-free treatment, the WR partial-weedy treatment had 21–50% and 14–56% lower rice tiller density, respectively, at 30 and 60 DAS. Considered with the CV, at 30 DAS, the cultivars hybrid “Arize” and “BRRI dhan26” had similar and higher tiller density compared with the cultivars “BRRI dhan48” and “BRRI dhan55”. However, at 60 DAS, the highest tiller density was recorded from the cultivar hybrid “Arize”, followed by “BRRI dhan26”, and followed by “BRRI dhan48” and “BRRI dhan55”. Considered with the SR, tiller density increased significantly ($p < 0.001$) with the increase of SR. Rice biomass was significantly ($p < 0.01$) affected by the WR, CV, and SR; however, none of the interactions were significant. Across WR and SR, the cultivar hybrid “Arize” always had higher rice biomass than the inbred cultivars except at 60 DAS where “BRRI dhan26” had similar biomass to the hybrid “Arize”. Across WR and CV, rice biomass increased by 35–75% and 15–60% at 30 DAS and 12–60% and 5–35% at 60 DAS when seeding rate increased from 20 to 40 and 40 to 80 kg ha$^{-1}$, respectively.
3.2. Weed Density and Weed Biomass

Total weed density and biomass at 30 and 60 DAS were significantly \((p < 0.01)\) affected by the CV and SR (but not their interaction), however, individual weed group (grass, broadleaf, and sedges) were not always affected (Tables 2 and 3).

Table 2. Effect of rice cultivars and seeding rates on weed density and biomass (dry weight basis) at 30 days after sowing in dry direct-seeded *aus* rice.

| Variables | Weed Density (no. m\(^{-2}\)) at 30 DAS | Weed Biomass (g m\(^{-2}\)) at 30 DAS |
|-----------|----------------------------------------|--------------------------------------|
|           | Grass | Broadleaf | Sedge | Total | Grass | Broadleaf | Sedge | Total |
| Rice cultivars (CV) | | | | | | | | |
| Hybrid Arize | 142 b | 53 | 229 | 424 b | 102 b | 14 | 38 b | 155 b |
| BRRI dhan26 | 265 a | 42 | 290 | 597 a | 101 b | 24 | 46 b | 172 b |
| BRRI dhan48 | 297 a | 53 | 208 | 557 a | 164 a | 14 | 47 b | 225 a |
| BRRI dhan55 | 295 a | 51 | 253 | 599 a | 119 ab | 8 | 81 a | 207 a |
| Seeding rate (SR) kg ha\(^{-1}\) | | | | | | | | |
| 20 | 273 a | 65 a | 269 | 607 a | 159 a | 17 | 72 a | 249 a |
| 40 | 268 a | 45 b | 260 | 573 a | 122 ab | 11 | 53 ab | 186 b |
| 80 | 208 b | 39 b | 205 | 452 b | 83 b | 17 | 42 b | 142 b |

\(P < F\)

| CV | 17.9 ** | 0.34 ns | 0.82 ns | 4.87 ** | 4.1 ** | 1.57 ns | 4.97 ** | 4.1 ** |
| SR | 5.9 ** | 3.80 * | 1.06 ns | 6.38 ** | 8.9 *** | 0.49 ns | 4.72 ** | 16.5 *** |
| CV × SR | 0.94 ns | 0.44 ns | 0.27 ns | 0.92 ns | 0.19 ns | 0.67 ns | 0.16 ns |

Means in a column (for rice cultivars and seeding rates) followed by the same small letter are not significantly different according to Tukey’s HSD at alpha = 0.05. ***, **, and * indicate significance at \(p < 0.001, 0.01, \) and 0.05. ns, indicates non-significance; DAS, indicates days after sowing.

Table 3. Effect of rice cultivars and seeding rates on weed density and biomass (dry weight basis) at 60 days after sowing in dry direct-seeded *aus* rice.

| Variables | Weed Density (no. m\(^{-2}\)) at 60 DAS | Weed Biomass (g m\(^{-2}\)) at 60 DAS |
|-----------|----------------------------------------|--------------------------------------|
|           | Grass | Broadleaf | Sedge | Total | Grass | Broadleaf | Sedge | Total |
| Rice cultivars (CV) | | | | | | | | |
| Hybrid Arize | 169 | 39 | 124 b | 332 b | 56 b | 13 | 90 b | 160 b |
| BRRI dhan26 | 142 | 72 | 163 a | 376 a | 96 a | 14 | 112 a | 222 a |
| BRRI dhan48 | 158 | 66 | 174 a | 398 a | 101 a | 12 | 121 a | 234 a |
| BRRI dhan55 | 171 | 56 | 180 a | 407 a | 91 ab | 11 | 130 a | 231 a |
| Seeding rate (SR) kg ha\(^{-1}\) | | | | | | | | |
| 20 | 185 a | 74 | 175 a | 434 a | 103 a | 18 a | 148 a | 269 a |
| 40 | 166 ab | 58 | 166 ab | 390 a | 89 ab | 11 ab | 124 a | 224 a |
| 80 | 129 b | 43 | 139 b | 310 b | 66 b | 7 b | 90 b | 165 b |

\(P < F\)

| CV | 0.75 ns | 1.94 ns | 6.8 *** | 2.44 * | 4.3 ** | 0.37 ns | 1.93 ns * | 2.8 * |
| SR | 4.6 * | 3.1 ns | 4.9 ** | 9.54 *** | 4.8 ** | 4.9 ** | 11.9 *** | 13.5 *** |
| CV × SR | 0.19 ns | 0.87 ns | 0.78 ns | 0.54 ns | 0.39 ns | 0.44 ns | 0.26 ns | 0.14 ns |

Means in a column (for rice cultivars and seeding rates) followed by the same small letter are not significantly different according to Tukey’s HSD at alpha = 0.05. ***, **, and * indicate significance at \(p < 0.001, 0.01, \) and 0.05. ns, indicates non-significance; DAS, indicates days after sowing.

Considered with the CV, at 30 DAS, the density and biomass of broadleaf weed, and density of sedge weed were not affected but the density and biomass of grass weed were affected significantly \((p < 0.01)\). The grass density, as well as total weed density at 30 DAS, was lowest for the CV hybrid “Arize”; however, the total weed biomass of hybrid “Arize” and “BRRI dhan26” were similar and significantly \((p < 0.01)\) lower than the cultivars “BRRI dhan48” and “BRRI dhan55”. At 60 DAS, the lowest weed density and biomass were recorded from the CV hybrid “Arize” and the other three inbred cultivars had similar weed density and biomass (Table 3). Among the weed group, only sedge weed density and biomass were affected by CV but not grass and broadleaf weed, and the lowest sedge
weed density was recorded from the CV hybrid “Arize”. Across CV, the SR of 20 kg ha$^{-1}$ always had lower weed density and biomass than the SR 80 kg ha$^{-1}$. At 30 DAS, the SR 20 and 40 kg ha$^{-1}$ had similar weed density and was significantly ($p < 0.001$) lower than the SR of 80 kg ha$^{-1}$, however, the weed biomass of SR 20 kg ha$^{-1}$ was significantly lower than the SR of 40 and 80 kg ha$^{-1}$.

At 60 DAS, the SR 20 and 40 kg ha$^{-1}$ had similar weed density and biomass and was significantly higher than the SR of 80 kg ha$^{-1}$. There was a significant ($p < 0.001$) and a negative correlation between rice biomass and weed biomass (Figure 2). Across CV and SR, the increase of weed biomass decreased the rice biomass and the relationship was slightly stronger at 30 DAS ($r = -0.44$, $p < 0.001$, $df = 35$) than in the 60 DAS ($r = -0.30$, $p < 0.001$, $df = 35$).

![Figure 2](image-url). Across rice cultivars and seeding rates, the relationship between weed biomass and rice biomass at 30 and 60 days after sowing in dry direct-seeded *aus* rice.

3.3. Days to 50% Flowering, Yield Components, and Yield

Days to 50% flowering were significantly ($p < 0.001$) affected by the WR, CV, SR, and the interaction of WR x CV (Table 4). Across CV and SR, flowering was delayed by around three days when the field was partially weedy compared with the weed-free treatment.
Among cultivars, the highest days required to reach 50% flowering of cultivar hybrid “Arize” (~100 days) followed by “BRRI dhan26” (~82 days) followed by “BRRI dhan48” (~78 days), and the lowest days for cultivar “BRRI dhan55” (~72 days). Considered with the SR, flowering was two to four days advanced when SR increased from 20 to 40 and 80 kg ha\(^{-1}\). Across CV and SR, panicle density was 20–55% higher for WR weed-free compared to the partially weedy. Among CV, the highest panicle density was recorded from the cultivar hybrid “Arize” which was significantly similar to the cultivar “BRRI dhan26” and “BRRI dhan55”. The lowest panicle density was recorded from the cultivar “BRRI dhan48”. Considered with the SR, the highest SR always had higher panicle density. However, the increasing trends of panicle numbers were higher in the partial weedy condition, than in the weed-free condition when SR increased from 20 to 80 kg ha\(^{-1}\) (Figure 3).

Figure 3. Rice panicles as influenced by the interaction of seed rate and weeding regimes in dry direct-seeded aus rice. Vertical bars indicate the standard error of the mean.

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Table 4. Effect of weeding regimes, rice cultivars, and seeding rates on days to 50% flowering, panicle density, florets panicle\(^{-1}\), florets fertility, and rice grain yield in dry direct-seeded aus rice.

| Variables | Days to 50% Flowering (days) | Panicle Density (no. m\(^{-2}\)) | Florets Panicle\(^{-1}\) | Florets Fertility (%) | Rice Grain Yield (t ha\(^{-1}\)) |
|-----------|-------------------------------|----------------------------------|------------------------|----------------------|---------------------------------|
| **Weeding regimes (WR)** |                               |                                  |                        |                      |                                 |
| Weed-free | 85 a                          | 319 a                            | 105 a                  | 77                   | 4.5 a                           |
| Partial-woody | 82 b                      | 212 b                            | 93 b                   | 75                   | 3.3 b                           |
| **Rice cultivars (CV)** |                               |                                  |                        |                      |                                 |
| Hybrid Arize | 100 a                     | 277 a                            | 122 a                  | 85 a                 | 5.4 a                           |
| BRRI dhan26 | 82 b                       | 264 ab                           | 83 c                   | 72 b                 | 2.9 c                           |
| BRRI dhan48 | 78 c                       | 251 b                            | 105 b                  | 75 b                 | 4.1 b                           |
| BRRI dhan55 | 72 d                       | 268 ab                           | 87 c                   | 72 b                 | 3.2 c                           |
| **Seeding rate (SR) kg ha\(^{-1}\)** |                               |                                  |                        |                      |                                 |
| 20      | 85 a                        | 221 c                            | 102 a                  | 77 a                 | 3.7 b                           |
| 40      | 83 b                        | 263 b                            | 100 a                  | 78 a                 | 4.1 a                           |
| 80      | 81 c                        | 311 a                            | 95 b                   | 73 b                 | 3.9 a                           |

Means in a column (for weeding regimes, rice cultivars, and seeding rates) followed by the same small letter are not significantly different according to Tukey’s HSD at alpha = 0.05. ***, **, and * indicate significance at \(p < 0.001\), 0.01, and 0.05. ns indicates non-significance. DAS indicates days after sowing.
Florets panicle$^{-1}$ was significantly ($p < 0.01$) influenced by the WR, CV, SR, and the interaction of WR × SR and WR × CV (Table 4). Under partial-weedy treatment, the florets panicle$^{-1}$ was 8–30% lower than the weed-free treatment. There was a decreasing trend of florets panicle$^{-1}$ in the weed-free condition when SR increased from 20 to 80 kg ha$^{-1}$ (Figure 4). However, under partial-weedy conditions, florets panicle$^{-1}$ were slightly increased when SR increased from 20 to 40 kg ha$^{-1}$, and thereafter, the further increment of SR to 80 kg ha$^{-1}$ had almost similar numbers to 40 kg ha$^{-1}$. Across SR, CV hybrid “Arize” had the highest number of florets (96–111 panicle$^{-1}$) followed by “BRRI dhan48” and followed by “BRRI dhan55” and “BRRI dhan26” in both WR (Figure 4).

![Figure 4](image-url)

**Figure 4.** Rice florets as influenced by the interaction of seed rate and weeding regimes (a), and interaction of cultivars and weeding regimes (b) in dry direct-seeded *aus* rice. Vertical bars indicate the standard error of the mean.

Rice grain yield was strongly affected ($p < 0.01$) by the interaction of WR, CV, and SR as well as the individual effect of all three variables (Table 4). Across CV and SR, partial weedy treatment had a 15–50% lower yield than the weed-free treatment. Across WR and SR, the highest grain yield was recorded from the cultivar hybrid “Arize” followed by cultivar “BRRI dhan48”. The lowest grain yield was recorded from the cultivar “BRRI dhan26” which was significantly similar to the grain yield of the cultivar “BRRI dhan55”. Across WR and CV, the highest grain yield was recorded from the seeding rate 40 kg ha$^{-1}$ and the seed rate 80 kg ha$^{-1}$ had a similar grain yield to the seed rate of 40 kg ha$^{-1}$. Compared to the seeding rate 40 and 80 kg ha$^{-1}$, grain yield was significantly lower for the seed rate of 20 kg ha$^{-1}$.

Under the weed-free condition, all three inbred cultivars had an increasing trend of grain yield when the seeding rate increased from 20 to 40 kg ha$^{-1}$, and thereafter grain yield was a decreasing trend when the seed rate increased from 40 to 80 kg ha$^{-1}$ (Figure 5). However, for the cultivar hybrid “Arize”, the highest grain yield was recorded from the SR 20 kg ha$^{-1}$, and thereafter, grain yield had a decreasing trend when the seed rate increased from 20 to 40 and 80 kg ha$^{-1}$. Under the partial-weedy condition, there was an increasing trend of grain yield for all three inbred cultivars when the seed rate increased from 20 to 80 kg ha$^{-1}$. However, for cultivar hybrid “Arize”, grain yield increased when the seed rate increased from 20 to 40 kg ha$^{-1}$, and thereafter, it was decreased when the SR increased from 40 to 80 kg ha$^{-1}$. There was no interaction of CV and SR on WCI; however, their individual effects were significant ($p < 0.001$) (Figure 6). Across SR, the hybrid cultivar “Arize” was significantly ($p < 0.001$) higher WCI than all the inbred cultivars, which had similar WCI. Considered with the SR, the highest SR always had higher WCI.
Figure 5. Rice grain yield as influenced by the interaction of weeding regimes, rice cultivars, and seeding rates in dry direct-seeded aus rice. Vertical bars indicate the standard error of the mean.

Figure 6. Weed competitive index for different cultivars and seed rates. The same small letters are not significantly different according to Tukey’s HSD at alpha = 0.05.

4. Discussion

The three-way interactions on rice grain yield among WR, CV, and SR were significant \((p < 0.001)\) in the current study, mainly due to the fact that cultivars that produced higher yield in weed-free conditions were not always higher yield in partial-weedy conditions (Figure 5). The present study also revealed that both weed competitive CVs and increased SR affected crop-weed competition in an additive way and decreased weed growth and yield loss. Therefore, using a strong weed-competitive CV with an optimum SR can effectively suppress weed growth resulting in a positive effect on crop yield. The results of the current study show that the hybrid ‘Arize’ was more weed-competitive than the inbred CVs which is at par with the results of Zhao et al. [24] and Mahajan et al. [28] who reported that hybrids have a smothering effect on weeds due to improved early vigor and quick canopy coverage and can enhance production in DSR systems. The performance of the hybrid is superior in the DSR system than that of the inbred due to its higher weed-competitive traits, which was also reported in other studies [34,35]. Wang et al. [36] reported that, compared with the general cultivar, the weed competitive cultivars in DSR systems were 7–9% higher yield.
The higher SR in partial-weedy conditions always had higher yields mainly because increasing crop density suppressed weed growth and reduced losses in grain yield. The results of the present study, also supported by several earlier studies [15,34,37], show that increasing rice seeding rates suppressed weed growth by reducing the intra-specific and inter-specific competition of weed.

The results of our study also suggest that SR is an important factor in DSR to obtain maximum yields because the final yield depends on panicle numbers per unit area which are mostly achieved by the optimum plant population [25]. It was reported from a previous study that the optimum rice plant density after emergence was found 161 to 215 plants m$^{-2}$ for inbred cultivars [38,39] and 86 to 108 plants m$^{-2}$ for hybrids [40]. Another study reported that 70–100 plants m$^{-2}$ in dry direct-seeded conditions was not adequate to obtain optimum yield when a short duration inbred cultivar was used, which was mainly due to the uneven distribution of plants due to lower plant density [25].

The initial plant stand establishment in the current study was not affected by the WR due to the fact that in direct-seeded rice systems, weeds and rice emerge together and competition starts between them around one to two weeks after emergence depending on the density of both rice and weed plants, soil moisture and nutrient conditions, types of weed species, and competitive ability of rice cultivars [14,15,23]. Once the competition starts some rice plants may die or if competition exists longer poor crop growth and fewer tiller production may happen [14]. Plant stand variation among the CV in the trial might be due to different seed size, seed vigor, and germination rate.

Previous studies indicated a possible positive relationship between panicle density and seeding rate while there was an inverse relation with filled grain [41,42]. We observed rice panicle numbers increased with the increase of SR in both weed-free and partial-weedy condition evidence from Figure 3 but the yield was not always increased (only increased for inbred cultivars under partial-weedy condition) mainly due to decrease of grains panicle$^{-1}$ (Figure 4) and decrease in average grain weight (data not present).

The weed control efficiency (WCE, calculated from the weed biomass data) in the current study was 10–31% higher for hybrid cultivar ‘Arize’ compared to the inbred cultivars and among the inbred cultivars, the “BRRI dhan26” had higher WCE than the other two cultivars mainly due to higher tiller numbers and tiller biomass of these cultivars, evidence from Table 2. Mahajan et al. [35] reported that the rice cultivars having tall and higher dry matter at the initial stages contributed to its greater weed suppression ability than the cultivars which are semi-dwarf and produced lower dry matter. Weed biomass was significantly and negatively correlated with rice biomass in the current study suggesting that tiller production was suppressed by weeds. Our result agrees with the findings of previous studies where a significant negative correlation was reported between the number of tillers plant$^{-1}$ or tiller biomass and weed biomass under weed competitive conditions [6,43]. Rice cultivars able to produce more grain yield in competition with weeds had greater early biomass also reported by Namuco et al. [44].

We found the lowest WCI from the lowest SR of 20 kg ha$^{-1}$ and this result was mainly due to the high intra-specific distance covering less ground area by the crop canopy and the micro-environment being favorable for weeds in terms of space and resources, facilitating fast growth and development of weeds, which resulted in greater weed biomass. However, when the SR was 80 kg ha$^{-1}$, the canopy was closed earlier due to faster crop growth, shading out the weeds, and providing a competitive advantage to the crop by reducing weed growth. A previous study reported that with an increase in crop plants m$^{-2}$ in weedy condition, weeds were suppressed due to an increase in the total plant biomass (crop plus weeds) [45,46].

The highest grain yield from the hybrid cultivar with the SR of 20 kg ha$^{-1}$ in weed-free condition and 40 kg ha$^{-1}$ in partial-weedy condition indicates that there is no need to increase SR more than 40 kg ha$^{-1}$ for hybrid cultivar where farmers usually do not manage weeds properly. However, under a good weed management condition, SR of 20 kg ha$^{-1}$ of hybrid is sufficient to achieve optimum yield. The seed price of hybrid is
very high, therefore, farmers are advised to use 20 kg seed ha\(^{-1}\) for hybrid cultivar for a well-managed field and if they face higher weed pressure then they can use a maximum of SR 40 kg ha\(^{-1}\). In the current study, across SR, the average yield loss under partially weedy conditions ranged from 25–55% for inbred cultivars and 10–35% for hybrid cultivar compared with weed-free conditions confirms that weeds are a crucial yield-limiting factor in DSR and that weed management should be properly addressed to make DSR cultivation more profitable. Ideal weed competitive cultivars are high-yielding under both weedy and weed-free conditions and have a strong weed-suppressive ability, as observed by Zhao et al. [37].

5. Conclusions

Weed infestations significantly reduced the grain yield in all the cultivars and even in partial-weedy conditions, the yield was 20–55% lower compared with the weed-free conditions, indicating the importance of weed management in DSR systems. Compared to the inbred cultivars, the hybrid showed more weed competitiveness even at the low SR, indicating that the cultivation of hybrids may be considered an important component of IWM in this system. Increasing rice seeding rates may help to suppress weed growth to some extent and reduce losses to weeds, however, other problems associated with high SR are requiring higher nitrogen fertilizer [4], lodging problems, rat and insect damage, and high prone to disease infestation [43]. The evaluation of hybrids in DSR confirms possession of weed-competitive traits and provides farmers with a wider choice of options when cultivating DSR. The results of our study indicate that, in Bangladesh, farmers can use a seeding rate of 20 kg ha\(^{-1}\) for hybrid and 40 kg ha\(^{-1}\) for an inbred cultivar in the situation of relatively low weed pressure. However, in the situation of high weed pressure and the absence of effective weed control options, farmers should use relatively higher seeding rates of 40 kg ha\(^{-1}\) in hybrid and 80 kg ha\(^{-1}\) in inbred to reduce yield losses due to weed infestation.

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References

1. FAO. Transforming Food and Agriculture to Achieve the SDGs. 20 Interconnected Actions to Guide Decision-Makers; Food and Agriculture Organization of the United Nations: Rome, Italy, 2018; 76p.
2. Rao, A.N.; Johnson, D.E.; Sivaprasad, B.; Ladha, J.K.; Mortimer, A.M. Weed management in direct-seeded rice. *Adv. Agron.* 2007, 93, 153–255.
3. Gopal, R.; Jat, R.K.; Malik, R.K.; Kumar, V.; Alam, M.M.; Jat, M.L.; Mazid, M.A.; Saharawat, Y.S.; McDonald, A.; Gupta, R. Direct Dry Seeded Rice Production Technology and Weed Management in Rice Based Systems; Technical Bulletin; International Maize and Wheat Improvement Center: New Delhi, India, 2010; 28p.

4. Ahmed, S.; Humphreys, E.; Salim, M.; Chauhan, B.S. Growth, yield and nitrogen use efficiency of dry-seeded boro and aman rice as influenced by nitrogen and seed rates in Bangladesh. Field Crops Res. 2015, 186, 18–31. [CrossRef]

5. Kumar, V.; Ladha, J.K. Direct seeding of rice: Recent developments and future research needs. Adv. Agron. 2011, 111, 297–413. [CrossRef]

6. Ahmed, S.; Chauhan, B.S. Performance of different herbicides in dry-seeded rice in Bangladesh. Sci. World J. 2014, 2014. [CrossRef]

7. Devkota, M.; Devkota, K.P.; Acharya, S.; McDonald, A.J. Increasing profitability, yields and yield stability through sustainable crop establishment practices in the rice-wheat systems of Nepal. Agric. Syst. 2019, 173, 414–423. [CrossRef]

8. Xu, L.; Li, X.; Wang, X.; Xiong, D.; Wang, F. Comparing the grain yields of direct-seeded and transplanted rice: A meta-analysis. Agronomy 2019, 9, 767. [CrossRef]

9. FAOSTAT. 2020. Available online: http://www.fao.org/faostat/en/#data/QC/visualize (accessed on 17 December 2020).

10. BBS. Bangladesh Bureau of Statistics, Dhaka, Bangladesh. 2017. Available online: www.bbs.gov.bd.2017 (accessed on 17 December 2020).

11. BRRI. 2019. Available online: http://www.brri.gov.bd/site/page/f6e878c8-ceac-402d-9bed-6fb29a787428/ (accessed on 26 December 2020).

12. Kumar, A.; Suresh, K.; Kuldeep, D.; Sundeep, K.; Mukesh, K. Productivity and economics of direct-seeded rice (Oryza Sativa L.). J. Appl. Nat. Sci. 2015, 7, 410–416. [CrossRef]

13. Nagargade, M.; Singh, M.K.; Tyagi, V. Ecologically sustainable integrated weed management in dry and irrigated direct-seeded rice. Adv. Plants Afric. Res. 2018, 8, 319–331.

14. Rahman, M.; Juraimi, A.S.; Suria, J.; Azmi, B.M.; Anawar, P. Response of weed flora to different herbicides in aerobic rice system. Sci. Res. Essays 2012, 7, 12–23. [CrossRef]

15. Ahmed, S.; Salim, M.; Chauhan, B.S. Effect of weed management and seed rate on crop growth under direct dry seeded rice systems in Bangladesh. PLoS ONE 2014, 9, e101919. [CrossRef]

16. Chauhan, B.S.; Ahmed, S.; Awan, T.H.U.; Jabran, K.; Manali, S. Integrated weed management approach to improve weed control efficiencies for sustainable rice production in dry-seeded systems. Crop. Prot. 2015, 71, 19–24. [CrossRef]

17. Bhullar, M.S.; Kumar, S.; Kaur, S.; Kaur, T.; Singh, J.; Yadav, R.; Chauhan, B.S.; Gill, G. Management of complex weed flora in dry-seeded rice. Crop. Prot. 2016, 83, 20–26. [CrossRef]

18. Heap, I.M. International survey of herbicide-resistant weeds: Lessons and limitations. In 1999 Brighton Crop Protection Conference: Weeds, Proceedings of an International Conference, Brighton, UK, 15–18 November 1999; British Crop Protection Council: Farnham, UK, 1999; Volume 3, pp. 769–776.

19. Mahajan, G.; Chauhan, B.S. The role of cultivars in managing weeds in dry-seeded rice production systems. Crop. Prot. 2013, 49, 52–57. [CrossRef]

20. Wu, H.; Pratley, J.; Lemerle, D.; Haig, T. Crop cultivars with allelopathic capability. Weed Res. 1999, 39, 171–180. [CrossRef]

21. Andrew, I.K.S.; Storey, J.; Sparkes, D.L. A review of the potential for competitive cereal cultivars as a tool in integrated weed management. Weed Res. 2015, 55, 239–248. [CrossRef] [PubMed]

22. Gibson, K.D.; Fisher, A.J. Competitiveness of rice cultivars as a tool for crop-based weed management. In Weed Biology and Management; Kulweer Academic Publisher: Amsterdam, The Netherlands, 2004; pp. 517–537.

23. Mahajan, G.; Chauhan, B.S.; Gill, M.S. Optimal nitrogen fertilization timing and rate in dry-seeded rice in North-west India. Agron. J. 2011, 103, 1676–1682. [CrossRef]

24. Zhao, D.L.; Atlin, G.N.; Bastiaans, L.; Spiertz, J.H.J. Developing selection protocols for weed competitiveness in Aerobic rice. Field Crop. Res. 2006, 97, 272–285. [CrossRef]

25. Ahmed, S.; Humphreys, E.; Salim, M.; Chauhan, B.S. Optimizing sowing management for short duration dry seeded aman rice on the High Ganges River Floodplain of Bangladesh. Field Crop. Res. 2014, 169, 77–88. [CrossRef]

26. Chauhan, B.S.; Singh, VP.; Kumar, A.; Johnson, D.E. Relations of rice seeding rates to crop and weed growth in aerobic rice. Field Crop. Res. 2011, 121, 105–115. [CrossRef]

27. Ismail, A.M.; Ella, E.S.; Vergara, G.V.; Mackill, D.J. Mechanisms associated with tolerance to flooding during germination and early seedling growth in rice (Oryza sativa L.). Ann. Bot. 2009, 103, 197–209. [CrossRef]

28. Mahajan, G.; Chauhan, B.S. Effects of planting pattern and cultivar on weed and crop growth in aerobic rice system. Weed Technol. 2011, 25, 521–525. [CrossRef]

29. Rahman, A.N.M.A.; Islam, A.K.M.M.; Arefin, M.A.; Rahman, M.R.; Anwar, M.P. Competitiveness of winter rice varieties against weed under dry direct sowned conditions. Agric. Sci. 2017, 8, 1415–1438. [CrossRef]

30. Arefin, M.A.; Rahman, M.R.; Rahman, A.N.M.A.; Islam, A.K.M.M.; Anwar, M.P. Weed competitiveness of winter rice (Oryza sativa L.) under the modified aerobic system. Arch. Agric. Environ. Sci. 2018, 3, 1–14. [CrossRef]

31. Kulak, S.S.; Hira, G.S.; Sidhu, A.S. Soil matric potential-based irrigation scheduling to rice (Oryza sativa L.). Irrig. Sci. 2005, 23, 153–159. [CrossRef]

32. Rezakanlou, A.; Aghabeigi, M.; Bagheri, H. Evaluation of some of competitiveness indexes in competition between cotton varieties and common cocklebur (Xanthium strumarium L.). Int. Res. J. App. Bas. Sci. 2012, 3, 1274–1278.
33. Sokal, R.R.; Rohlf, F.J. *Biometry: The Principles and Practice of Statistics in Biological Research*, 3rd ed.; W.H. Freeman and Co.: New York, NY, USA, 1995.

34. Awan, T.H.; Lim, C.A.A.; Ahmed, S.; Chauhan, B.S. Weed-competitive ability of a hybrid and an inbred rice cultivar in managing *Ischaemum rugosum* in dry direct-seeded conditions. *Pak. J. Agric. Sci.* 2018, 55, 739–748. [CrossRef]

35. Mahajan, G.; Poonia, V.; Chauhan, B.S. Integrated weed management using planting pattern, cultivar, and herbicide in dry-seeded rice in North-west India. *Weed Sci.* 2014, 62, 350–359. [CrossRef]

36. Wang, H.Q.; Bouman, B.A.M.; Zhao, D.L.; Wang, C.; Moya, P.F. Aerobic rice in northern China: Opportunities and challenges. In *Water-Wise Rice Production, Proceedings of the International Workshop on Water-Wise Rice Production, Los Baños, Philippines, 8–11 April 2002*; Bouman, B.A.M., Hengsdijk, H., Hardy, B., Bindraban, P.S., Tuong, T.P., Ladha, J.K., Eds.; International Rice Research Institute: Los Baños, Philippines, 2002; pp. 143–154.

37. Zhao, D.L.; Bastiaans, L.; Atlin, G.N.; Spiertz, J.H.J. Interaction of genotype x management on vegetative growth and weed suppression of aerobic rice. *Field Crop. Res.* 2007, 100, 327–340. [CrossRef]

38. Klosterboer, A.D.; Turner, F.T. Seeding rates. In *Rice Production Guidelines*; Blair, C., Ed.; Texas Agricultural Experiment Station: Austin, TX, USA, 2001; Volume 7, p. 1253.

39. Wilson, C.E.; Branson, J.W.; Davis, C.H. Rice Seed. Arkansas Cooperative Extension Service. 2006. Available online: http://www.uaex.edu/ (accessed on 26 December 2020).

40. RiceTec. Planting Recommendations. RiceTec Inc. 2006. Available online: http://www.ricetec.com/publications/mgmtRecomm_2006.pdf (accessed on 26 December 2020).

41. Gravois, K.A.; Helms, R.S. Seeding rate effects on rough rice yield, head rice, and total milled rice. *Agron. J.* 1996, 88, 82–84. [CrossRef]

42. Mobasser, H.R.; Yadi, R.; Azizi, M.; Ghanbari, A.M.; Samdali, M. Effect of density on morphological characteristics related-lodging on yield and yield components in varieties rice (*Oryza sativa* L.) in Iran. *Am. Eurasian J. Agric. Environ. Sci.* 2009, 5, 745–754.

43. Fischer, A.J.; Ramirez, H.V.; Gibson, K.D.; Pinheiro, B.D.S. Competitiveness of semidwarf upland rice cultivars against palisadegrass (*Brachiaria brizantha*) and signalgrass (*B. decumbens*). *Agron. J.* 2001, 93, 967–973. [CrossRef]

44. Namuco, O.S.; Cairns, J.E.; Johnson, D.E. Investigating early vigour in upland rice (*Oryza sativa* L.): Part I. Seedling growth and grain yield in competition with weeds. *Field Crop. Res.* 2009, 113, 197–206. [CrossRef]

45. Lemerle, D.; Causens, R.D.; Gill, L.S.; Peltzer, S.J.; Moerkerk, M.; Murphy, C.E.; Collins, D.; Cullis, B.R. Reliability of higher seed rates of wheat for increased competitiveness with weeds in low rainfall environment. *J. Agric. Sci.* 2004, 142, 395–409. [CrossRef]

46. Phuong, L.T.; Denich, M.; Vlek, P.L.G.; Balasubramanian, V. Suppressing weeds in direct seeded low land rice: Effects of methods and rates of seeding. *J. Agron. Crop. Sci.* 2005, 191, 185–194. [CrossRef]