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Weed-Free Durations and Fertilization Regimes Boost Nutrient Uptake and Paddy Yield of Direct-Seeded Fine Rice (*Oryza sativa* L.)

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Abstract: Under the changing climate, fertilization regimes and weed infestation management in aromatic direct-seeded fine rice (DSR) remain vital for curbing environmental hazards and ensuring food security. A multi-year field study was undertaken to appraise the influence of fertilization techniques and weed-free periods on weed dynamics, nutrient uptake and paddy yield in a semi-arid environment. Treatments included two fertilization methods (broadcasting and side placement) and five weed-free durations (20, 30, 40, 50 post-seeding days, DAS) along with a weed-free crop for a whole season. Weed competition for a season-long crop (weedy check) was maintained for each fertilizer application method. Our results revealed that the side placement of fertilizers resulted in a significantly lower weed density and biomass, even under season-long weed competition. The highest paddy yield was recorded for a crop without weeds, while weed-free duration of up to 50 DAS followed it. The uptake of nitrogen (N), phosphorus (P) and potassium (K) for a weed-free duration of up to 50 DAS were only 19%, 9% and 8%, respectively, as compared to the weedy check. The uptake of N, P and K by weeds in the broadcast method was 18%, 30% and 24% higher, compared to side-placed fertilizers. The period of 20–50 DAS remained critical in DSR as far as weed control was concerned. Thus, the side placement of fertilizers and controlling weeds for up to 50 days after rice sowing can be recommended for general adoption in semi-arid agro-ecological conditions.

Keywords: broadcasted fertilization; side-dressing; paddy growth; weeds competition; macro-nutrients

1. Introduction

Rice (*Oryza sativa* L.) constitutes the major staple crop after wheat, which feeds billions of people across the globe and is hence referred to as the global grain [1–3]. It is being grown in all habitable continents of the world, owing to its wide adaptability to a wide range of pedo-climatic conditions [4,5]. In Asia, it is cultivated with irrigation systems, while in Pakistan, rice is ranked the third most prominent crop, covering 10% of the cultivated area and contributing 17% to the total cereal production [6–8]. However, rice cultivation through nursery transplanting in a puddled field is cumbersome, time-consuming and is a prodigal water use method [9]. Under the changing climate, looming water crises and the uncertainty of climatic optima have endangered the sustainability of transplanted rice's production systems, which no longer seems a feasible technique, especially in South Asian countries, such as Pakistan, China, India and Bangladesh. It is estimated that 800 L of water are applied for producing 1 kg paddy globally, whereas the corresponding value in Pakistan stands at 3000–5000 L of water [7]. Another consequence of puddled transplanted rice is the delayed sowing of wheat, which reduces its yield by 33% [10].

Direct seeding of rice (DSR) has emerged as an alternate and pragmatic approach to tackling production constraints [10] and imparting sustainability to the rice-wheat cropping system [11,12]. The DSR offers several advantages, including faster plant growth, avoidance of transplanting shock, ease in cultivation, less labor and water requirements as well as early maturity [13–17]. Additionally, a significant reduction in methane emission was also accomplished with DSR [6]. However, weed infestation has remained the prime biological constraint limiting the productivity of DSR by up to 75–80% [14,18]. High weed infestation in DSR was attributed to recalcitrant weed flora, dry conditions, frequent tillage, alternate wet and dry periods and the lesser competitive ability of 30–35 day old rice seedling against genetically superior weed flora, as these have better plant infrastructure [19]. The critical period of weed competition (CPWC) in DSR is a prerequisite to be determined for devising a strategy to keep weeds below the threshold level [20]. Johnson et al. [21] determined the CPWC in rice as 5–79 DAS (days after sowing), while in contrast, Anwar et al. [22] concluded that the CPWC for DSR was 7–50 DAS. Additionally, it was documented that the presence of weeds in DSR beyond 20 DAS adversely affected yield components which led to reduced growth as well as reduced paddy yield. It was also inferred that the reduction in paddy yield was proportional to CPWC up to 30 DAS [20,23,24].

Under changing climate scenarios, the severity of competition rendered by weeds in DSR can be modified by optimizing cultural practices that simultaneously affect both crops and weeds. Among these cultural practices, fertilizer management remains instrumental in determining the competitive outcomes of the weed-crop association [23,24]. Deep banding or the side placement of nitrogenous fertilizers (whereby fertilizers might be placed in the side of crop rows manually or drilled) reduces the growth of weeds and nitrogen (N) uptake compared to broadcasted fertilizers [25]. Rasmussen et al. [26] inferred that reducing weed density and fertilizer management concurrently increased the paddy yield by 28%. The broadcast fertilizer remained inferior to the side-band application method, owing to an increase in weed emergence and reduction in crop growth which reduced grain yield by 10% [27]. These findings suggested that the manipulation of crop fertilization application techniques may impart significant influence on weed density in DSR and must be evaluated in tandem with respect to CPWC [28,29].

Numerous studies have evaluated weed dynamics and the resultant yield losses in DSR, either by using increasing weed-free or weedy duration approaches [20,22,30–33]. Nevertheless, none of these has assessed weed competition in response to fertilization techniques in DSR. Numerous studies have also elaborated the potential of fertilizer application techniques for maintaining nutrient status, along with boosting fertilizer use efficiency (FUE) [24,25,34]. The fertilization application technique involving fertilizer placement at a depth of 5 cm and 5 cm apart from crop seeds significantly improved the above-ground biomass and paddy yield in comparison to the manual surface broadcast fertilization method [26]. This method (burying of fertilizers below 5 cm) promoted the growth of rice roots which triggered the growth of crop plants during the early vegetative growth stages [18]. Additionally, appropriate fertilization methods, such as band fertilization, effectively reduced the quantities of fertilizers needed for DSR without adversely affecting the rice plants' growth and paddy yield [27]. The broadcasted fertilizers resulted in higher losses by emissions, while deep fertilization increased the nutrient absorption by rice roots by minimizing loses as leaching and gaseous emissions [33]. The side placement of fertilizers significantly enhanced peroxidase and catalase in DSR. In addition, it inferred that mechanically deep-buried fertilization delayed rice leaf senescence by improving the activities of antioxidant enzymes and reducing the malonic dialdehyde in DSR, which led to a higher paddy yield. Under the changing climate, the optimization of fertilization method has become even more important owing to its potential for 40% and 54% reduction in methane (CH4) and nitric oxide (NO) emissions, respectively [6]. Therefore, optimization of the fertilization method constitutes a potent strategy to mitigate environmental pollution which is contributed to by methane emissions from rice fields.

It is hypothesized that fertilization regimes could exert a growth-restricting influence on weed growth by reducing nutrient availability to weeds. In contrast, a specific weed-free duration could potentially boost the rice yield in DSR culture. Therefore, the present study was undertaken to appraise the influence of the fertilization methods and weed-free duration on weed dynamics, nutrient uptake and the paddy yield of DSR.

2. Materials and Methods

2.1. Description of Meteorological and Physico-Chemical Characteristics of Experimental Site

The Agronomic Research Farms of the University of Agriculture Faisalabad, Pakistan (31.4504° N, 73.1350° E, altitude of 186 m) [35], was the location of the experiments undertaken for this study during two consecutive years (2018 and 2019). The sowing of the experiment was done after the harvest of the winter wheat crop. The mean temperature and rainfall of the experimental site during both growing seasons (end of May to mid-October), as per the recordings of meteorological observatory located in the close vicinity of our experimental site, are presented in Figure 1. The irrigations (3 inches depth and last irrigation of 4 inches depth) were applied fortnightly through the flood irrigation method, however the interval between irrigations was reduced, keeping in view the high temperature and crop needs. In total, 10–14 irrigations were applied on an average during both years of the study.

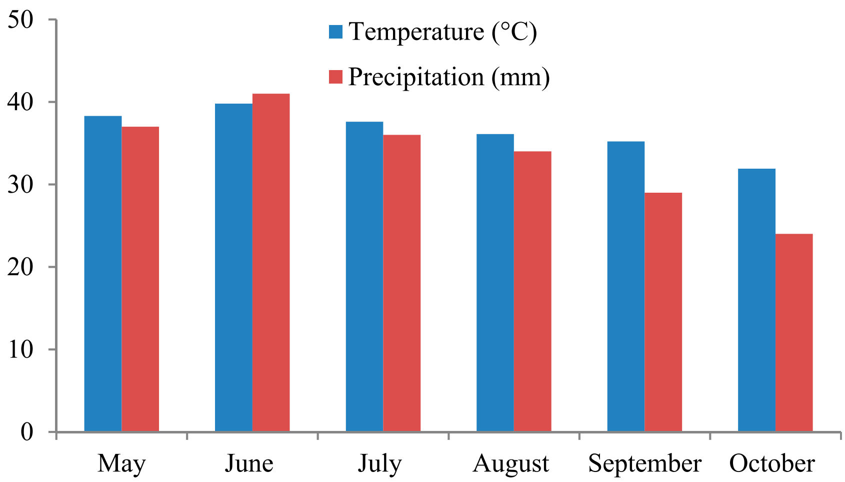

Figure 1. The meteorological features (temperature and precipitation) of experimental site (Faisalabad, Punjab, Pakistan) during crop growing seasons, (2 years mean data).

To conduct pre-experiment soil physico-chemical analyses, soil samples (0–15 cm and 15–30 cm depths) were taken from the four corners and the middle of the experimental area (net plot size was 6 m × 3 m, while there were 12 experimental plots per replication making total experimental area 648 m^2, excluding water channels, walking paths and replication separating fellow area). The collected samples from both depths were thoroughly homogenized by hand for subsequent analyses. Thereafter, the samples were dried under shade, grounded and subsequently sieved with the help of a sieve with a pore size of 2 mm. For measuring the pH, the samples were prepared using 1:2.5 ratios of soil and water while the glass electrode was used to record the pH [36]. The electrical conductivity (EC) was also measured using the conductivity meter [23]. The wet oxidation method was followed for organic carbon (OC) estimation volumetrically. Meanwhile, the Walkley–Black methodology was used to determine the organic matter (OM) content of the soil samples [37]. To estimate the total nitrogen (N) content, a Kjeldahl apparatus was used for distillation which followed titration using concentrated H_2SO_4 [38]. Additionally, the phosphorous (P) content of the soil samples was estimated by performing Olsen's method (0.5 N $NaHNO_3$ at 8.5 pH by maintaining soil: extractant ratio of 1:10) using spectrophotometer (by setting wavelength at 882 nm in a system containing sulfuric acid) [39]. At the same time, potassium (K) was determined by following the standard procedure involving the ammonium acetate extraction of air-dried soil samples through shaking them with an ammonium acetate solution (0.5 M) for 30 min, which led to the displacement of positively charged K ions and a flame photometer was used to detect them. Subsequently, the methodology described in [37] was used for the K calculation. As far as the micronutrients were concerned, the available iron (Fe) content was estimated using an extraction method with an ammonium acetate solution (CH_3COONH_4) by maintaining 3.0 pH. Thereafter, a spectrophotometer (510 nm wavelength) was used by following the colorimetric method to determine the Fe content of the soil extracts. Furthermore, the rest of the micronutrients, including zinc (Zn), boron (B), copper (Cu) and manganese (Mn), were estimated using the extraction method involving diethylenetriaminepentaacetic acid [40–42]. The soil had a loam texture, with a pH 8.2, while OM remained at only 0.55%, indicating exhaustive cultivation of the soil. The soil had a bulk density and EC of 1.39 cm^{-3} and 0.47 dS m^{-1}, respectively. The NPK contents remained 77, 4.1 and 113 mg kg^{-1}, respectively. Among the micronutrients, B, Mn, Fe, Cu and Zn were 1.00, 20.9, 10.17, 1.8 and 1.21 mg kg^{-1} of soil, respectively.

2.2. Experimentation Details

The field trial was comprised of two fertilization methods (FM), including broadcasted fertilizers (BF) and the side placement (SP) method, along with six weed-free periods (WFD), for instance, 20, 30, 40 and 50 days after sowing (DAS), and full crop season weed-free (WF) and a weedy check (WC) for comparison. The fertilizer was broadcasted in each plot separately, while side placement was done along the crop lines using a single row hand drill. The experiment was executed using a randomized complete block design (RCBD) with factorial scheme, while three replications of each experimental treatment were maintained. The unit plot size (excluding the water channel and field path area) was 6 m × 3 m (experimental plots were separated by 2 feet wide bunds and 5 feet fellow area, similarly 5 m fellow area was maintained among the replications). Rice seeds (cv. Super Basmati that is a short stature, early maturing, highly aromatic cultivar that is currently being cultivated over a large area in the rice-belt of Punjab province) were hydro-primed for 24 hr to obtain a higher germination and vigorous seedling growth. The soaked seeds were shade dried and stored at 10 °C. To ensure that the seed-bed obtained fine tilth, three ploughings with a tractor-driven common cultivator were performed, while subsequent planking was also done to pulverize the soil. The crop was sown (50 kg seed rate ha^{-1}) during the last week of May with a single row hand drill in 20 cm apart rows. Chemical fertilizers, such as urea (125 kg N ha^{-1}), di-ammonium phosphate (55 kg P ha^{-1}) and sulphate of potash (40 kg K ha^{-1}), were applied manually in both techniques (broadcast and side placement involving fertilizer dressing at 10 cm away from the seeds and at a depth of 5 cm). At the sowing time, P and K and half of N were applied with the last ploughing. The remaining N was equally divided and subsequently applied at the tillering and panicle formation stages. The crop was kept free of weeds for different duration's: 0, 20, 30, 40, 50 DAS and season long. Weeds were manually removed up to the completion of the respective weed-free period. Once a specific weed-free period was accomplished, weeds were not controlled and competition with rice seedlings was allowed. The first irrigation was applied at 5 DAS, while the subsequent irrigation scheduling depended on the weather conditions and crop needs.

2.3. Data Recordings of Response Variables

Data on weed growth (density WD and dry biomass WB) were recorded at harvesting from two randomly selected quadrats (100 cm × 100 cm = 1 m^2) from each experimental unit plot. The weed density of grasses, sedges and broader leaf weeds was measured.

Weeds were clipped off near the soil surface and were sundried for five days. Weeds' dry biomass was taken separately using oven-dried (for 48 h at a constant temperature of 70 °C) samples. Data pertaining to the response variables were recorded by randomly selecting fifteen plants per experimental plot, and their average was computed. Panicle bearing tiller (m^{-2}) numbers were counted using two random sites of each experimental plot and were subsequently averaged. The random sampling of kernels was done in each plot for recording 1000-kernels weight. The crop in each experimental plot was manually harvested (on October 14 during the first year and October 18 during the subsequent year) and then tied into bundles. The experimental plots were separately threshed for recording the paddy yield and were subsequently converted into tons per hectare. For the nutrient uptake by rice and weeds, the grinding of oven-dried material was completed (Cyclotec 1093 Sample Mill, Sweden) and the material was subsequently passed through a 40-meshscreen. The N-P-K concentrations in rice and weeds' samples (collected at harvest) were determined as described in the laboratory manual of ICARDA [43].

2.4. Statistical Analyses

The data regarding parameters under investigation were arranged and subsequently analyzed statistically by employing Bartlett's test, which showed that the year had a non-significant effect and, as a result, data about the year were transformed into mean values and used for subsequent analyses. Thereafter, Fisher's ANOVA technique was employed, and a comparison of treatment means was made using Duncan's multiple range test (DMRT) at 5% level of probability [44].

3. Results and Discussion

3.1. Weeds Density and Dry Biomass

The results revealed that the fertilization regimes and weed-free duration significantly influenced the weeds (grasses, sedges and broad leaf) density and dry matter (Figure 1). In the experimental plots, weeds of the *Gramineae* family were *Echinochloa crusgalli*, *Echinochloa colonum*, *Dactyloctenium aegyptium*, *Eclipta prostrata*, *Cynodon dactylon*, *Leptochloa chinensis* and *Eleusine indica*. The weeds of the Cyperaceae family were *Cyperus rotundus* and *Cyperus iria* (sedges), while some of the broad-leave weeds were *Trianthema portulacastrum*, *Ipomoea aquatica* and *Portulaca oleracea*. It was observed that weeds emerged profusely between 15–25 DAS, and the pace of weed emergence was at a peak up to 40 DAS in weedy check plots. After 40 DAS, weeds emergence and their growth slowed remarkably, owing to the rice seedling establishment in the season-long weed-free treatment. Weed biomass remained statistically on par at 40 and 50 DAS for broadcast and side placed fertilizers (Figure 2b), indicating 20–30 DAS as the most critical period for attaining biomass by weed flora.

Regarding weed density and dry biomass, the interactive effect of FM with WFD remained significant ($p \leq 0.05$) (Figure 2a,b), and weed biomass remained significantly lesser, especially at 20 and 30 DAS for SP fertilizers compared to BF (Figure 2b). In the WC plot, WD and WB were 301.67 m^2 and 144.89 g m^2, respectively, for BF against 286.33 m^2 and 132.87 g m^2 in SP. For the WF plots up to 50 DAS, WD and WB were reduced to 88.33 m^2 and 45.893 g m^2, respectively, while their corresponding values for SP were 51 m^2 and 40 g m^2. This corresponds to 42 and 13% higher WD and WB for BF, compared to SP. These declined significantly as the WFD was increased up to 50 DAS. However, the WB recorded by BF and SP remained statistically at par to each other, at 40 and 50 DAS (Figure 2b).

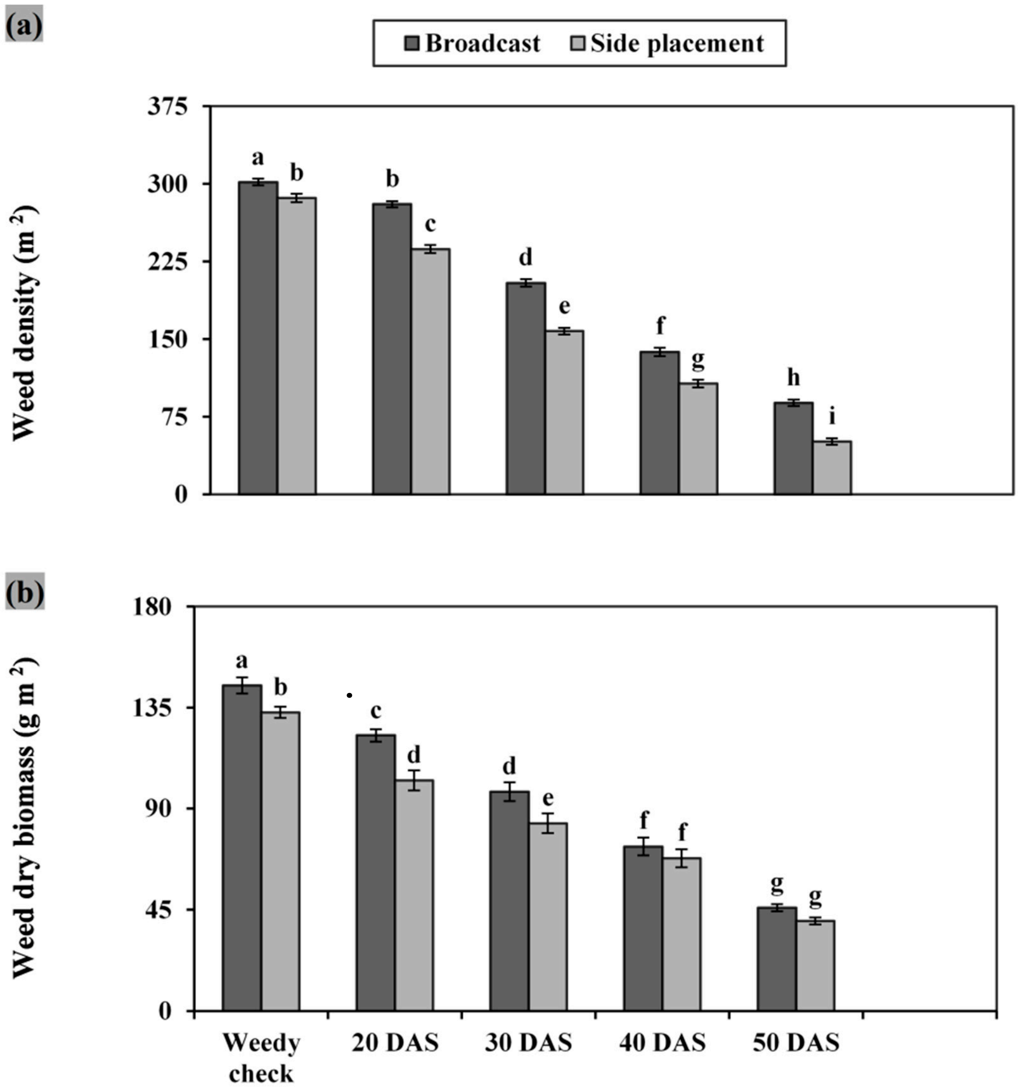

Figure 2. Effects of different weed-free periods on (**a**) weed density and (**b**) weed dry biomass in direct-seeded rice under different fertilizer application methods. Vertical bars above mean denote the standard error (±) of six replicates and letters depict significane at 5% probability level. Units on *x*-axis remain same for both a and b figures, (2 years mean data).

The grass weed proportion remained higher compared to broad leaf weed sedges up till 30 DAS, nevertheless, it manifested a sharp increment thereafter (Figure 3). Although the broad leaf weed proportion was lesser during the first 30 DAS, however, they continued to show up until the end of the season. Later in the season, narrow-leaved weeds gradually replaced the broadleaved weeds. It was observed that FM had no significant effect on the different weed types. Weed density and sedge biomass remained the same for a whole season. Previously, it was concluded that broad-leaf weeds dominated initially for up to 30 DAS, while grasses surpassed broadleaves afterwards. Additionally, it was noted that DSR had a higher density of grasses followed by broad-leaf weeds and sedges [45]. Our results suggested that the weed density and biomass were higher by 20% and 10%, respectively, for BF compared to SP (Figure 2). This might be attributed to the nutrients being readily available to weeds in broadcasted plots, leading to a profound increase in weed infestation in comparison to side-placed fertilizers. Our findings are also in concurrence with those of [46], who opined that the side-placement fertilization method recorded 40% lower weed density, owing to significantly lesser available nutrients in comparison to broadcasted fertilizer. It was also inferred that side-injected fertilizers resulted in a significantly higher nutrient uptake (23%) by crop plants and lesser nutrient losses (over 31%) which led to a noticeable decline in the free nutrients that were available to weeds seedling and, ultimately, their competitive superiority was decreased. Notably, crop plants were able to attain robust earlier growth. Rasmussen et al. [26] also reported a lower density of weeds (10%) and weed biomass (55%) when fertilizer was side-applied, as this resulted in a slow release of nutrients compared to broadcasted fertilizers, which were readily absorbed by weeds and lost to the environment through leaching and gaseous emissions. It was concluded broadcasted fertilizers were equally available to weeds and crop plants, however owing to botanical superiority, weeds were able to extract more nutrients than crop plants which caused a significant increase in their fresh and dry biomass [2,14,21,25,26]. Weeds were able to absorb and utilize environmental resources, such as solar radiation and CO_2, more efficiently and, resultantly, tended to record more vigorous growth compared to crop plants [46]. More importantly, weeds occupied more space owing to rigorous growth and the resulting lesser space in the rhizosphere remained available to crop plants for nutrient absorption from the soil solution [28,31]. However, fertilization did not significantly effect weed biomass when weeds were controlled by herbicides. However, under unrestricted weed growth, fertilizer placement above the soil surface increased weed biomass substantially more than the placement of fertilizer below the soil surface [28].

3.2. Yield Components and Paddy Yield

The yield components contributing to paddy yield were largely influenced by fertilization methods and the duration of the weed-free period, and their interaction also remained significant ($p \leq 0.05$) (Figure 4a–d). The number of panicles (m^{-2}) of DSR in the weed-free plots of up to 20 DAS were more numerous for SP than BF (Figure 4b). However, for the rest of the weed-free periods, both fertilizer application methods remained statistically alike (Figure 4a). Side placement of fertilizer also realized more kernels per panicle in those plots that were kept free of weeds for up to 20 DAS and throughout the growing season than the broadcast method (Figure 3b). The treatment effect on the 1000-kernel weight was relatively less pronounced, with the exception of those plots in which weeds were controlled for up to 40 DAS, where the side placement application of fertilizer produced heavier kernels (Figure 4c). In the plots which had no weeds for 20–50 DAS and, afterwards, were subjected to unrestricted weed growth, side placement of fertilizer produced a distinct yield advantage over the broadcast method (Figure 4d). However, FM remained non-significant when either weeds were controlled or not controlled at all throughout the growing season. The numbers of tillers having panicles, kernels in each panicle and weight of 1000 kernels and paddy yield were increased with a weed-free duration. Moreover, weed-free conditions for the whole season were instrumental in improving (5–10%) the yield attributes, especially under the side-placed fertilization treatment (Figure 4a–c). Interestingly in comparison to WF, weed competition for the whole season reduced the amount of panicles bearing tillers, kernels per panicle and kernel weight, as well as the paddy yield by 40%, 50%, 20% and 75%, respectively (Figure 4). These findings are in agreement with those of [47], who reported that fertilizer placement remained instrumental in boosting grain yield, as compared to broadcasted fertilizers, owing to lesser wastage through leaching and votalization, along with maximized uptake by crop plants. Likewise, a number of previous studies [26,27,48–52] reported the superiority of side-placed fertilization for increasing the grain yield by 28% compared to broadcasted fertilization. It was also inferred that the rice yield was lowered by 0.75 kg for each kg of weed biomass, as weeds had overtaken the crop plants in terms of acquiring growth resources, such as CO_2 and solar radiation [20]. Chauhan and Johnson [32] revealed a net loss of 24% in paddy yield when weeds kept growing for 28 DAS of rice. Weed competition for the whole crop season resulted in over 80% grain yield loss owing to severe competition for growth resources, especially moisture and nutrients. It was also inferred that, owing to weeds' genetic superiority, as indicated by better root architecture, imparted edge over crop plants in terms of nutrients acquisition and ultimately robust growth of weeds, led to a serious decline in rice growth. Khaliq and Matloob [20] observed that weed infestation up to 200 m^{-2} significantly reduced paddy yield (51–64%) compared to the WF crop. Furthermore, previous studies found that weed interference had a varied impact on rice growth, depending upon the duration of the weed's dominance and the growth stage of the rice seedlings. This implies that if weed-free conditions are maintained for this stipulated period, it equates to providing weed-free conditions for a whole season, which has the potential to significantly increase paddy yield. These findings corroborate with earlier results where weed presence beyond 55 DAS did not remain drastic for rice [20,21]. Hence, it was suggested that subsequent weed control could be of little use and, rather, it could be economically unviable, incurring additional expenditures and leading to a higher cost of production [22–24].

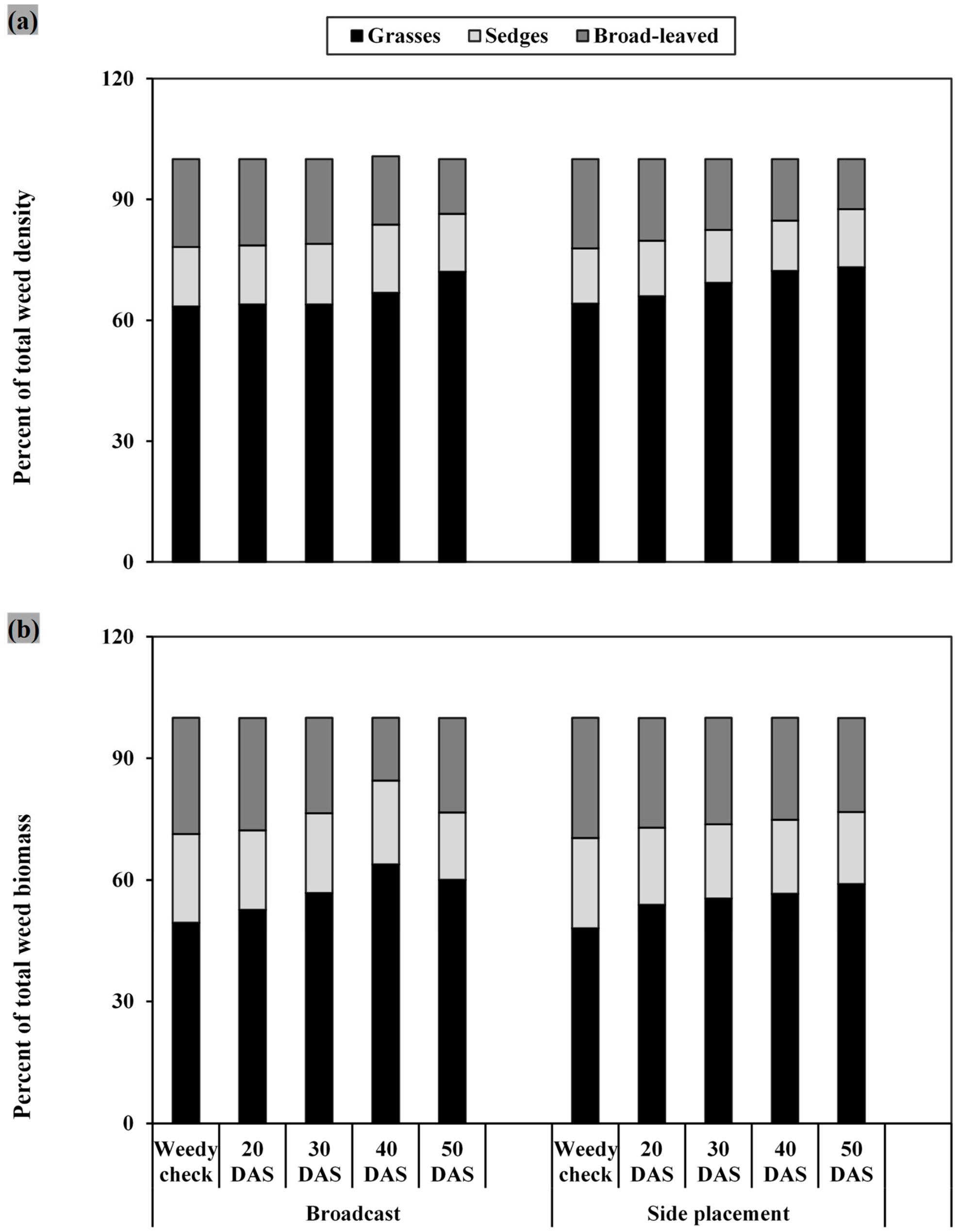

Figure 3. Relative proportion of different weed types (grasses, sedges and broad leaf weeds) on percentage basis in total (**a**) weed density and (**b**) weed dry biomass in direct-seeded rice under different fertilizer application methods. Units on *x*-axis remain same for both a and b figures, (2 years mean data and six replicates).

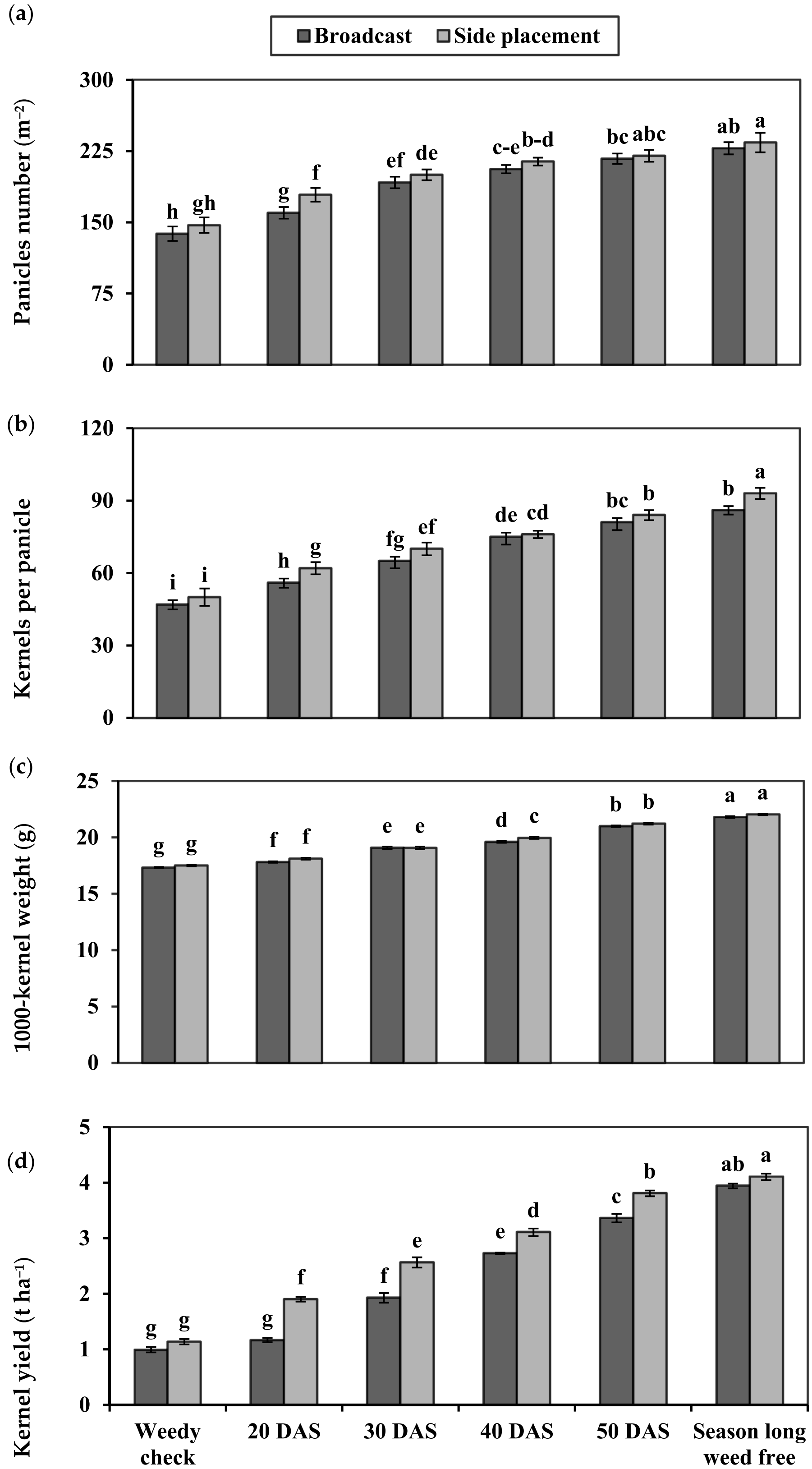

Figure 4. Effects of different weed-free periods on (**a**) number of panicles, (**b**) kernels per panicle, (**c**) 1000 kernels weight and (**d**) kernel yield of direct-seeded rice under different fertilizer application methods. Vertical bars above mean denote the standard error (±) of six replicates and letters depict significane at 5% probability level. Units on *x*-axis remain same for a, b, c and d figures, (2 years mean data).

3.3. Nutrient Uptake by Weeds and Directly Seeded Rice

The amount of absorbed nutrients by weeds and rice seedlings was significantly affected by the fertilization technique (FM) and weed-free durations (WFD) (Figures 5 and 6). The interactive effect of the FM and WFD remained significant for nutrient uptake; however, N absorption was the only exception whereby the two fertilization techniques did not differ (Figure 5a). Weeds extracted more nutrients from BF, suggesting their competitive advantage imparted by better plant architecture and genetic diversity. The nutrient uptake by weeds in plots kept weeds free for up to 50 DAS was only 19% (N), 9% (P) and 8% (K) compared to the weedy check, while NPK uptake remained 18%, 30%, and 24% higher for BF compared to SP (Figure 5). The NPK uptake of rice seedlings increased significantly with the weed-free duration; however, an opposite trend was observed for weeds. It was also inferred that being WF for beyond 50 DAS also produced a higher uptake of NPK by the rice seedlings. The interaction of FM and WFD remained significant, as far as nutrient uptake was concerned (Figure 6). The SP of the fertilizers improved the nutrient uptake in DSR compared to the BF. The maximum decline of N (70%), P (90%) and K (95%) were recorded in DSR, which confronted season-long weed competition, compared to WF. The SP recorded N, P and K uptake of 15%, 26% and 31% higher than BF (Figure 6). These results are also in harmony with those of [25–28], who recorded losses of 37 kg N, 30 kg P_2O_5 and 37 kg K_2O m^{-2} as a result of unchecked weed growth, and it was inferred that weeds dominated crop plants in terms of acquiring nutrients and, resultantly, significantly lesser nutrients could make their way to the targeted crop plants. It was also suggested that the presence of weeds throughout the crop season remained more drastic for rice seedlings in comparison to the fertilization technique, owing to a superior root network which enabled weeds to extract more nutrients, including N, P and K. Additionally, previous field investigations have also revealed that the presence of season-long weeds and type of fertilization placement depleted 21 kg N, 19 kg P_2O_5 and 77 kg K_2O m^{-2}, which led to a serious decline in the growth and development of rice plants and, ultimately, yield attributes, along with the paddy yield, were noticeably declined compared to the weedy check crop [30,31,53–57]. It was inferred that side-injected fertilizers remained effective in boosting yield attributes and grain yield by over 19%, compared to broadcasted fertilizers, as the nutrient uptake was 43% higher. It was concluded that broadcasted fertilizers resulted in the vigorous growth of weeds up to 50 DAS, which imparted adverse effects on the nascent rice seedling and, resultantly, yield attributes were seriously compromised. In comparison, N losses as volatilization were reduced by over 73% [53–57]. Prior studies have also concluded that the broadcast technique of fertilization was responsible for the excessive use of fertilizers and must be replaced with side-dressed fertilization in order to boost crop yield through higher nutrient use efficiency and through overcoming the votalization and leaching challenges in an economically viable way.

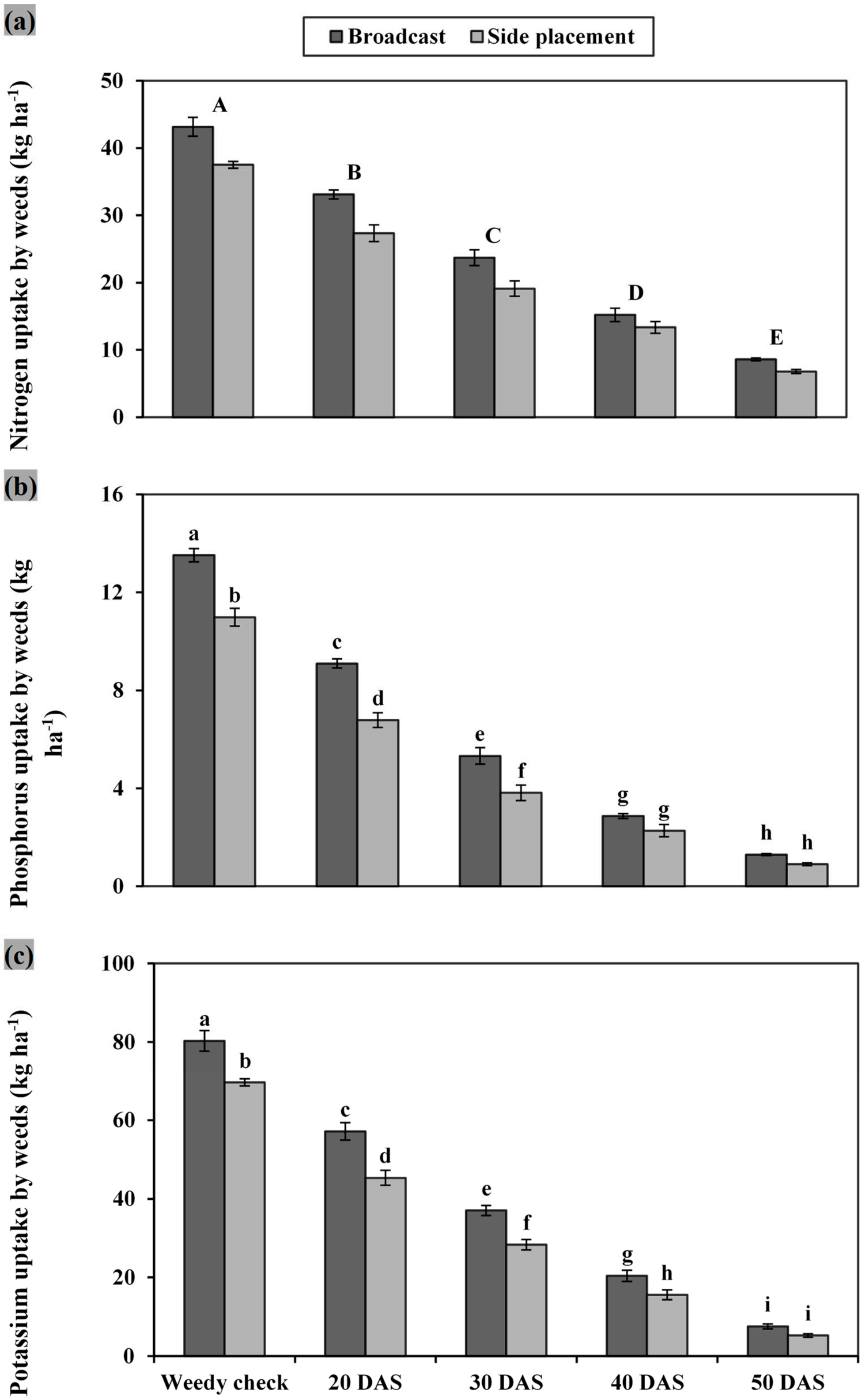

Figure 5. Effects of different weed-free periods on (**a**) nitrogen uptake, (**b**) phosphorous uptake and (**c**) potassium uptake by weeds in direct-seeded rice under different fertilizer application methods. Vertical bars above mean denote the standard error (±) of six replicates small letters depict significance at 5% probability level. Units on *x*-axis remain same for a, b and c figures. Capital letters represent same letter for both fertilizers methods, (2 years mean data).

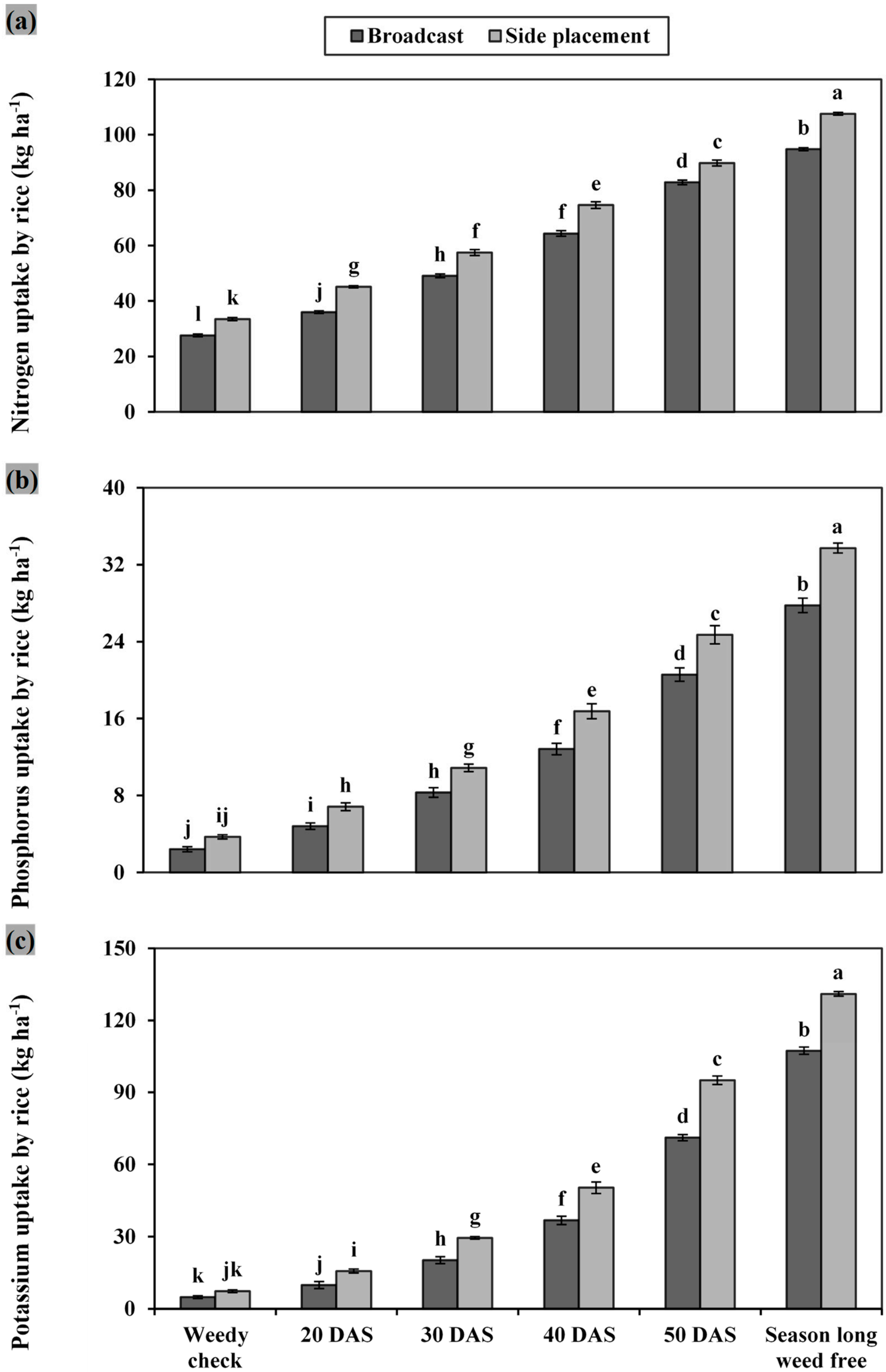

Figure 6. Effects of different weed-free periods on (**a**) nitrogen uptake, (**b**) phosphorous uptake and (**c**) potassium uptake by direct-seeded rice under different fertilizer application methods. Vertical bars above mean denote the standard error (±) of six replicates and letters depict significance at 5% probability level. Units on *x*-axis remain same for a, b and c figures, (2 years mean data).

4. Conclusions

The findings proved to be in line with the postulated hypothesis, as the fertilization technique and weed-free duration effectively influenced the weed infestation, yield attributes, paddy yield and nutrient uptake by crop plants in direct-seeded fine rice (DSR). Our study suggested that maintaining weed-free plots for the whole crop season remained instrumental in yielding the highest paddy yield, and it was also inferred that DSR requires 10 to 50 DAS weed-free days to achieve the optimum growth, maximum yield attributes and the highest paddy yield. Considering the fertilizer application methods, side-placement was better for improving the rice yield and yield components and also recorded a higher nutrient uptake in DSR. Thus, these results might be helpful in boosting the DSR yield in semi-arid and arid regions of the world by using the biologically viable agronomic practices of weeding and fertilization techniques. These findings may serve as a reference to conduct further studies involving other fertilizer application methods, such as band placement and fertigation, aimed at increasing nutrient availability to crop plants and reducing their losses through absorption by weeds and other wastages (leaching, volatilization and other gaseous emissions). At the same time, the impact of the weed-free duration in terms of economic viability also needs to be quantified in order to determine the economic viability of weed-free durations and fertilization application techniques.

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References

1. Gómez de Barreda, D.; Pardo, G.; Osca, J.M.; Catala-Forner, M.; Consola, S.; Garnica, I.; López-Martínez, N.; Palmerín, J.A.; Osuna, M.D. An Overview of Rice Cultivation in Spain and the Management of Herbicide-Resistant Weeds. *Agronomy* **2021**, *11*, 1095. [CrossRef]
2. Vitalini, S.; Orlando, F.; Vaglia, V.; Bocchi, S.; Iriti, M. Potential role of Lolium multiflorum Lam. In the management of rice weeds. *Plants* **2020**, *9*, 324. [CrossRef]
3. Islam, A.K.M.M.; Nasir, M.; Akter Mou, M.; Yeasmin, S.; Islam, M.S.; Ahmed, S.; Anwar, M.P.; Hadifa, A.; Baazeem, A.; Iqbal, M.A.; et al. Preliminary reports on comparative weed competitiveness of Bangladeshi monsoon and winter rice varieties under puddled transplanted conditions. *Sustainability* **2021**, *13*, 5091. [CrossRef]
4. Martins, M.B.; Agostinetto, D.; Fogliatto, S.; Vidotto, F.; Andres, A. Aeschynomene spp. Identification and Weed Management in Rice Fields in Southern Brazil. *Agronomy* **2021**, *11*, 453. [CrossRef]
5. Martin, R.; Chhun, S.; Yous, S.; Rien, R.; Korn, C.; Srean, P. Survey of Weed Management Practices in Direct-Seeded Rice in North-West Cambodia. *Agronomy* **2021**, *11*, 498. [CrossRef]
6. Haque, M.M.; Datta, J.; Ahmed, T.; Ehsanullah, M.; Karim, M.N.; Akter, M.S.; Iqbal, M.A.; Baazeem, A.; Hadifa, A.; Ahmed, S.; et al. Organic amendments boost soil fertility and rice productivity and reduce methane emissions from paddy fields under sub-tropical conditions. *Sustainability* **2021**, *13*, 3103. [CrossRef]
7. Ahmad, M.; Akhtar, M.; Anwar, M. Basmati rice: Progress, issues and prospects for rice crop in Pakistan. *Soil Environ.* **2005**, *30*, 50–57.
8. Akram, M. Aromatic rice of Pakistan-a review. *Pak. J. Agric. Sci.* **2009**, *22*, 154–160.
9. Saha, S.; Munda, S.; Singh, S.; Kumar, V.; Jangde, H.K.; Mahapatra, A.; Chauhan, B.S. Crop Establishment and Weed Control Options for Sustaining Dry Direct Rice Production in Eastern India. *Agronomy* **2021**, *11*, 389. [CrossRef]
10. Ali, S.; Liu, Y.; Ishaq, M.; Shah, T.; Ilyas, A.; Din, I. Climate change and its impact on the yield of major food crops: Evidence from Pakistan. *Foods* **2017**, *6*, 39. [CrossRef] [PubMed]
11. Kumar, V.; Jat, H.S.; Sharma, P.C.; Singh, B.; Gathala, M.K.; Malik, R.K.; Kamboj, B.R.; Yadav, A.K.; Ladhaa, J.K.; Raman, A.; et al. Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of

production? Assessing sustainable intensification options in the breadbasket of India. *Agric. Ecosyst. Environ.* **2018**, *252*, 132–147. [CrossRef]
12. Rao, A.N.; Brainard, D.C.; Kumar, V.; Ladha, J.K.; Johnson, D.E. Preventive weed management indirect-seeded rice: Targeting the weed seed bank. *Adv. Agron.* **2017**, *144*, 45–142.
13. Liu, H.; Hussain, S.; Zheng, M.; Peng, S.; Huang, J.; Cui, K.; Nie, L. Dry direct-seeded rice as an alternative to transplanted-flooded rice in Central China. *Agron. Sustain. Dev.* **2015**, *35*, 285–294. [CrossRef]
14. Hakim, A.R.; Juraimi, S.M.; Rezaul, K.; Khan, M.S.I.; Islam, M.S.; Choudhury, M.K.; Soufan, W.; Alharby, H.; Bamagoos, A.; Iqbal, M.A.; et al. Effectiveness of herbicides to control rice weeds in diverse saline environments. *Sustainability* **2021**, *13*, 2053. [CrossRef]
15. Ali, S.; Iqbal, M.A.; Afzal, S.; Afzal, M.I. Growth, kernel quality and yield assessment of aerobic aromatic rice (*Oryza sativa* L.) under different mulching types and spatial arrangements. *World J. Agric. Sci.* **2015**, *12*, 84–90.
16. Iqbal, M.A.; Ali, S. Evaluation of yield and yield components of aerobic fine rice (*Oryza sativa* L.) as influenced by different mulches and planting patterns. *Am. Eur. J. Agric. Environ. Sci.* **2015**, *14*, 1089–1094.
17. Iqbal, M.A. Productivity and quality of direct seeded rice under different types of mulches and planting patterns: A review. *Am. Eur. J. Agric. Environ. Sci.* **2015**, *14*, 1240–1247.
18. Marchesi, C.; Saldain, N.E. First report of herbicide-resistant Echinochloa crus-galli in Uruguayan rice fields. *Agronomy* **2019**, *9*, 790. [CrossRef]
19. 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.
20. Khaliq, A.; Matloob, A. Weed crop competition period in three fine rice cultivars under direct seeded rice culture. *Pak. J. Weed Sci. Res.* **2011**, *17*, 229–243.
21. Johnson, D.E.; Wopereis, M.C.S.; Mbodj, D.; Diallo, S.; Powers, S.; Haefele, S.M. Timing of weed management and yield losses due to weeds in irrigated rice in the Sahel. *Field Crop. Res.* **2004**, *85*, 31–42. [CrossRef]
22. Anwar, M.P.; Juraimi, A.S.; Samedani, B.; Puteh, A.; Man, A. Critical period of weed control in aerobic rice. *Sci. World J.* **2012**, *20*, 1–10. [CrossRef] [PubMed]
23. Di-Tomaso, J.M. Approaches for improving crop competitiveness through manipulation of fertilization strategies. *Weed Sci.* **1995**, *43*, 491–497. [CrossRef]
24. Blackshaw, R.E.; Molnar, L.J.; Larney, F.J. Fertilizer, manure and compost effects on weed growth and competition with winter wheat in western Canada. *Crop Protect.* **2005**, *24*, 971–980. [CrossRef]
25. Iqbal, M.A. Nano-Fertilizers for Sustainable Crop Production under Changing Climate: A Global Perspective. In *Sustainable Crop Production*, 1st ed.; Hasanuzzaman, M., Ed.; Intechopen Ltd.: London, UK, 2019; pp. 1–10.
26. Rasmussen, K.; Rasmussen, J.; Petersen, J. Effects of fertilizer placement on weeds in weed harrowed spring barley. *Acta Agric. Scand. B-Plant Soil Sci.* **1996**, *46*, 192–196. [CrossRef]
27. Kirkl, K.J.; Beckie, H.J. Contribution of nitrogen fertilizer placement to weed management in spring wheat (*Triticum aestivum* L.). *Weed Technol.* **1998**, *12*, 507–514. [CrossRef]
28. Mahajan, G.; Timsina, J. Effect of nitrogen rates and weed control methods on weeds abundance and yield of direct-seeded rice. *Arch. Agron. Soil Sci.* **2011**, *57*, 239–250. [CrossRef]
29. Khaliq, A.; Matloob, A.; Ihsan, Z.A.; Abbas, R.N.; Aslam, Z.; Rasul, F. Supplementing herbicides with manual weeding improves weed control efficiency, growth and yield of dry seeded rice. *Int. J. Agric. Biol.* **2013**, *15*, 191–199.
30. Khaliq, A.; Mahmood, S.; Matloob, A.; Khan, M.B.; Awan, I.U. Optimizing seeding density and tank mixture of herbicides help reduce yield losses in dry seeded fine rice. *Pak. J. Weed Sci. Res.* **2012**, *18*, 167–181.
31. Cathcart, R.J.; Chandler, K.; Swanton, C.J. Fertilizer N rate and the response of weeds to herbicide. *Weed Sci.* **2004**, *52*, 291–296. [CrossRef]
32. Chauhan, B.S.; Johnson, D.E. Row spacing and weed control timing affect yield of aerobic rice. *Field Crops Res.* **2011**, *121*, 226–231. [CrossRef]
33. Chauhan, B.S.; Abugho, S.B. Fertilizer placement affects weed growth and grain yield in dry-seeded rice (*Oryza sativa* L.) systems. *Am. J. Plant Sci.* **2013**, *4*, 1260–1264. [CrossRef]
34. Evans, S.; Knezevic, S.; Lindquist, J.; Shapiro, C.; Blankenship, E. Nitrogen application influences the critical period for weed control in corn. *Weed Sci.* **2003**, *51*, 408–417. [CrossRef]
35. Abbas, R.N.; Arshad, M.A.; Iqbal, A.; Iqbal, M.A.; Imran, M.; Raza, A.; Chen, J.-T.; Alyemeni, M.N.; Hefft, D.I. Weeds spectrum, productivity and land-use efficiency in maize-gram intercropping systems under semi-arid environment. *Agronomy* **2021**, *11*, 1615. [CrossRef]
36. Addis, H.; Andreas, K.; Theib, O.; Stefan, S. Linking selected soil properties to land use and hill slope- A watershed case study in the Ethiopian highlands. *Soil Water Res.* **2016**, *11*, 163–171. [CrossRef]
37. Black, C.A. *Methods of Soil Analysis, Part II*; American Society of Agronomy: Madison, WI, USA, 1965.
38. Sparks, D.L.; Page, A.L.; Helmke, P.A.; Leoppert, R.H.; Soltanpour, P.N.; Tabatabai, M.A.; Johnston, G.T.; Sumner, M.E. *Methods of Soil Analysis*; Soil Science Society of America: Madison, WI, USA, 1996.

39. Naresh, R.K.; Tomar, S.S.; Kumar, D.; Samsher, P.; Singh, S.; Dwivedi, P.; Kumar, A. Experiences with rice grown on permanent raised beds: Effect of crop establishment techniques on water use, productivity, profitability and soil physical properties. *Rice Sci.* **2014**, *21*, 170–180. [CrossRef]
40. AOAC. *Official Methods of Analysis*, 17th ed.; Association of Official Analytical Chemists: Arlington, VI, USA, 2003.
41. Jackson, M.L. *Soil Chemical Analysis*; Prentice Hall: Englewood Cliffs, NJ, USA, 1962.
42. Piper, C.S. *Soil and Plant Analysis*; Press Adelaide: Adelaide, Australia, 1950.
43. Ryan, J.; Estefan, G.; Rashid, A. *Soil and Plant Analysis Laboratory Manual*, 2nd ed.; International Center for Agricultural Research in the Dry Areas (ICARDA): Aleppo, Syria; National Agriculture Research Center (NARC): Islamabad, Pakistan, 2001.
44. Steel, R.G.D.; Torrie, J.H.; Dickey, D. *Principles and Procedures of Statistics: A biometrical Approach*; McGraw Hill Book Co. Inc.: New York, NY, USA, 1997; pp. 172–177.
45. Ahmed, S.; Alam, M.J.; Hossain, A.; Islam, A.K.M.M.; Awan, T.H.; Soufan, W.; Qahtan, A.A.; Okla, M.K.; El Sabagh, A. Interactive Effect of Weeding Regimes, Rice Cultivars, and Seeding Rates Influence the Rice-Weed Competition under Dry Direct-Seeded Condition. *Sustainability* **2021**, *13*, 317. [CrossRef]
46. Javed, T.; Afzal, I.; Mauro, R.P. Seed Coating in Direct Seeded Rice: An Innovative and Sustainable Approach to Enhance Grain Yield and Weed Management under Submerged Conditions. *Sustainability* **2021**, *13*, 2190. [CrossRef]
47. Mohanta, S.; Banerjee, M.; Malik, G.C.; Shankar, T.; Maitra, S.; Ismail, I.A.; Dessoky, E.S.; Attia, A.O.; Hossain, A. Productivity and Profitability of Kharif Rice Are Influenced by Crop Establishment Methods and Nitrogen Management in the Lateritic Belt of the Subtropical Region. *Agronomy* **2021**, *11*, 1280. [CrossRef]
48. Guan, S.; Fukami, K.; Matsunaka, H.; Okami, M.; Tanaka, R.; Nakano, H.; Sakai, T.; Nakano, K.; Ohdan, H.; Takahashi, K. Assessing Correlation of High-Resolution NDVI with Fertilizer Application Level and Yield of Rice and Wheat Crops Using Small UAVs. *Remote Sens.* **2019**, *11*, 112. [CrossRef]
49. 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]
50. Basavalingaiah, K.; Ramesha, Y.M.; Paramesh, V.; Rajanna, G.A.; Jat, S.L.; Dhar Misra, S.; Kumar Gaddi, A.; Girisha, H.C.; Yogesh, G.S.; Raveesha, S.; et al. Energy Budgeting, Data Envelopment Analysis and Greenhouse Gas Emission from Rice Production System: A Case Study from Puddled Transplanted Rice and Direct-Seeded Rice System of Karnataka, India. *Sustainability* **2020**, *12*, 6439. [CrossRef]
51. Shekhawat, K.; Rathore, S.S.; Chauhan, B.S. Weed Management in Dry Direct-Seeded Rice: A Review on Challenges and Opportunities for Sustainable Rice Production. *Agronomy* **2020**, *10*, 1264. [CrossRef]
52. Chen, Y.; Fan, P.; Mo, Z. Deep Placement of Nitrogen Fertilizer Affects Grain Yield, Nitrogen Recovery Efficiency, and Root Characteristics in Direct-Seeded Rice in South China. *J. Plant Growth Regul.* **2021**, *40*, 379–387. [CrossRef]
53. Yao, Y.L.; Zhang, M.; Tian, Y.H.; Zhang, B.W.; Zhao, M.; Zeng, K.; Yin, B. Urea deep placement for minimizing NH3 loss in an intensive rice cropping system. *Field Crops Res.* **2018**, *218*, 254–266. [CrossRef]
54. Xu, J.Z.; Liao, L.X.; Tan, J.Y.; Shao, X.H. Ammonia volatilization in gemmiparous and early seedling stages from direct seeding rice fields with different nitrogen management strategies: A pots experiment. *Soil Till Res.* **2013**, *126*, 169–176. [CrossRef]
55. Wang, W.Q.; Peng, S.B.; Liu, H.Y.; Tao, Y.; Huang, J.L.; Cui, K.H.; Nie, L.X. The possibility of replacing puddled transplanted flooded rice with dry seeded rice in central China. A review. *Field Crops Res.* **2017**, *214*, 310–320. [CrossRef]
56. Pan, S.G.; Wen, X.C.; Wang, Z.M.; Umair, A.; Tian, H.; Duan, M.Y.; Mo, Z.W.; Fan, P.S.; Tang, X.R. Benefits of mechanized deep placement of nitrogen fertilizer in direct-seeded rice in South China. *Field Crops Res.* **2017**, *203*, 139–149. [CrossRef]
57. Zhu, C.; Xiang, J.; Zhang, Y.; Zhu, D.; Chen, H. Mechanized transplanting with side deep fertilization increases yield and nitrogen use efficiency of rice in Eastern China. *Sci. Rep.* **2019**, *9*, 5653. [CrossRef]