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Full Length Article

Quantifying the Impact of Plant Spacing and Critical Weed Competition Period on Fine Rice Production under the System of Rice Intensification

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Abstract

Rice is one of the important cereal crops over the world and its average yield is low as compared to its potential production due to traditional growing techniques and weed infestation. System of rice intensification (SRI) has emerged as an alternative to conventional intensive rice cultivation system. This two-year study was conducted to investigate the impact of different transplant spacing (PS) (20 cm × 20 cm, 25 cm × 25 cm and 30 cm × 30 cm) and the critical periods of weed competition (CP) *viz*., 20, 40, 60, and 80 DAT (days after transplanting) in rice cultivated through SRI. A weedy check and a weed free for full crop season were kept as control treatments. After weed free control, minimum total weed density (17.0 and 21.3 m^{-2}) and minimum total weed dry biomass (5.5 and 8.4 gm^{-2}) were noted in the case of 20 cm × 20 cm rice transplant spacing in interaction with weed competition period for 20 DAT ($PS_1 \times CP_2$) during the full crop growing season. Weed density and weed dry biomass gradually increased and reached at their peaks by increasing weed competition periods and crop plant spacing for full growing season. Regarding yield related traits, the maximum number of fertile tillers per hill, 1000-kernal weight and normal kernel percentage were recorded with 30 cm × 30 cm spacing in weed free conditions ($PS_3 \times CP_6$) while the highest kernel yield (5.6 t ha^{-1}) was achieved in plant spacing of 25 cm × 25 cm under weed free conditions ($PS_2 \times CP_6$) during both years. However, by increasing or decreasing plant spacing from 25 cm × 25 cm caused significant decline in kernel yield of rice even under weed free conditions. In conclusion, fine rice should be transplanted with 25 cm × 25 cm plant spacing and weeds should be controlled within 20 DAT under SRI for better weeds control and to avoid yield losses.

Keywords: *Oryza sativa*; Plant spacing; Competition period; Weeds; Kernel yield

Introduction

Rice (*Oryza sativa* L.) is an important cereal crop of the world (FAO 2019). It fulfils food needs of about 90% population of Asia and more than half of the world's population (Fukagawa and Ziska 2019). In Pakistan, it is very important staple food and main exportable cash crop which contributes in agriculture and gross domestic product (GDP) by about 3.0 and 0.6%, respectively (GOP 2018–19). Its production is very important for the livelihood of about billions of people. Besides the availability of high production varieties, pesticides, fertilizers and other agronomical resources, its production and area has not been increased. Presently at global scale, its production in irrigated areas is mostly affected by the water scarcity, poor management of inputs and resources and losses from weeds, pests and diseases across the world (Jabran *et al.* 2017; Rao *et al.* 2017). Besides some natural factors of climate change, management practices including untimely sowing, inappropriate irrigation management and inadequate weed control may also be a hindrance in getting higher rice yield. For the sustainable agriculture, a new approach to rice cultivation the system of rice intensification (SRI) has emerged as an alternative rice production method being eco-friendly, sustainable and productive as compared to the conventional rice production techniques (Glover 2011). It is a system rather than a technology and is based upon the ideas of getting more outputs from fewer inputs (Uphoff 2003). The SRI requires fewer inputs like seeds, fertilizers, pesticides, water and gives high yield (Styger *et al.* 2011). It has been indorsed as a management approach of crop in integration with resources for the more rice cultivation

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(Tsujimotoa *et al.* 2009). This system also plays an important role as a mechanical weed management approach against major weeds in rice field (Styger *et al.* 2011). It is also stated that the reduced plant density of rice grown through SRI is compensated by increased yield per plant through high numbers of fertile tillers and panicles (Menete *et al.* 2008). This system also discourages the use of chemicals; however, are applied if necessary (Thakur *et al.* 2010a). The SRI leads to the better agronomic and phenotype performances for rice genotypes at variable range (Lin *et al.* 2005, 2006). It provides less competition, more space, and the interaction by allelochemicals to the growing roots and this system is eventually also leading to more production of dry matter of every hill in the rice crop (San-oh *et al.* 2004). The system of rice intensification ensures the source of sunlight and air to the single plant in wide spacing of rice plants and settlement of individual seedling $hill^{-1}$ (Satyanarayana *et al.* 2007). Single plant spacing in transplanted rice seedling plays a vital role in a variety of physiological and agronomical parameters, resulted to improve, or reduce the production of rice crop (Mishra and Salokhe 2010). It is well known that weeds are the major restrictions to high yield and the effective weed management is the major problem for the farmers (Singh *et al.* 2003). Under all conditions, no one is the best weed controlling method (Riaz *et al.* 2006). The density of weed, competition period, type, growth stage, crop sowing time and method are the major reasons of the losses in crop yield due to un-controlled weed emergence (Ashiq *et al.* 2003; Mansoor *et al.* 2004). About 80% losses in grain yield occur due to un-checked weed growth (Babu *et al.* 1992). The competition between rice crop and weeds start at their specific growth stage and if it is kept uncontrolled, then up to 50–60% yield losses may occur under puddled transplanting conditions (Dass *et al.* 2017). Under the traditional system of rice transplanting, the initial 40 days after transplanting were considered critical for crop-weed competition in rice (Thapa and Jha 2002). All the yield related traits are affected by weed competition duration (Uremis *et al.* 2009) and there is no effect on yield after critical weed competition period (Johnson *et al.* 2004).

In contrast to SRI, a modified system of rice intensification (MSRI) has been developed using higher transplant density that was proved to be more successful as it gained higher rice yields, sustained soil fertility and farmers' income (Das *et al.* 2018). In MSRI, it was supposed that narrow plant spacing could enhance the crop yield by the increased number of tillers per unit area that allows lesser weeds to grow among crop plants. Dass *et al.* (2017) documented that narrower plant spacing in puddled transplanted rice resulted in higher productivity with minimum weed infestations. However, by modifying the planting geometry of rice, there will definitely be a change in critical weed-crop competition period. Therefore, there was dire need to find out the most suitable plant spacing for Super Basmati rice cultivar and to explore the critical weed-crop competition period under variable plant spacing so that farmers and the researchers will know the best time to manage the weeds in rice fields economically before or after which they would be losing their money and time. Keeping in view the potential benefits of SRI observed by different researchers in various rice growing countries, it was the need of time to validate this technology under agro-ecological conditions of Punjab, Pakistan. Therefore, this two-year field study was planned to know the effect of plant spacing and the critical period of weed competition in rice crop sown through SRI and the goal of this study was to provide an appropriate package to the rice growers for the best resources utilization at the most suitable time and management of the problematic weeds in SRI.

Materials and Methods

Site description

This field study was conducted in 2010 and 2011 at the Agronomic Research Area, University of Agriculture, Faisalabad, Pakistan and the experimental site location was 30.35–31.47°N latitude, 72.08–73°E longitude and at 150 m altitude. The principles and practices of the system of rice intensification were followed during soil, water and crop management (Stoop *et al.* 2002). Soil of investigation site was loam having organic matter 0.98 and 1.08%, pH 7.6 and 7.7, total nitrogen (N) 0.053 and 0.056%, available phosphorus (P) 12.9 and 13.3 mg kg^{-1} and available potassium (K) 128 and 132 mg kg^{-1} of soil during years 2010 and 2011, respectively. Average rainfall of season was 96.98 mm in 2010 and 74.08 mm in 2011.

Treatments and experimental details

Rice was transplanted using different transplant spacing (PS) as 20 cm × 20 cm, 25 cm × 25 cm and 30 cm × 30 cm under various weed competition periods (CP) *viz*., 20, 40, 60 and 80 DAT (days after transplanting). A weedy check and weed free period for whole crop season were kept as controls. The experiment was conducted in the randomized complete block design (RCBD) with split plot arrangement and there were three replications for each treatment. The net plot size was 3.0 m × 6.0 m for each treatment and plant spacing factor was allocated to main plots while weed competition period to sub-plots.

Crop husbandry

The bed for raising rice nursery was prepared in close proximity of the study field to be transplanted with these seedlings to avoid seedling shock at the time of transplanting (Thakur *et al.* 2010b). Well-rotted farm yard manure at the rate of 1 kg m^{-2} was mixed thoroughly with the soil before seed sowing. The paddy (CV. Super Basmati) seeds were soaked in the tap water for 10 min in a bucket and sank seeds were used for sowing while the floated seeds were discarded. The seed rate of 1.25 kg per 25.32 m^2 was broadcasted for sowing and covered with rice straw to preserve moisture and guard of germinated seed from predators. At the time of field preparation for transplanting, the farm yard manure was mixed thoroughly with soil at the rate of 5 t ha^{-1} and rice seedlings of 21 days were transplanted in the prepared field. Muddy conditions were maintained by the applying water in the field during transplantation (Thakur *et al.* 2010b) and no synthetic fertilizer was applied. Rice seedlings were transplanted using one seedling per hill and assuring that the root tips were not inverted upward. For the initial two weeks after transplanting, irrigation was applied three times per week to maintain 3 cm standing water in the field. After that, an alternate wetting and drying schedule was followed up to the start of grain formation and making sure that irrigation was applied only after drainage of ponded water. From the grain formation to the harvesting, 3 cm irrigation was applied with the five days' interval.

Crop harvesting and data recording

Three major weeds such as *Echinochloa colona* L., *Trianthema portulacastrum* L. and *Cyperus rotundus* L. were dominant in the rice field. Weed density and weed dry biomass were recorded at 55 and 85 DAT, respectively to observe the weed dynamics. In each experimental unit, a quadrate having the size of 0.5 m × 0.5 m was placed randomly at two different points and weeds were counted for the measurement of weed density and cut from base to measure fresh and dry weight. Two readings of weed density and dry weight were obtained per plot and the values were averaged and converted into m^{-2}. For the measurement of rice root length, the plants were dug-out from the soil and their roots were washed with tap water and the length of the longest root was measured by the measuring scale/tape from the stem-root junction to the end of the root tip and the roots of individual plants were removed from the above ground part to measure the root mass by the help of electronic balance. To record the number of fertile tillers per hill, ten hills from every experimental plot were randomly selected and counted the number of panicle-bearing tillers and averaged. The 1000-kernel weight was taken in gram by electronic balance after taking three normal kernel samples from each treatment of each replication and taken its average. Normal kernels (lucid, translucent and immaculate) were counted and their percentage was calculated by dividing with total number of kernels. Kernels yield was taken after harvesting whole plot by sickle and threshing manually, and the yield recorded was converted into kg ha^{-1} of clean rough rice at grain moisture content of 14%.

Statistical analysis

The Fisher's two-way analysis of variance (ANOVA) technique was applied for analysis of recorded data, and the LSD (least significant difference) test was used at 5% probability to compare the significance among treatment means (Steel *et al.* 1997).

Results

Weed growth characteristics

The interaction of different transplant spacing and weed competition durations or periods significantly affected the weed density and weed dry biomass of three major weeds *i.e*., *E. colona, T. portulacastrum,* and *C. rotundus* in SRI field (Table 1). The strong relationship between total weed density and weed competition period was presented in Fig. 1. The data explained that minimum (17.0 and 21.3 m^{-2}) total weed density was seen when the combination was $PS_1 \times CP_2$ (20 cm × 20 cm spacing and 20 DAT weed competition period) during both the years excepting the weed free combinations with all the spacing, and the value of minimum total weed density was statistically as par with 20.7 and 24.7 m^{-2} that was recorded in the situation of $PS_2 \times CP_2$ (25 cm × 25 cm spacing and 20 DAT competition period). With the increase in the spacing of rice plants and the competition period of weed, the total weed density also gradually increased and reached at maximum values of 96.0 and 103 m^{-2} during 2010 and 2011, respectively, at 30 cm × 30 cm spacing in competition of weed for full growth period/weedy check ($PS_3 \times CP_1$). The individual density of all the three weeds including *E. colona, T. portulacastrum,* and *C. rotundus* also followed the same trend during the both years of the study. However, among these weeds, *C. rotundus* density remained the highest whereas *T. portulacastrum* and *E. colona* remained at second and third position, respectively, with respect to their densities. Similarly, the lowest total dry biomass (5.5 and 8.4 g m^{-2}) was measured at $PS_1 \times CP_2$ (20 × 20 cm spacing in 20 DAT competition period) throughout both years and highest total dry biomass (94.1 and 100.5 g m^{-2}) was calculated at $PS_3 \times CP_1$ (plant spacing 30 cm × 30 cm and control/weedy check) (Table 1). Individual weed dry biomass also followed the similar trend as shown by total weed dry biomass in response to different plant spacing in combination with different competition periods. The strong relationship between total weed dry weight and competition period has been shown during both years of study (Fig. 2).

Root growth, yield and yield contributing traits of rice

The interactive effect of different rice plant spacing and weed competition durations on the root growth, yield and yield contributing traits of rice remained significant during both the year of study (Table 2). Data indicated that the

Table 1: Effect of plant spacing and competition period on weed density and dry biomass in rice

Treatments		Weed density (plants m^{-2})								Weed dry biomass (g m^{-2})							
		Total		*Echinochloa colona*		*Trianthema portulacastrum*		*Cyperus rotundus*		Total		*Echinochloa colona*		*Trianthema portulacastrum*		*Cyperus rotundus*	
		2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
PS_1	CP_1	81.3c	86.0c	6.3a-c	7.0bc	18.0bc	18.7bc	57.0b	60.3c	81.4c	86.6c	13.6ab	14.6b	20.3c	21.8c	47.5c	50.2c
	CP_2	17.0l	21.3l	1.0i	1.3gh	1.7l	2.3j	14.3k	17.7j	5.5m	8.4n	0.9j	1.3g	1.3k	2.1j	3.3j	5.0k
	CP_3	39.3j	43.7j	3.0f-h	4.0ef	4.7i-k	5.0hi	31.7i	34.7h	26.3k	30.6l	4.1i	5.3f	5.4i	6.6i	16.7i	18.7i
	CP_4	56.3gh	62.0gh	4.0e-g	5.0de	9.7h	11.7ef	42.7fg	45.3f	43.8h	48.7i	6.1gh	7.7e	10.3g	11.6g	27.4f	29.4g
	CP_5	67.3ef	72.0ef	5.0c-e	6.0cd	14.3ef	16.0d	48.0de	50.0e	59.6e	65.0f	9.7de	11.4c	16.0e	17.3e	33.9e	36.3e
PS_2	CP_1	87.7b	93.5b	7.0ab	8.0ab	19.0b	19.8b	61.7a	65.7b	89.1b	94.0b	15.3a	15.3b	22.9b	24.0b	50.9b	54.7b
	CP_2	20.7kl	24.7l	1.3hi	2.0g	2.7kl	3.0ij	16.7jk	19.7j	7.0lm	10.2n	1.1j	1.6g	2.1jk	3.2j	3.8j	5.5jk
	CP_3	46.7i	51.0i	4.3d-f	5.0de	5.7ij	6.0gh	36.7h	40.0g	31.1j	35.6k	4.9hi	5.6f	6.1hi	7.2i	20.0h	22.7h
	CP_4	62.3fg	67.0fg	5.0c-e	6.0cd	10.7gh	11.3f	46.7ef	49.7e	47.7g	52.0h	7.3fg	8.2e	11.3fg	12.4fg	29.1f	31.5f
	CP_5	72.0de	78.0d	6.0bc	7.0bc	15.3de	17.3cd	50.7cd	53.7d	62.9e	67.6e	10.7cd	12.2c	16.6e	17.6e	35.7e	37.8e
PS_3	CP_1	96.0a	103.3a	8.0a	8.7a	22.0a	24.3a	66.0a	70.3a	94.1a	100.5a	15.3a	16.9a	24.6a	26.9a	53.9a	56.7a
	CP_2	26.7k	30.3k	2.3g-i	2.7fg	3.7j-l	4.0h-j	20.7j	23.7i	9.4 l	13.0m	1.6j	2.3g	2.9j	3.6j	4.9j	7.1j
	CP_3	52.3hi	57.3h	5.0c-e	6.0cd	6.7i	7.3g	40.7gh	44.0f	39.1i	44.2j	6.6f-h	7.7e	7.5h	8.9h	25.0g	27.6g
	CP_4	69.0e	74.3de	6.0b-d	7.0bc	12.7fg	17.7e	50.3de	53.7d	55.3f	60.6g	8.2ef	9.7d	12.4f	13.7f	34.7e	37.2e
	CP_5	78.0cd	84.7c	7.0ab	8.0ab	16.7cd	18.7bc	54.3bc	58.0c	75.1d	81.2d	12.6bc	14.3b	18.6d	19.5d	43.9d	47.4d
LSD($P \leq 5\%$)		6.26	5.04	1.67	1.63	2.13	2.30	4.63	3.61	3.84	2.40	2.01	1.28	1.55	1.66	2.08	1.97

The means following the same letters, within a column for each trait, did not significantly differ at 5% probability level
Plant spacing (PS_1= 20 cm ×20 cm, PS_2= 25 cm ×25 cm, PS_3= 30 cm × 30 cm); Weed crop competition periods (CP_1= weedy check/control, CP_2= 20 DAT (Days after transplanting), CP_3= 40 DAT, CP_4= 60 DAT, CP_5= 80 DAT

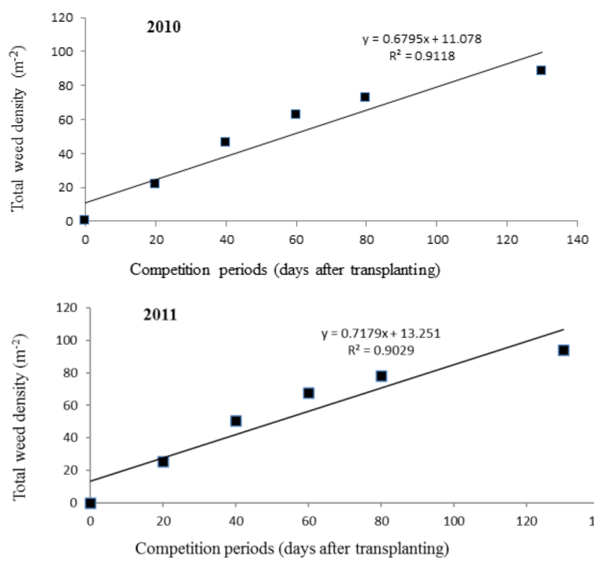

Fig. 1: Relationship between competition period and total weed density in rice under system of rice intensification as affected by competition period during 2010 and 2011

highest root length (30.9 cm and 30.0 cm) and root biomass (34.5 g and 32.9 g) was achieved by rice plants harvested from plots with widest plant spacing (30 cm × 30 cm) in weed free conditions ($PS_3 \times CP_6$). This combination however did not differ significantly from plant spacing of 25 cm × 25 cm in interaction with no weed competition ($PS_2 \times CP_6$) regarding root length and root biomass throughout both experimental years. A significant decline in root length and biomass started to occur by decreasing rice transplant spacing to 20 cm × 20 cm under the same without weed conditions. Consequently, the narrowest plant spacing (20 cm × 20 cm) in combination with weedy check ($PS_1 \times CP_1$) produced the lowest rice root length (12.2 and 11.4 cm) and root biomass (10.0 and 9.6 g) (Table 2).

Similarly, the highest fertile tillers per hill (55.8 and 53.4), 1000-kernal weight (24.7 and 23.8 g) and normal kernel percentage (81.37 and 79.13 %) were recorded with 30 cm × 30 cm transplant spacing in no weed competition ($PS_3 \times CP_6$) while the kernel yield was maximum (5.6 and 5.6 t ha^{-1}) in the interaction of $PS_2 \times CP_6$ (25 cm × 25 cm transplant spacing with no weed conditions) during years 2010 and 2011, respectively. However, the maximum values of fertile tillers $hill^{-1}$, 1000-kernal weight and normal kernel percentage were statistically similar to those noted with 25 cm × 25 cm transplant spacing in interaction with the absence of weed competition ($PS_2 \times CP_6$). The count of fertile tillers per hill and the percentage of normal kernel were proved more sensitive to weed infestation as these were prone to significant reduction under weed competition in all plant spacing. While, the lowest count of fertile tillers $hill^{-1}$, 1000-kernal weight and normal rice kernel percentage were calculated in combination of any of rice transplant spacing (PS_1=20 × 20 cm, PS_2=25 × 25 cm, and PS_3= 30 × 30 cm) with full season competition (CP_1=weedy check), while the lowest rice kernel yield (1.8 and 1.8 t ha^{-1}) was achieved in the interaction of 30 cm × 30 cm spacing of rice transplantation with full season competition ($PS_3 \times CP_1$) throughout the both years of experimental study (Table 2).

Discussion

Narrowing the crop row spacing in rice is known as a significant component of integrated weed management system as it results in reduced weed infestation and higher crop yields (Ali *et al.* 2019). By extending the weed competition period in rice, weed density and dry weight

Table 2: Effect of plant spacing and competition period on root length, root mass, fertile tillers, 1000-kernel weight, kernel yield and normal kernels

Treatments		Root length (cm)		Fertile tillers hill^{-1}		1000-kernel weight (g)		Kernel yield (t ha^{-1})		Normal kernels (%)	
		2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
PS_1	CP_1	12.2l	11.4k	11.2m	10.8k	13.7h	13.6i	2.0n	1.9m	67.79m	66.18m
	CP_2	25.8d	25.4d	40.4d	36.3e	23.0bc	22.3a-d	5.2c	5.1c	78.11e	76.21d
	CP_3	22.6f	22.0f	30.9g	27.6g	21.2de	20.8c-e	4.6e	4.4f	76.08g	74.31fg
	CP_4	18.7h	18.0h	21.3i	19.4i	19.3f	18.9ef	3.9h	3.7h	73.34i	72.21i
	CP_5	15.4j	14.8j	15.5jk	12.8jk	16.6g	12.6i	2.9k	2.8j	70.46k	69.26k
	CP_1	27.8c	26.8c	48.4c	45.6d	23.6ab	23.4ab	5.4b	5.3bc	79.33d	77.41c
PS_2	CP_2	12.4kl	11.9k	12.9lm	12.4jk	14.4h	14.1hi	2.3m	2.2l	68.69l	67.11lm
	CP_3	29.3b	28.0b	52.0b	47.7cd	24.1ab	23.7a	5.4b	5.3b	79.91cd	78.12bc
	CP_4	24.4e	23.7e	33.3f	31.6f	21.9cd	21.3b-e	4.8d	4.7e	76.73fg	74.70ef
	CP_5	20.3g	19.5g	24.8h	22.2hi	19.9ef	19.5e	4.1g	4.0g	74.23h	72.79hi
	CP_1	16.0ij	15.5ij	16.0j	11.0k	16.9g	16.4f-h	3.1j	3.0i	71.29j	70.18jk
	CP_2	30.0ab	29.1ab	53.8a	51.8ab	24.3ab	23.7a	5.6a	5.6a	80.74ab	78.55ab
PS_3	CP_3	13.5k	12.4k	13.8kl	12.9jk	15.0h	14.4g-i	1.8n	1.8m	69.34l	67.75l
	CP_4	30.8a	28.3b	54.4a	50.2bc	24.5a	22.5a-c	5.1c	4.8e	80.49bc	78.70ab
	CP_5	24.8de	24.0e	35.4e	33.6ef	22.2cd	19.7e	4.4f	4.2f	77.33f	75.36de
	CP_1	21.1g	19.9g	26.6h	22.9h	20.3ef	19.9de	3.7i	3.6h	74.80h	73.42gh
	CP_2	16.8i	16.0i	17.1j	15.1j	17.2g	16.7fg	2.8l	2.5k	71.89j	70.74j
	CP_3	30.9a	30.0a	55.8a	53.4a	24.7a	23.8a	5.3b	5.2cd	81.37a	79.13a
LSD value at 5%		1.16	1.08	1.98	3.15	1.39	2.51	0.14	0.14	0.749	0.943

The means following the same letters, within a column for each trait, did not significantly differ at 5% probability level

Plant spacing (PS_1= 20 cm ×20 cm, PS_2= 25 cm ×25 cm, PS_3= 30 cm × 30 cm); Weed crop competition periods (CP_1= weedy check/control, CP_2= 20 DAT (Days after transplanting), CP_3= 40 DAT, CP_4= 60 DAT, CP_5= 80 DAT, CP_6= weed free)

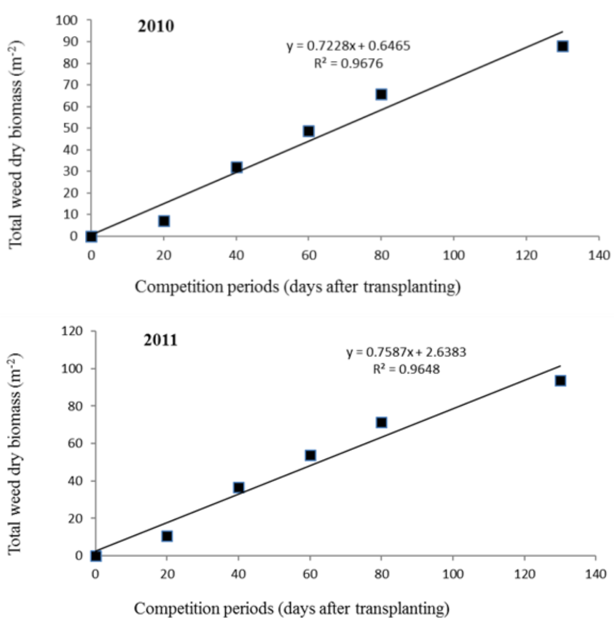

Fig. 2: Relationship between competition period and total weed dry biomass in rice under system of rice intensification as affected by competition period during 2010 and 2011

tend to increase (Bajwa *et al.* 2020). In the present studies, significant difference in weed density existed among different transplant spacing in rice and competition periods of weed during two years of experimental study and the significant increase in weed density occurred by widening the row spacing of rice crop. It was probably due to fact that wider spacing allowed the more growing area accessible for the growth of weed plants. While the weed density was restricted by the narrow spacing because transplantation of rice plants in close to each other won the utilization race of resources from the neighbouring weed plants by using most of growing land as compared to the weeds for their growth. By increasing competition period, weed density was increased due to more availability of time for germination of weeds from soil weed seed bank. Similarly, weed dry biomass also showed an increasing trend in response to rise in rice transplant spacing and competition period of weed plants while significant reduction in weed dry weight was caused with the decreased rice plant spacing. That reduction in dry weight was the result of increased severity in competition imposed on weeds by rice crop due to leaving very less space for weed flourishment. While under wider plant spacing, weed germination, growth and development was enhanced due to more space available for weeds (Table 1). Ali *et al.* (2019) also reported that weed dry biomass was diminished with decline in inter row spacing. Increase in weed dry biomass by prolongation in weed competition period was obviously due to more availability of germination time for weed and its growth and development. As strong positive correlation between crop row spacing and weed competition period in rice was shown by Chauhan and Johnson (2011). They concluded that wider row spacing of rice prolonged weed competition period that resulted in significant increase in weed density and dry biomass. Ashraf *et al.* (2014) recorded significant decline in weed density and biomass by imposing closer planting geometry in puddled rice. A gradual enhancement in density and dry biomass of weeds in response to increasing weed competition duration in rice was also documented by Matloob *et al.* (2015).

The rice root growth in terms of higher root mass and root length suffered from significant decline in response to extended weed competition period which was attributed to higher root density and dry weight under prolonged weed competition period. However, narrowing the crop row spacing resulted in higher intra-specific competition between rice plants that caused rice root growth inhibition. Consequently, significantly reduced root biomass and root length of rice plants were noted in narrow crop spacing and significant linear reductions in count of fertile tillers hill^{-1}, 1000-kernal weight, normal kernel percentage, and rice kernel yield were observed as weed competition period was increased from 0 to 80 days after transplanting (Table 2). This declining response of number of tillers of rice to prolonged weed competition was probably owed to increased weed competition stress faced by rice crop that suppressed its tiller production. In the same way, narrower plant spacing of rice aggravated the intra-specific competition stress among rice plants that reduced its number of tillers hill^{-1}. Juraimi *et al.* (2009) reported that with increase in competition period, decline in rice tillers occurred. In weed free conditions, rice transplant spacing of 20 cm attained the maximum normal kernel percentage. However, under weedy conditions, there was significant increase in normal kernel percentage of rice in by widening crop transplant spacing from 20 to 25 cm beyond this no significant increase in normal kernel percentage was recorded showing that 25 cm plant spacing is best for this parameter. Our results are in line with the outcomes of Vijayakumar *et al.* (2006) who obtained maximum number of kernels per panicle when plant spacing was 25 cm × 25 cm and Salahuddin *et al.* (2009) who also obtained higher number of kernels per panicle when spacing between plants was 20 cm × 20 cm. Nandal and Singh (1995) reported that with the increase in competition duration with weed resulted in less number of normal kernel percentage. Significantly the higher kernel yields of rice in all competition periods of weed were achieved in response to transplant spacing of 25 × 25 cm. However, plant spacing narrower or wider than it produced lower kernel yields of rice. The maximum kernel yield of rice at 25 × 25 cm plant spacing appears to be because of higher 1000-grain weight and normal kernel percentage, the two important yield contributing traits observed with this plant spacing. Our results are similar to findings of Vijayakumar *et al.* (2006) who obtained the maximum rice kernel yield when plant spacing was 25 × 25 cm. Our results are in contrary to those of some of the researchers (Kumar *et al.* 2019; Saju *et al.* 2019; Verma *et al.* 2019) who found narrower plant spacing to be more advantageous in gaining higher kernel yield of puddled rice. One the reasons of this contradiction seems to be the agro-climatic and rice genotypic differences as varieties used in those studies were non-basmati coarse grain rice.

Conclusion

It is concluded that under the agro-environmental conditions of Punjab-Pakistan, the best transplant spacing for Super Basmati rice is 25 cm × 25 cm and critical weed competition period is 20 days after transplanting (DAT). Therefore, a weed management strategy must be employed within this period to obtain the maximum yield from Basmati rice under the system of rice intensification (SRI).

Author Contributions

ARC and MAN planned the research experiments, HHA, MES and MSK interpreted the results, ARC, AR, MA and MH made the write-up, MMJ statistically analyzed the data and LA reviewed the whole manuscript grammatically and technically.

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