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Consequences of Varied Planting Geometry and Early Post Emergence Herbicides for Crop-Weed Interventions in Rice Under Semi-Arid Climate[1]

Como as Variações das Geometrias de Plantio e Aplicação Inicial de Herbicidas Pós-Emergentes Podem Afetar as Intervenções entre Cultura de Arroz e Infestantes em Clima Semiárido

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ABSTRACT - Adjustment of planting geometry along with reduced applications of herbicides can be a viable tool for effective weed management in rice. This present study has examined the effects of three planting geometries (20 cm x 20 cm, 20 cm x 10 cm and 10 cm x 10 cm); along with early post emergence herbicides, *viz;* bispyribac sodium 20% WP at 39.50 g a.i. ha^{-1}, bispyribac sodium 100 SC at 39.50 g a.i. ha^{-1}, cyhalofop-butyle 10% EC at 49.50 g a.i. ha^{-1}, and penoxulam 240 EC at 15 g a.i. ha^{-1} on weed growth, and rice performance under semi-arid climate. A weedy check was maintained as control where no herbicide was applied. Results showed that the narrowest plant spacing (10 cm x 10 cm) effectively controlled weeds; however, it also resulted in reduced rice growth and yield. More weed infestation and a season-long weed growth in weedy check plots have damaged rice growth and yield performance. All herbicides were effective in reducing weed density and biomass; however, reductions were greatest for 10 cm x 10 cm spaced plants. Among different plant spacings, the highest grain yield (4.35 ton ha^{-1}) was obtained from plots where rice was planted at 20 cm x 20 cm; while narrowest plant spacing led to reduced tiller production, panicle development, grains per panicle, 1000-grain weight, and grain yield, but increased sterility % and biological yield. Further, weed dry biomass was negatively correlated with grain and biological yield of rice at all spacings. Although narrow plant spacing was effective in controlling weeds, it also reduced rice productivity, suggesting the need for further studies to overcome intra-specific competition in narrow spaced rice plants through improved resource management.

Keywords: herbicides, plant spacings, rice growth, weed interference, yield loss.

RESUMO - A combinação da geometria de plantio com aplicações reduzidas de herbicidas pode ser uma ferramenta viável para o manejo eficaz de plantas daninhas na cultura do arroz. O presente estudo examinou os efeitos de três geometrias de plantio (20 x 20 cm, 20 x 10 cm e 10 x 10 cm), juntamente com a aplicação inicial de herbicidas pós-emergentes: bispiribac de sódio a 20% WP em 39,50 g i.a. ha^{-1}, bispiribac de sódio 100 SC em 39,50 g i.a. ha^{-1}, cialofope-butil 10% da CE a 49,50 g i.a. ha^{-1} e penoxsulame 240 CE em 15 g i.a. ha^{-1}, no crescimento de plantas daninhas e no desempenho do arroz sob clima semiárido. Uma testemunha sem capina foi mantida como controle, na qual nenhum herbicida foi aplicado. Os resultados mostraram que o mais estreito espaçamento entre as plantas (10 x 10 cm) efetivamente gerou o controle das plantas daninhas; no entanto, também gerou menos crescimento e produtividade do arroz. Maior infestação de plantas daninhas e seu crescimento, ao longo da temporada, em parcelas de testemunhas sem capina têm prejudicado o crescimento e a produtividade do arroz. Todos os herbicidas foram eficazes na redução da densidade

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e biomassa de plantas daninhas, sendo as maiores reduções observadas nos espaçamentos de 10 x 10 cm. Entre os diferentes espaçamentos, o maior rendimento de grãos (4,35 t ha^{-1}) foi percebido em parcelas onde o arroz foi plantado a 20 x 20 cm, ao passo que espaçamentos mais estreitos causaram redução na produção de perfilhamento, no desenvolvimento da panícula, nos grãos por panícula, no peso de mil grãos e na produtividade de grãos, porém aumentaram a esterilidade e o rendimento biológico. Além disso, a biomassa seca das plantas daninhas foi negativamente correlacionada à produção de grãos e ao rendimento biológico do arroz em todos os espaçamentos. Embora o espaçamento estreito tenha sido eficaz no controle de plantas daninhas, também reduziu a produtividade de arroz, o que sugere a necessidade de mais estudos para combater a concorrência intraespecífica em espaçamentos estreitos de plantas de arroz através de uma gestão de recursos mais eficaz.

Palavras-chave: herbicidas, espaçamentos, crescimento do arroz, interferência das plantas daninhas, perdas de produtividade.

INTRODUCTION

Rice (*Oryza sativa*) is a staple cereal crop for more than half of the world's population. The ever-increasing population demands rapid increase in rice productivity to ensure global food security (Chauhan et al., 2011; Abid et al., 2015). However, sub-optimal plant population and weed infestation are the major threats for higher paddy yield (Baloch et al., 2000).

Ubiquitous weeds in nature cause crop loss by competing for available resources (nutrition, light, space and water); disease incidence by serving as hosts of various pests; and interfere with crop growth by releasing different kinds of allelochemicals in the rhizosphere (Khaliq et al., 2014a). However, weed persistence over a period of time, its type and density, emergence time, and its interference period with the crop, are directly associated with weed-related losses in crop yields (Hussain et al., 2015). Simultaneous emergence of weeds and crops under resource-limited conditions may cause severe losses in crop productivity (Zimdahl, 2007). Weed density, its competitive ability, and growth rate thus have a strong but negative correlation with crop yield in maize (Fahad et al., 2014). About 71, 80, and 40-100% yield losses due to weed infestation were reported in paddy fields of Philippines (Phoung et al., 2005), Pakistan (Khaliq et al., 2012), and South Korea (Kim & Ha, 2005), respectively. Hence, judicious weed management options should be addressed to attain sustainability in crop production to meet present and to secure future food demands, especially in developing countries (Chauhan et al., 2012).

Different weed control strategies (cultural, manual, mechanical and chemical) are being practiced nowadays for weed management in paddy fields. The adoption of a specific method solely depends on the socio-economic conditions of the farmer, availability of technology, and technical approach of the grower (Ashraf et al., 2014). Manual weeding is economical under excess availability of labor at low wages, however, 'crop mimicry' of some weeds at early growth stages make this approach difficult to employ (Awan et al., 2015). Therefore, chemical weed control is the most effective, quick, time saving, economical and resource efficient way to control weeds in rice (Ashraf et al., 2014). Among various herbicides, penoxulam, bispyribac-sodium and cyhalofop-butyl are widely used as early post emergence herbicides to control weed infestation in rice (Khaliq et al., 2012). However, extensive and promiscuous use of herbicides induces weed resistance, alters weed population dynamics and dominance pattern, weed population shifts, and serious implications to soil micro-biota. It further causes serious agro-ecological and environmental complications that imbalance the plant-soil-environmental relationships (Chauhan et al., 2012). Integrated weed management (IWM) is the best way to control weeds in the most secure way (Chauhan & Johnson, 2010). Therefore, all those approaches that suppress weed growth and enhance crop competitive ability must be integrated (Chauhan & Opeña, 2012).

Understanding weed-crop interference is necessary to develop a strong and integrated weed management option. Adaptation of suitable crop management strategies using the principles of biological and ecological weed management can significantly reduce herbicide usage (Anjum et al., 2014). Till now, little work has been done in semi-arid climate of Pakistan regarding the effects of planting geometry and post-emergence herbicides on weed interference in rice. Therefore, this present study was initiated to ascertain the influence of planting geometry and early post emergence herbicides on weed infestation, weed indices, and growth and yield response of rice. The findings of this present study will help design IWM packages to enhance rice productivity through effective weed management in the future.

MATERIALS AND METHODS

Experimentation

Nursery of fine rice cultivar 'Super Basmati' was sown during the 1st week of June 2012. Puddled conditions were created to transplant seedlings by cultivating the field followed by planking (after water application) to level it. The experimental site soil was loamy, and contained organic matter 0.98 g kg^{-1}, EC 1.46 dS m^{-1}, pH 8.1, available nitrogen 1.35 g kg^{-1}, available phosphorous 10.8 ppm, available potassium 180 ppm with 38% saturation percentage. The climatic of the experimental site (31.25 °N latitude, 73.09 °E longitude, 184 m above sea level) is semi-arid where temperature ranges from 4.4 °C (in January) to 48 °C (in June) with mean annual rainfall of 200-250 mm.

Thirty five days old seedlings were transplanted in three different plant spacings, viz., 20 cm x 20 cm, 20 cm x 10 cm and 10 cm x 10 cm. Herbicides were used for weed control treatments, *viz;* Bispyribac sodium 20% WP at 39.50 g a.i. ha^{-1} (Bisp WP), Bispyribac sodium 100 SC at 39.50 g a.i. ha^{-1} (Bisp SC), Cyhalofop-butyle 10% EC at 49.50 g a.i. ha^{-1} (Clf-but), Penoxulam 240 EC at 15 g a.i. ha^{-1} (Penox) while a weedy check (WC) was also maintained as control, where no herbicide was applied. All herbicides were applied just once to their respective experimental plots at field capacity (0.36 cm^3 cm^{-3}) 20 days after transplanting as early post emergence by using a flat-jet type nozzle fitted to a manual knap sack sprayer. Volume of spray (250 L ha^{-1}) was calibrated using water prior to treatment application.

A standard dose of $N:P_2O_5:K_2O$ at 155:55:40 kg ha^{-1} was applied in the form of urea, di-ammonium phosphate (DAP) and sulphate of potash (SOP). All of phosphorus, potassium and one-third of nitrogen fertilizers were applied as basal dose at 2 days prior to transplanting while the remaining nitrogen was applied in two equal splits at 27 and 45 days after transplanting. Irrigations were applied according to the need of the crop. No serious incidences of insects or diseases were observed, therefore, no insecticide or fungicide was applied during the whole period of crop growth.

Observations

Weed density was recorded from two randomly placed quadrates (0.5 m^{-2}) in each experimental plot. Weeds were clipped off the soil surface and total weed counts were made for every quadrate from each plot after 35 and 50 DAT (days after transplanting). Weed samples were then placed in oven at 70 °C till constant weight. Weeds dry samples were weighed by using a digital scale (TX323L, Shimadzu, Japan). Leaf area of the crop was measured using a leaf area meter (Licor, Model 3100). Leaf area index (LAI) was then calculated as the ratio of leaf area to land area (Watson, 1947) and crop growth rate was measured according to Hunt (1978). At physiological maturity, fifteen rice plants were randomly selected from each plot to record growth and yield related attributes. Crop was manually harvested during the second week of November, 2012 leaving appropriate borders to get grain and biological yield. Harvest index (HI) was calculated as: (grain yield/biological yield) X100.

Weed indices

Several weed indices viz., weed persistence index (WPI), crop resistance index (CRI), weed management index (WMI), and agronomic management index (AMI) were calculated according to Misra & Misra (1997) and Devasenapathy et al. (2008). The WPI indicates the resistance in weeds against the tested treatments and confirms the effectiveness of the selected herbicides. The WPI was computed by using the following formula:

$$WPI = \frac{Weed\ biomass\ of\ treated\ plot}{Weed\ biomass\ of\ control\ plot} \times \frac{Weed\ density\ of\ control\ plot}{Weed\ density\ of\ treated\ plot}$$

The CRI indicates the relationship between a proportionate increase in crop biomass and a proportionate decrease in weed biomass in the treated plots, and was calculated as:

$$CRI = \frac{Biomass\ of\ crop\ in\ treated\ plot}{Biomass\ of\ crop\ in\ control\ plot} \times \frac{Biomass\ of\ weeds\ in\ control\ plot}{Biomass\ of\ weeds\ in\ treated\ plot}$$

The WMI is the ratio of yield increase over the control because of weed management and percent control of weeds by the respective treatment, and was computed as:

$$WMI = \frac{Percent\ yield\ increase\ over\ control}{Percent\ control\ of\ weeds}$$

The AMI was calculated by the following formula:

$$AMI = \frac{Percent\ yield\ increase\ -\ Percent\ control\ of\ weeds}{Percent\ control\ of\ weeds}$$

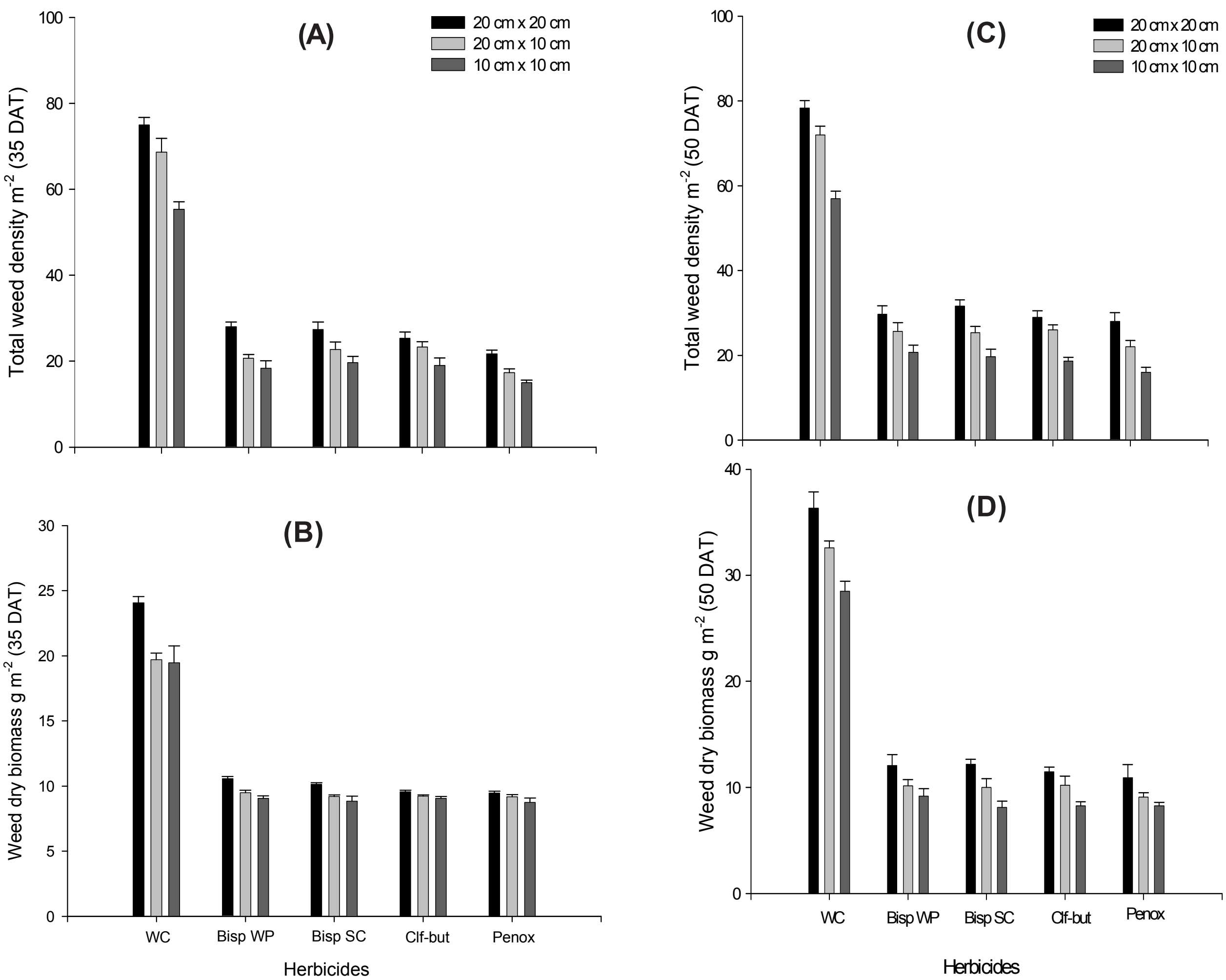
Experimental design and statistical analyses

The experiment was laid out in randomized complete block design (RCBD) under factorial arrangements with three replications. The recorded data were statistically analyzed by using Statistix 8.1 (Analytical Software, Tallahassee, FL, USA). The differences amongst treatments were separated using least significant difference (LSD) test at $p \leq 0.05$ and relationships were calculated by using polynomial linear regression and correlation analyses on SigmaPlot 9.0 (Systat Software Inc., San Jose, CA, USA).

RESULTS AND DISCUSSION

Weed infestation

Weed flora of the experimental site comprised of *Alternanthera philoxeroides* (Amaranthaceae) and *Conyza stricta* (Asteraceae) as broad-leaved; *Cynodon dactylon* (Poaceae), *Dicanthium annulatum* (Poaceae), *Echinochloa crus-galli* (Poaceae), *Echinochloa colona* (Poaceae), *Dactyloctenium aegyptium* (Poaceae), and *Pasplaum distchium* (Poaceae) as grasses; *Cyperus rotundus* (Cyperaceae), *Cyperus difformis* (Cyperaceae) and *Cyperus iria* (Cyperaceae) as sedges. Results depicted significant variations ($p \leq 0.05$) in total weed density, as well as total weed dry biomass in rice under the influence of planting geometry and post emergence herbicides. Interactive effect of planting geometry with herbicides was also significant ($p \leq 0.05$) for these attributes at both 35 and 50 DAT. Compared with WC, maximum reduction in weed density (80% and 79%), and weed dry (64% and 77%) at 35 and 50 DAT, respectively was recorded at 10 cm × 10 cm plant spacing where Penox was applied (Figure 1A-D). Overall, weed infestation was significantly higher in wider spaced plants compared with 10 cm x 10 cm. Furthermore, all herbicides were found at par in a specific planting geometry while varied considerably as a cross comparison among them. Averaged across different plant spacing and herbicide treatments, higher weed density and weed biomass was observed at 50 DAT compared with 35 DAT. No doubt, narrow spaced rice accomplished more space and suppressed weed emergence by efficiently exploiting inter-row and intra-plant space. Moreover, in narrow spacing, plants have an edge over



Capped bars above means represent S.E. of three replicates. WC: weedy check; Bisp WP: Bispyribac sodium 20% WP at 39.50 g a.i. ha^{-1}; Bisp SC: Bispyribac sodium 100 SC at 39.50 g a.i. ha^{-1}; Clf-but: Cyhalofop-butyle 10% EC at 49.50 g a.i. ha^{-1}; Penox: Penoxulam 240 EC at 15 g a.i. ha^{-1}.

Figure 1 - Effects of varied planting geometry and early post emergence herbicides on (A) total weed density, (B) weed dry biomass at 35 as well as (C) total weed density, and (D) weed dry biomass 50 days after transplanting (DAT).

weeds in utilizing water, nutrition, light and other resources that inhibited weed growth effectively (Ashraf et al., 2014). Chauhan & Johnson (2011) argued that uniform and optimum plant population is necessary to enhance the competitive ability of rice over weeds to get yield benefits. Zimdahl (2007) reported that planting geometry induced alterations in weeds emergence and growth by altering incoming light energy and its spectral composition on weed seedlings. So, higher planting rates (narrow spaced crops) covers ground fully than lower plant densities (wider spacings) at earlier growth stages thus suppress weeds to emerge and establish. Planting geometry also alters the light interception patterns where smaller weeds are less exposed and could not harvest the light due to exponential nature of light extinction within crop canopies (Weiner et al., 2001).

Although application of pre-emergence herbicides is quite tricky throughout weed management in rice fields, the occurrence of erratic rains and due to some other causes farmers must rely on post emergence or early post emergence herbicides (Weiner et al., 2001). Among the early post emergence herbicides, Bisp, Clf-butyl and Penox are widely used by farmers in paddy fields, however, each herbicide has its own specific mechanism of action regarding weed control (Mahajan & Chauhan, 2013). In this study, all herbicides reduced weed density and their dry biomass however, a rebuild of weed biomass of leftover/resistant or escaped weeds substantially increased at 50 DAT that suggested the importance of sequential and tank mixture application of herbicides than once/alone or sole application. Various studies conducted in India, Pakistan and Bangladesh suggested that application of sequential or tank mixture of herbicides are more effective regarding weed control in rice than alone or single application of herbicides (Mahajan & Chauhan, 2013; Khaliq et al., 2014a). Mostly, single application of herbicides fails to fully control the weeds in rice thus resistant/or escaped weeds may grow and may lead to yield penalty. Nonetheless, early post emergence herbicides help control weeds at seedling stage thus favor the crop to establish more vigorously (Awan et al., 2015).

Rice growth and yield response

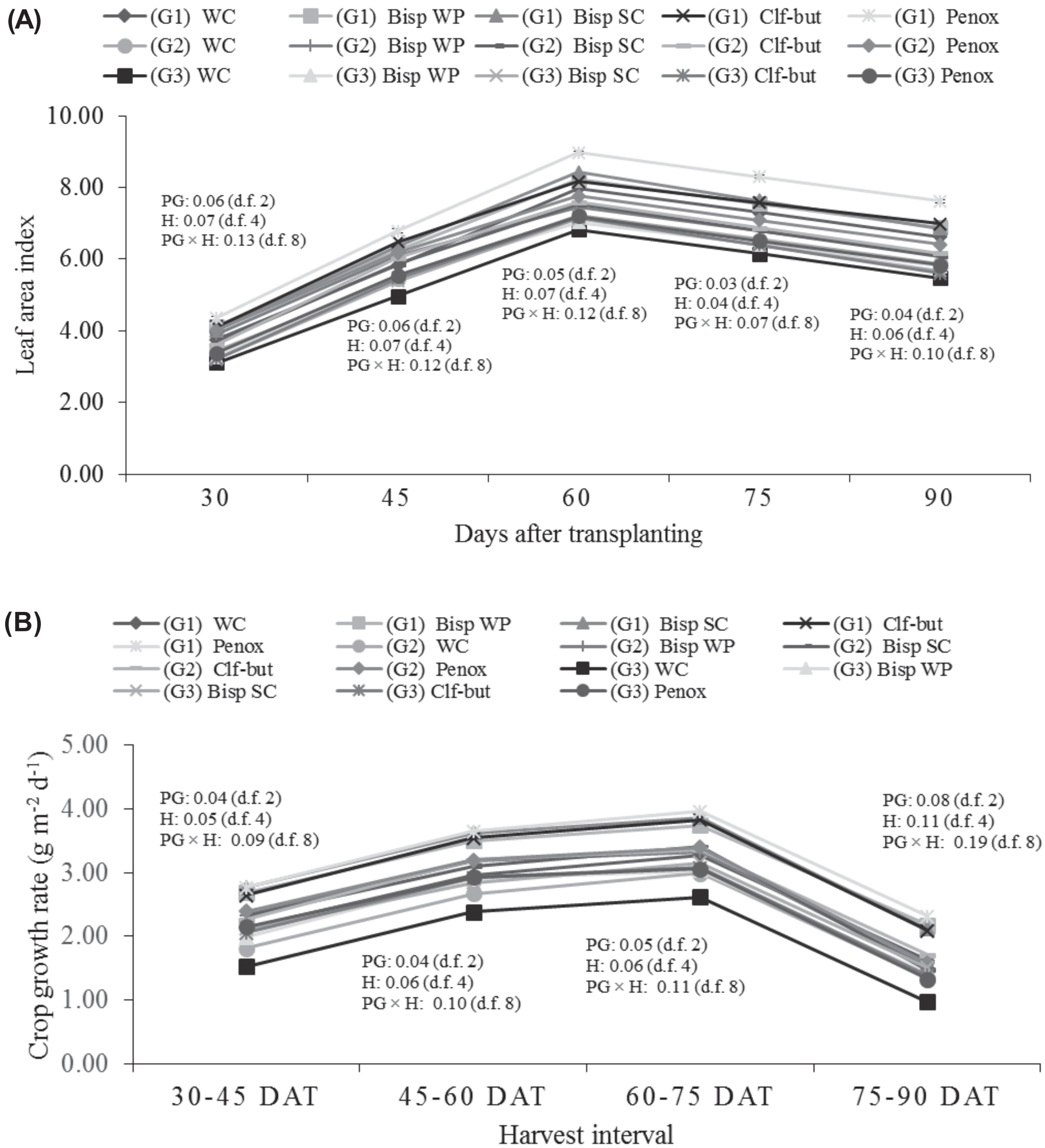
The LAI and CGR of rice were significantly ($p≤0.05$) influenced by the interaction of planting geometry and herbicide treatments. The maximum values of LAI and CGR were achieved where rice was transplanted at 20 cm x 20 cm spacing, and Penox was sprayed. However, intense weed population in WC reduced LAI as well as CGR significantly at all plant spacings. Furthermore, a linear increase in both LAI and CGR up to 60 DAT, followed by gradual decrease was observed afterwards (Figure 2A and B).

Plant height and number of tillers varied significantly ($p≤0.05$) under the effect of planting geometry and herbicides. The tallest plants and the maximum tillers were recorded for 20 cm x 20 cm spacings, while shortest plants with reduced tillers were recorded for 10 cm x 10 cm spacing, indicating a linear relationship of both these characters with plant spacing. Compared with 10 cm x 10 cm spaced plants, 7% higher plant height and almost twice number of tillers per hill was counted in 20 cm x 20 cm spaced plants. Plant spacing of 20 cm x 10 cm was moderately effective for both these attributes. All herbicides were equally effective in increasing plant height and tillering ability of rice by controlling weeds, however, severe weed infestation in weedy check resulted in stunted growth and less tillers (Table 1).

Panicle length and grains per panicle were also significantly ($p≤0.05$) affected by planting geometry and herbicide treatments. The longest panicles and the maximum grains per panicle were observed for 20 cm x 20 cm spaced plants, followed by 20 cm x 10 cm and 10 cm x 10 cm. Application of herbicides also increased panicle length and number of grains by reducing weed infestation. However, reduced panicle length and grains per panicle were perceived in weedy check due to higher weed density (Table 1).

Minimum panicle sterility % and maximum 1000 grain weight were recorded in plant spacing of 20 cm x 20 cm compared with all other treatments. Plantation of rice at 10 cm x 10 cm led to 70% higher grain sterility and 12% less grain weight than 20 cm x 20 cm plant spacing. Regarding herbicide application, the highest sterility % and lowest 1000 grain weight were recorded in control (WC) while all herbicides were found statistically similar in reducing grain sterility and 1000-kernel weight of rice (Table 1).

Different planting geometries affected grain and biological yield as well as the harvest index of rice. The highest grain yield was recorded in plant spacing of 20 cm x 20 cm. The 20 cm x 10 cm and 10 cm x 10 cm were statistically similar with each other for grain yield, while 20 cm x 20 cm and 10 cm x 10 cm were similar for biological yield. The maximum values for harvest index were recorded in 20 cm x 20 cm, followed by 20 cm x 10 cm and 10 cm x 10 cm. Furthermore, all herbicides were statistically similar for grain and biological yield of rice compared with control. Grain and biological yields were increased up to 22% and 15%, respectively in herbicide treated plots than WC. Nonetheless, harvest index was unaffected by herbicides (Table 1). Although weed population was poor in narrow spaced crops but wider spacings recorded better growth and yield of rice. Dense population might be helpful in early weed control, but an intra-plant competition for



DAT, days after transplanting; PG, planting geometry; H, herbicides; d.f. values of associated degrees of freedom. Values outside parenthesis are standard error of the difference (S.E.D). G_1: 20 cm x 20 cm; G_2: 20 cm x 10 cm; G_3: 10 cm x 10 cm. WC: weedy check; Bisp WP: Bispyribac sodium 20% WP at 39.50 g a.i. ha^{-1}; Bisp SC: Bispyribac sodium 100 SC at 39.50 g a.i. ha^{-1}; Clf-but: Cyhalofop-butyle 10% EC at 49.50 g a.i. ha^{-1}; Penox: Penoxulam 240 EC at 15 g a.i. ha^{-1}.

Figure 2 - (A) Leaf area index (LAI) and (B) crop growth rate (CGR) as influenced by different planting geometries and ealry post emergence herbicides.

available resources in later stages of the crop might discourage growth and yield of transplanted rice. Improved growth and yield characteristics in this present study under widest spacing might be attributed to maximum utilization of light, water and other inputs to produce and then translocate photo-assimilates into sink (Khaliq et al., 2011). An incessant translocation of carbohydrates to rice panicles under reduced weed-crop competition was also reported by Irshad et al. (2008).

Table 1 - Rice growth and yield as influenced by different planting geometries and early post emergence herbicides

Treatments	Plant height (cm)	Tillers hill^{-1}	Productive tillers hill^{-1}	Panicle length (cm)	Grains panicle^{-1}	Sterility (%)	1000-grain weight (g)	Grain yield (ton ha^{-1})	Biological yield (ton ha^{-1})	Harvest index (%)
20 cm × 20 cm	125.4±1.06a	12.60±0.77a	9.49±0.8a	26.79±0.70a	120.1±3.26a	6.18±0.39c	21.47±0.2a	4.35±0.25a	16.50±0.62a	26.39±1.64a
20 cm × 10 cm	118.55±2.1b	8.37±1.01b	6.39±1.01b	24.02±0.99b	113.6±2.19b	8.43±0.41b	19.62±0.5b	3.87±0.37b	14.30±0.85b	26.94±1.66a
10 cm × 10 cm	117.59±1.2b	5.47±0.67c	4.61±0.64c	23.56±0.92b	106.0±1.96c	10.52±0.48a	19.24±0.4b	3.48±0.21b	16.70±0.60a	20.83±1.46b
F-value	32.26	132.80	93.14	19.63	25.29	107.95	30.23	9.48	14.12	21.67
LSD ($p≤0.05$)	2.17	1.15	1.19	1.14	4.05	0.60	0.62	0.40	1.02	2.10
WC	113.73±0.8c	8.63±0.60b	6.91±0.70c	23.14±0.95c	104.3±1.11c	11.22±0.56a	19.39±0.37b	3.22±0.25b	13.86±0.55b	23.31±1.31
Bisp WP	120.18±1.0b	10.33±0.95a	8.70±1.07b	24.58±1.02bc	114.2±2.49ab	8.09±0.39b	19.97±0.46ab	4.03±0.39a	16.14±1.06a	25.16±2.23
Bisp SC	121.82±2.3ab	10.16±0.80a	9.13±0.96ab	24.90±0.96b	113.4±1.75b	7.92±0.37b	20.17±0.38ab	4.06±0.30a	16.33±0.66a	24.99±1.79
Clf-but	122.97±1.67ab	10.22±0.96a	9.01±0.79ab	24.69±0.81b	114.8±2.26ab	7.89±0.56b	20.14±0.45a	3.92±0.20a	15.97±0.63a	24.64±0.80
Penox	123.87±1.55a	11.40±0.75a	10.39±0.60a	26.64±0.66a	119.3±1.75a	6.78±0.27c	20.62±0.53a	4.28±0.31a	16.86±0.57a	25.50±1.81
F-Value	17.30	3.73	5.54	6.02	9.16	38.35	2.85	4.85	6.34	0.82
LSD ($p≤0.05$)	2.80	1.48	1.53	1.47	5.24	0.78	0.81	0.52	1.32	ns
Geometry	**	**	**	**	**	**	**	**	**	**
Herbicide	**	*	**	**	**	**	*	**	**	ns
Geometry × Herbicide	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Values (means±S.E.) sharing letters in common within a column are statistically non-significant. *significant ($p≤0.05$); **significant ($p≤0.01$); ns non-significant. WC: weedy check; Bisp WP: Bispyribac sodium 20% WP at 39.50 g a.i. ha^{-1}; Bisp SC: Bispyribac sodium 100 SC at 39.50 g a.i. ha^{-1}; Clf-but: Cyhalofop-butyle 10% EC at 49.50 g a.i. ha^{-1}; Penox: Penoxulam 240 EC at 15 g a.i. ha^{-1}.

A season growth of weeds in unsprayed WC reduced crop growth and yield compared with herbicides treated plots. A significant reduction (~95%) was also reported by Chauhan et al. (2011) due to free weed growth in weedy check. However, higher LAI and CGR were obtained when there was no or lesser weed competition and adequate resource availability to the crop (Ali et al., 2008; Ashraf et al., 2014). Furthermore, growth, tillering ability and yield attributes in widest spacing were presumably higher due to more space available for tillering that was limited in narrower spacing due to limited space available for rice plants to thrive (Phoung et al., 2005; Chauhan & Johnson, 2011; Khaliq et al., 2011). Our results showed that 20 cm x 20 cm spacing produced more grain yield. Although closer spacings reduced weed density and biomass accumulation, but chances of intra-plant competitions for available resources were also high, therefore, reduced availability of resources resulted in decreased tillers production and yield formation while enhanced sterility %. Chauhan et al. (2011) stated that higher planting density is beneficial to reduce the chances of insect/pest damage to get optimum yield.

Weed indices and regression analysis

Data regarding various weed indices are presented in Table 2. Application of Penox gave higher CRI, WMI, and AMI while lower WPI

Table 2 - Weed indices in rice as influenced by different early post emergence herbicides at 35 and 50 days after transplanting (DAT)

	Weed control treatments	WPI	CRI	WMI	AMI
35 DAT	WC	1.00	1.00	0.00	0.00
	Bisp WP	0.72	3.45	0.46	0.53
	Bisp SC	0.77	3.36	0.47	0.52
	Clf-but	0.73	3.38	0.40	0.59
	Penox	0.60	4.48	0.59	0.40
50 DAT	WC	1.00	1.00	0.00	0.00
	Bisp WP	0.88	3.62	0.39	0.60
	Bisp SC	0.91	3.79	0.41	0.58
	Clf-but	0.87	3.75	0.34	0.66
	Penox	0.84	4.20	0.48	0.52

WPI = weed persistence index, CRI = crop resistance index, WMI = weed management index, and AMI = agronomic management index

Table 3 - Polynomial linear regression and correlation analysis of grain and biological yield of rice transplanted under three different planting geometries with weed dry biomass at 35 and 50 days after transplanting (DAT)

Planting geometry	Y	X 35 DAT	Regression equation	R^2	X 50 DAT	Regression equation	R^2
20 cm × 20 cm	Grain yield (kg ha^{-1})	Weed dry biomass (kg ha^{-1})	y = -0.14x + 757.56	0.57	Weed dry biomass (kg ha^{-1})	y = -0.25x + 1263	0.56
	Biological yield (kg ha^{-1})	Weed dry biomass (kg ha^{-1})	y = -0.06x + 1216.9	0.69	Weed dry biomass (kg ha^{-1})	y = -0.11x + 2051.9	0.68
20 cm × 10 cm	Grain yield (kg ha^{-1})	Weed dry biomass (kg ha^{-1})	y = -0.09x + 481.62	0.99	Weed dry biomass (kg ha^{-1})	y = -0.21x + 947.23	0.99
	Biological yield (kg ha^{-1})	Weed dry biomass (kg ha^{-1})	y = -0.03x + 591.09	0.98	Weed dry biomass (kg ha^{-1})	y = -0.07x + 1186.3	0.99
10 cm × 10 cm	Grain yield (kg ha^{-1})	Weed dry biomass (kg ha^{-1})	y = -0.10x + 462.86	0.88	Weed dry biomass (kg ha^{-1})	y = -0.19x + 786.85	0.86
	Biological yield (kg ha^{-1})	Weed dry biomass (kg ha^{-1})	y = -0.03x + 655.09	0.89	Weed dry biomass (kg ha^{-1})	y = -0.06x + 1149.1	0.87

than other herbicides. However, higher weed densities in weedy plots resulted in highest WPI but lowest for CRI, WMI and AMI (Table 2). Regression analysis depicted that grain and biological yields of rice were negatively correlated with weed biomass at 35 and 50 DAT. With increase in weed biomass, corresponding reductions were recorded up to 33% in grain and 21% in biological yield. More than 57, 98 and 88% associations were observed among grain and biological yield with weed dry biomass at 35 DAT three plant spacings (from wider to narrower), respectively. Similarly, weed biomass at 50 DAT has strong but negatively correlated with grain (R^2= 56%, 99% and 86%) and biological (R^2= 68%, 99% and 87%) yield at G_1, G_2 and G_3, respectively (Table 3). Weed control, as well as herbicide efficacy, can be better explained in terms of weed indices, such as CRI, WMI, AMI and WPI. Herbicides having higher values for CRI, WMI, AMI and lower for WPI can be regarded as ideal and indicate the relative effectiveness of specific herbicide to kill weeds (Suria et al., 2011). Our results corroborate with the findings of Khaliq et al. (2014b) who stated that herbicide application reduced the values of WPI while increased CRI, WMI, AMI due to better weed control. However, opposite results were obtained in weedy check with high yield loss due to weed dominance.

To sum up, narrow inter- and intra-plant spacings averted weed growth and its population pressure in rice, and amplifies the importance of this approach for better weed management. Nevertheless, narrow plant spacing was not effective regarding rice growth and yield due to higher intra-specific competition, which entails some studies of different planting geometries with better nutrition management in future. Although sole application of herbicides used in this study reduced weed density and biomass, but better results can be achieved by applying tank mixtures rather alone application of a single herbicide. Combination of planting geometries and rice cultivars with prompt canopy closure and more competitive ability could further be tested to contrive better integrated weed management programs.

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