INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
12–070/MFA/2012/14–4–499–508
http://www.fspublishers.org

Full Length Article

Seeding Density and Herbicide Tank Mixtures Furnish Better Weed Control and Improve Growth, Yield and Quality of Direct Seeded Fine Rice

ABDUL KHALIQ[1], AMAR MATLOOB, SAQIB MAHMOOD, RANA NADEEM ABBAS AND MUHAMMAD BISMILLAH KHAN†

Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
†*Department of Agronomy, University College of Agriculture, Bahauddin Zakariya University, Multan, Pakistan*
[1]Corresponding author's e-mail: khaliquaf@gmail.com

ABSTRACT

Cultural practices are often employed for enhancing weed competitiveness in crops and their integration with herbicides further broaden the spectrum and activity for weed suppression. A field study was carried out to evaluate the efficacy of herbicide tank mixture for weed control in direct seeded rice sown at two seeding densities (50 & 75 kg ha^{-1}). Sunstar Gold 60WG (ethoxysulfuron ethyl) at 30 g a.i. ha^{-1} was tank mixed with Stomp 455CS (pendimethalin, 1137 g a.i. ha^{-1}) as pre-emergence (0 DAS), with Terminator 10WP (pyrazosulfuron ethyl, 30 g a.i. ha^{-1}), Nominee 100SC (bispyribac sodium, 30 g a.i. ha^{-1}) and Ryzelan 240SC (penoxsulam, 15 g a.i. ha^{-1}) and were applied as early post emergence (15 DAS). A weedy check and weed free treatments were run for comparison. Higher seeding density resulted in less weed count and biomass and more grain yield even in weedy check. A combination of bispyribac sodium+ethoxysulfuron realized greater suppression of weeds both in terms of density and dry weight. This treatment also improved rice yield and kernel quality attributes over weedy check. Tank mixture of penoxsulam+ethoxysulfuron was the second effective treatment regarding its ability to suppress weeds and increase rice yield. Higher seeding density and herbicide tank mixture furnished effective weed control in direct seeded rice.

Key Words: Seeding density; Herbicide tank mixture; Direct seeding; Rice yield; Kernel quality

INTRODUCTION

Chemical weed control is a commonly used and reliable method to control weeds in direct seeded rice (DSR) fields. Appropriate use of both pre-emergence and post-emergence herbicides has been found effective in the paddy fields (Singh *et al.*, 2006). Since, DSR fields are characterized by floristically diverse weed communities (Rao *et al.*, 2007), hence a single herbicide cannot furnish satisfactory and cost-effective weed control (Khaliq *et al.*, 2011). Using a single herbicide may control either sedges or broadleaf or grassy weeds effectively (Ahmed & Bhuiyan, 2010). Sole reliance on a single herbicide can lead to inter and intra specific shifts as well as evolution of herbicide-resistant weed biotypes due to herbicide selection pressure (Wrubel & Gressel, 1994; Shrestha *et al.*, 2010). This warrants the diversification of weed management practices that help keep weed population's off-balance. An integrated approach is indispensable to combat weed peril and prevent any change in weed community structure (Maity & Mukherjee, 2008). Herbicide tank mixture is a useful practice in intensive agriculture to broaden weed control spectrum and cope with herbicide resistance. Thus perception of herbicide tank mixture seems a superior option to handle recalcitrant and diverse weed flora in DSR. Practically, optimum herbicide combination should exhibit enhanced activity against weeds (Damalas, 2004).

Cultural practices also have a direct impact on weed infestation in DSR (Tuong *et al.*, 2000). Integrating weed control and cultural practices for weed management can have a great impact on weeds and need to be coordinated with other crop production practices that affect agro-ecosystems (Alsaadawi *et al.*, 2011). Planting density has been exploited as an effective tool in ameliorating the impact of weed competition (Mahajan *et al.*, 2010). Increased seed rate helps weed suppression besides compensating poor stand establishment. Increase in rice yield was observed in weedy plots as a result of increasing seeding rate (Azmi *et al.*, 2000). Zhao *et al.* (2007) reported that increasing seed rate from 100 to 300 seeds m^{-2} caused significant increase in rice yield coupled with decreased weed biomass. Higher seed rate often imparts a competitive advantage to the crop under only weedy conditions, which is lost under weed-free conditions (Chauhan *et al.*, 2011). Contrarily, Gibson *et al.* (2001) reported an insignificant impact of rice seeding rate on weed growth. The patterns of

To cite this paper: Khaliq, A., A. Matloob, S. Mahmood, R.N. Abbas and M.B. Khan, 2012. Seeding density and herbicide tank mixtures furnish better weed control and improve growth, yield and quality of direct seeded fine rice. *Int. J. Agric. Biol*., 14: 499–508

weed and crop growth often vary under varying planting densities that can be used as a tool in lowering weed pressure. Role of seeding density and herbicide tank mixture in combating weeds remains a germane issue in DSR and limited information is available on how weed growth and DSR productivity is influenced by these under local agro-ecological conditions. The present work attempts to elucidate suitable seeding density and herbicide tank mixture to prevent yield losses due to weed infestation in DSR fields.

MATERIALS AND METHODS

Site description: Field experiment was conducted at Agronomic Research Farm, University of Agriculture Faisalabad. Soil belongs to Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification & Haplic Yermosols in FAO classification). The pH of saturated soil paste was 7.5 and total soluble salts were 0.83 dS m^{-1}. Organic matter, total nitrogen, available phosphorus and potassium were 0.61%, 0.050%, 7.7 ppm, and 179 ppm, respectively. Mean annual rainfall of the area is about 200 mm.

Experimentation: The experiment was laid out in randomized complete block design (RCBD) with four replications under factorial arrangement during summer 2010. The net plot size was 6 m x 2.70 m. Seed of popular rice cv. Super basmati was obtained from Rice Research Institute, Kala Shah Kaku. Crop was sown in the first week of July with single row hand drill, using two seeding densities, i.e., 50 and 75 kg ha^{-1} and maintaining 22.5 cm distance between crop rows. A basal fertilizer dose of 125 kg N, 55 kg P_2O_5 and 40 kg K_2O ha^{-1} was applied in the form of urea (46% N), diammonium phosphate (18% N, 46% P_20_5) and sulphate of potash (50% K_2O). The whole phosphorus and potassium and one third of nitrogen were applied at the time of sowing. The remaining nitrogen was top dressed in two splits at tillering and panicle initiation. First irrigation was applied 10 days after sowing (DAS), while crop was irrigated subsequently as and when needed. The crop was manually harvested at maturity.

Herbicide application: Sunstar Gold 60WG (ethoxysulfuron ethyl) at 30 g a.i. ha^{-1} was tank mixed with Stomp 455CS (pendimethalin, 1137 g a.i. ha^{-1}) as pre-emergence (0 DAS), with Terminator 10WP (pyrazosulfuron ethyl, 30 g a.i. ha^{-1}), Nominee 100SC (bispyribac sodium, 30 g a.i. ha^{-1}) and Ryzelan 240SC (penoxsulam, 15 g a.i. ha^{-1}) and were applied as early post emergence (15 DAS). A weedy check and weed free treatment was run for comparison. Spraying was done by Knapsack sprayer fitted with a flat fan nozzle and volume of spray (300 L ha^{-1}) was determined by calibration using water.

Data collection: Data on weed (density & dry weight) for each experimental unit was recorded from two randomly selected quadrats (50 × 50 cm) at 30 and 45 days after sowing. Weeds were counted and clipped from ground surface. These were dried in an oven at 70ºC for 48 h and dry weight recorded. A 0.5 m long row of rice crop was harvested at fortnight interval after leaving appropriate borders. Plant material was separated into respective fractions (stem, leaves & panicles) and fresh and dry weight determined. Growth attributes of rice crop were computed by following procedures of Watson (1947) and Hunt (1978). Data on agronomic and yield traits of rice were recorded from 15 randomly selected plants from each plot and computing the average. Productive tillers (m^{-2}) were counted from two randomly selected sites from each plot and averaged. Crop was harvested, tied into bundles in respective plots. Each experimental plot was manually threshed grain yield was recorded and are presented as t ha^{-1}. A random sample of rice kernels was taken from the produce of each plot, thousand grains were counted manually and weighed on an electric balance.

Kernel length and width was determined with a digital Vernier caliper. Abortive, chalky, opaque and normal kernels were separated by positioning panicle in front of a common electric bulb fitted with a flexible stand as a light source, and are expressed as % of total. Kernel nitrogen was determined by Micro-Kjeldhal digestion followed by ammonia distillation, and was transformed to crude kernel protein using a multiplication factor of 5.95 (AOAC, 1990). Kernel amylose contents were determined as per Juliano (1971). The intensity of blue color was read out in a UV visible spectrophotometer meter (UV-4000, ORI, Germany) at 620 nm. Water absorption ratio of kernels was calculated as suggested by Juliano *et al.* (1965):

$$\text{WAR} = \frac{\text{Weight of cooked rice}}{\text{Weight of raw rice}}$$

Statistical and economical analyses: The data collected were subjected to Fisher's analysis of variance using "MSTATC" statistical package (Freed & Scott, 1986) and least significance difference test at $P \leq 0.05$ was used to compare treatments' means (Steel *et al*., 1997).

RESULTS AND DISCUSSION

Weed growth: Suppressive activity of different herbicide tank mixtures against weed density varied as a function of seeding density as the interactive effect was significant ($P \leq 0.05$) both at 30 and 45 DAS (Fig. 1). Nevertheless, the trend in control of weeds by different tank mixtures remained almost similar at both seeding densities. Highest weed pressure in terms of density was observed in weedy check, although weed count was less (22%) at higher seeding density (75 kg ha^{-1}). After the weed free treatment, tank mixture of ethoxysulfuron ethyl with bis-pyribac sodium reduced total weed density by 83 and 87% at seeding of 50 and 75 kg ha^{-1}, respectively at 30 DAS. But at 45 DAS both seeding densities depicted 92% weed suppression by this mixture over control. Combination of penoxsulam with ethoxysulfuron recorded 86 and 82% and 91 and 92% reduction in weed density at these times when seeded at densities of 50 and 75 kg ha^{-1}, respectively. Pyrazosulfuron ethyl+ethoxysulfuron ethyl suppressed weed density by 80%, while pre-emergence application of pendimethalin in combination with ethoxysulfuron ethyl proved inferior in retarding weed count and scored a weed inhibition of only 32 and 18% and 48 and 38% at 30 and 45 DAS, respectively under both seeding densities.

Weed dry weight also varied significantly for seeding densities of rice as well as various weed control measures (Fig. 2). At 30 and 45 DAS, weed biomass was significantly ($P\leq0.05$) greater (28.65 & 78.01 g) at seeding density of 50 kg ha^{-1} than that observed (16.32 & 60.85 g) at 75 kg ha^{-1},

Fig. 1: Interactive effect of seed densities and herbicide tank mixture on weed density at (a) 30 DAS and (b) 45 DAS in dry seeded fine rice. Vertical bars above mean denote standard error of three replicates. LSD for interaction is (a) 4.586 and (b) 5.141 for 30 and 45 DAS, respectively. W_1: Weedy check, W_2: Weed free, W_3: Pendimethalin + ethoxysulfuron, W_4: Pyrazosulfuron + ethoxysulfuron, W_5: Bispyribac sodium + ethoxysulfuron, W_6: Penoxsulam + ethoxysulfuron.

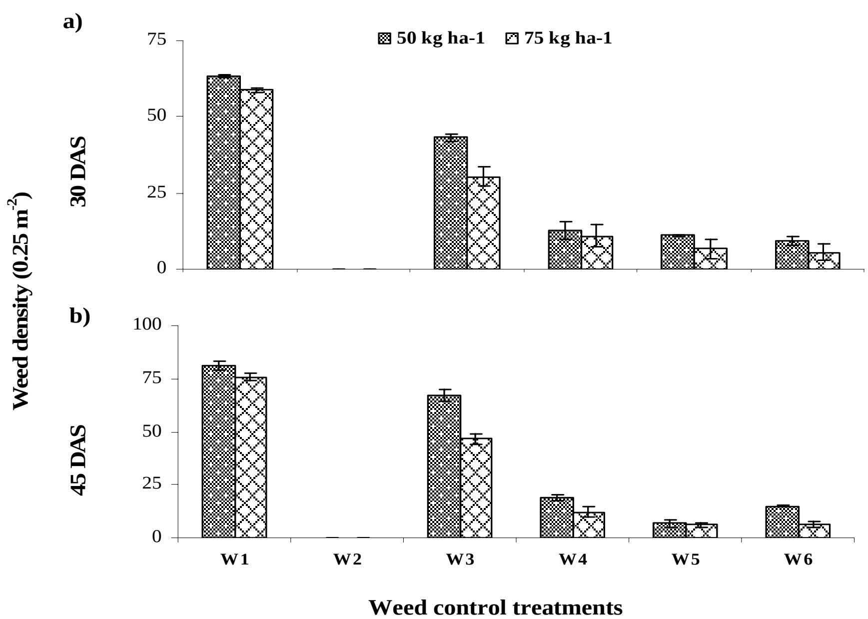


Fig. 2: Interactive effect of seeding densities and herbicide tank mixture on weed dry weight at (a) 30 DAS and (b) 45 DAS in dry seeded fine rice. Vertical bars above mean denote standard error of three replicates. LSD for interaction is (a) 3.033 and (b) 3.845 for 30 and 45 DAS, respectively

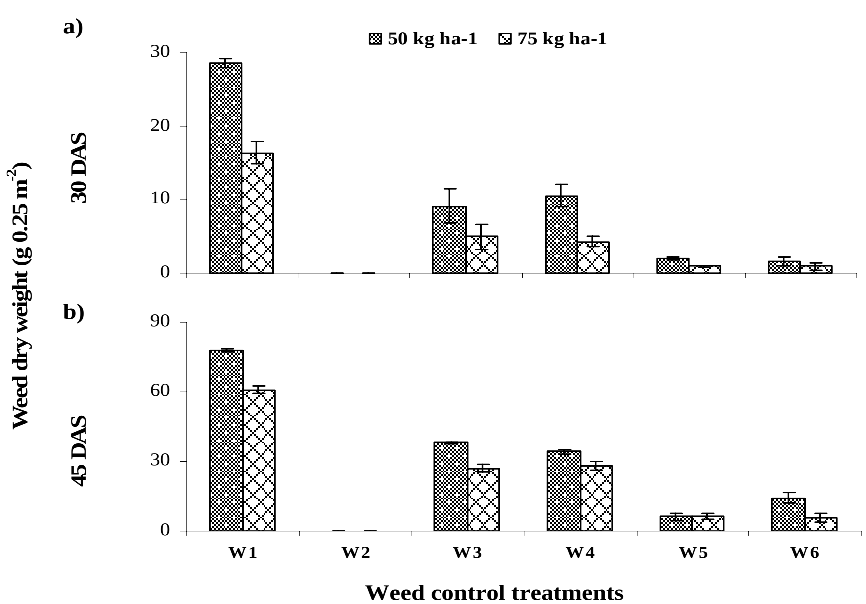


Fig. 3: Influence of herbicide tank mixtures on leaf area index in dry seeded fine rice sown at different density. Vertical bars above mean denote standard error of three replicates

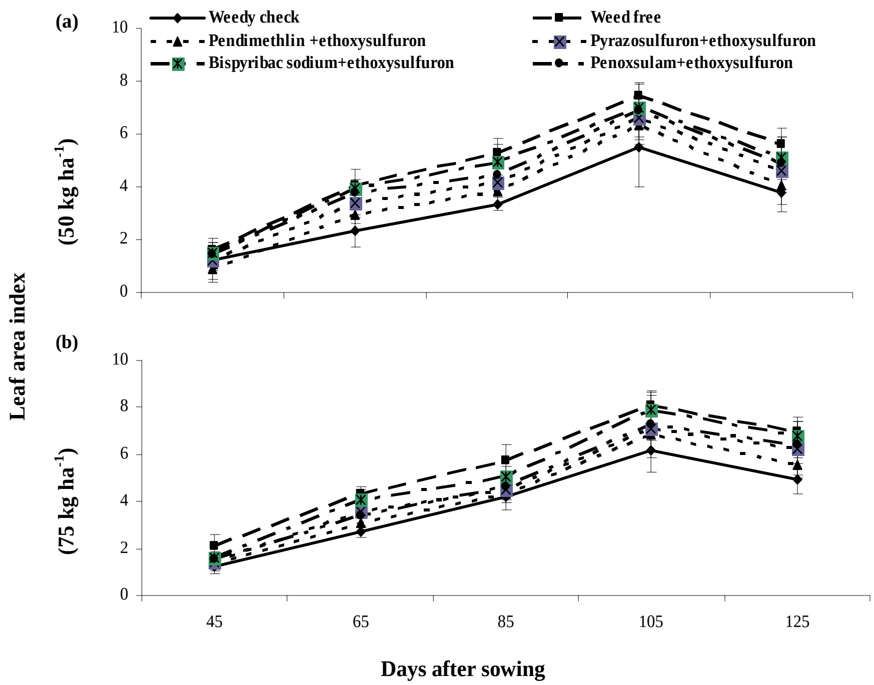
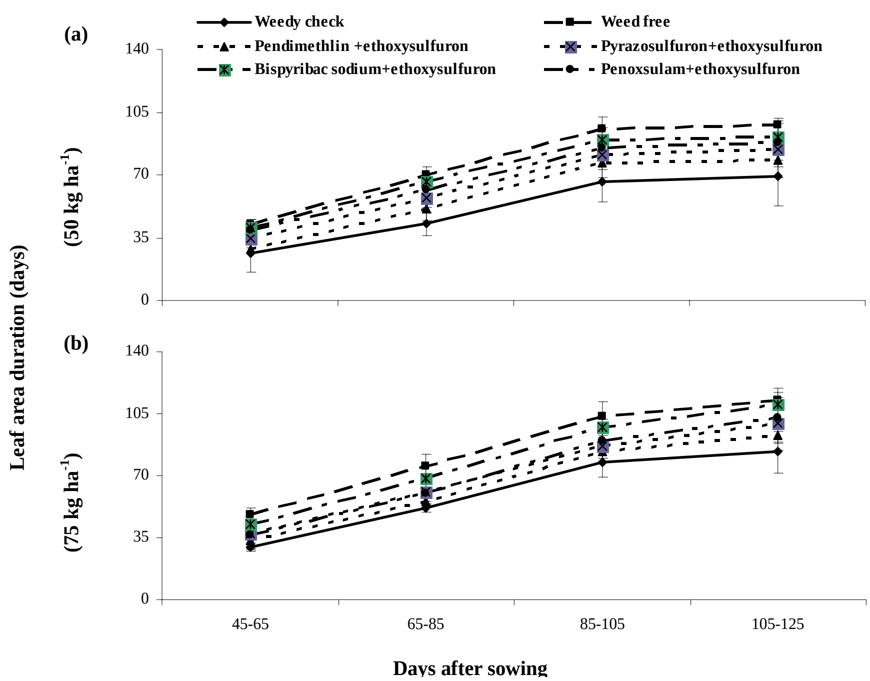


Fig. 4: Influence of herbicide tank mixtures on leaf area duration in dry seeded fine rice sown at different density. Vertical bars above mean denote standard error of three replicates.



respectively. A seeding density of 75 kg ha^{-1} accounted for 43 and 22% less weed biomass than 50 kg ha^{-1} in weedy check at 30 and 45 DAS. Tank mixture of bispyribac sodium and penoxsulam with ethoxysulfuron appeared superior as these scored >90% inhibition in weed biomass at 30 and 45 DAS. Rest of the tested herbicide combinations suppressed weed dry biomass to a tune slightly greater than 65 and 50% at 30 and 45 DAS, respectively.

The efficacy of herbicide tank mixture was enhanced at higher seeding density presumably due to lower weed count and weed biomass than lower seeding density as observed for weedy check plots (Fig. 1 & 2).

Fig. 5: Influence of herbicide tank mixtures on dry matter accumulation in dry seeded fine rice sown at different density. Vertical bars above mean denote standard error of three replicates

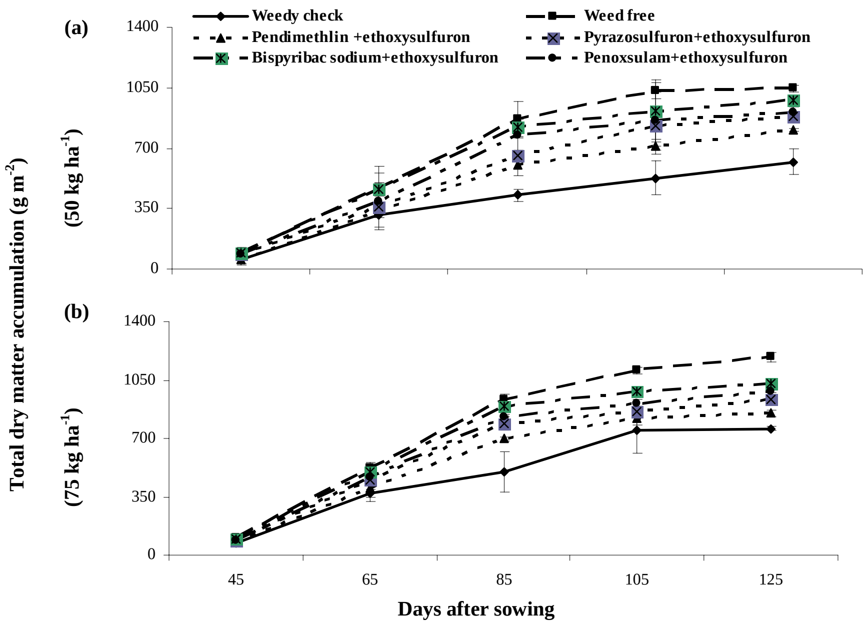
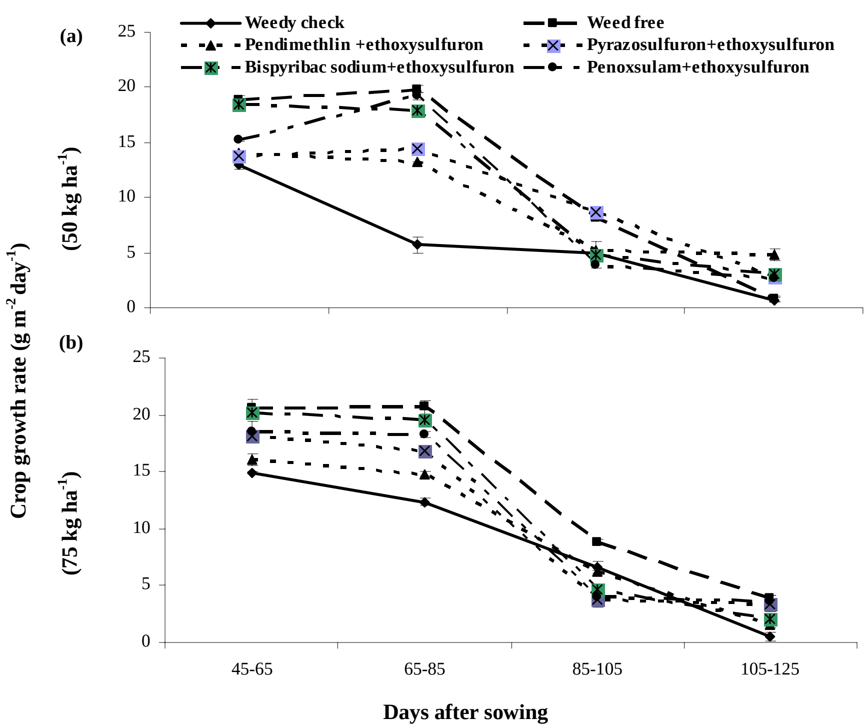


Fig. 6: Influence of herbicide tank mixtures on crop growth rate of dry seeded fine rice sown at different density. Vertical bars above mean denote standard error of three replicates



Cultural practices can influence and regulate the competitive balance between crops and weeds. Seeding rate has been reported to modify the relative importance of inter and intra-specific competition through its influence on resource acquisition and use (Khan *et al.,* 2009). Increased crop density in combination with other weed control measure can be crucial, while dealing with a crop that is a poor weed competitor (Mohler, 2001) as is the case with rice

(Saito, 2010). Effectiveness of a cultural practice in imparting the crop a competitive advantage over weeds can be judged by weed biomass produced under weedy condition. Seeding density of a crop governs canopy coverage, radiation interception, leaf area index and dry matter accumulation that determine its weed suppressive ability expressed as weed biomass (Anwar *et al.*, 2011). The competitive edge determines the level and efficacy of weed control that can be achieved with herbicides (Khaliq & Matloob, 2011). Weeds in plots seeded at 50 kg ha^{-1} had higher survival and growth as indicated by higher weed biomass (Fig. 2) resulting in more competitive weed community (Phuong *et al.*, 2005). Anwar *et al.* (2011) reported that lowered seeding density might provide congenial environment for weed growth in DSR. Reduced weed growth at higher seed rate can be attributed to rapid canopy closure by rice plants resulting in higher leaf area index leading to more light interception (Guillermo *et al.*, 2009) that imparts the crop a competitive edge. The results of present study corroborate those of Phuong *et al.* (2005), Mahajan *et al.* (2010) and Anwar *et al.* (2011) who demonstrated that an inverse relation exists between seeding density and weed growth.

Rice growth and development: Different weed control treatments depicted a positive bearing on rice allometry. Leaf area index was significantly improved by various weed control treatments (Fig. 3) and temporal increase in leaf area index was observed with maximum values achieved at 105 DAS, which declined thereafter. Nonetheless, more leaf area index was noticed at higher seeding density (75 kg ha^{-1}) for all weed control treatments. Highest leaf area indices were associated with weed free treatment and tank mixture of bispyribac sodium+ethoxysulfuron. Leaf area duration also showed same response (Fig. 4). Dry matter accumulation

Fig. 7: Effect of seeding densities and herbicide tank mixture on yield and its components in dry seeded fine rice. Vertical bars above mean denote standard error of three replicates. LSD for interaction is (a) 17.580, weed control treatments (b) 10.39 (c) 2.88 and interaction (d) 0.169, where applicable

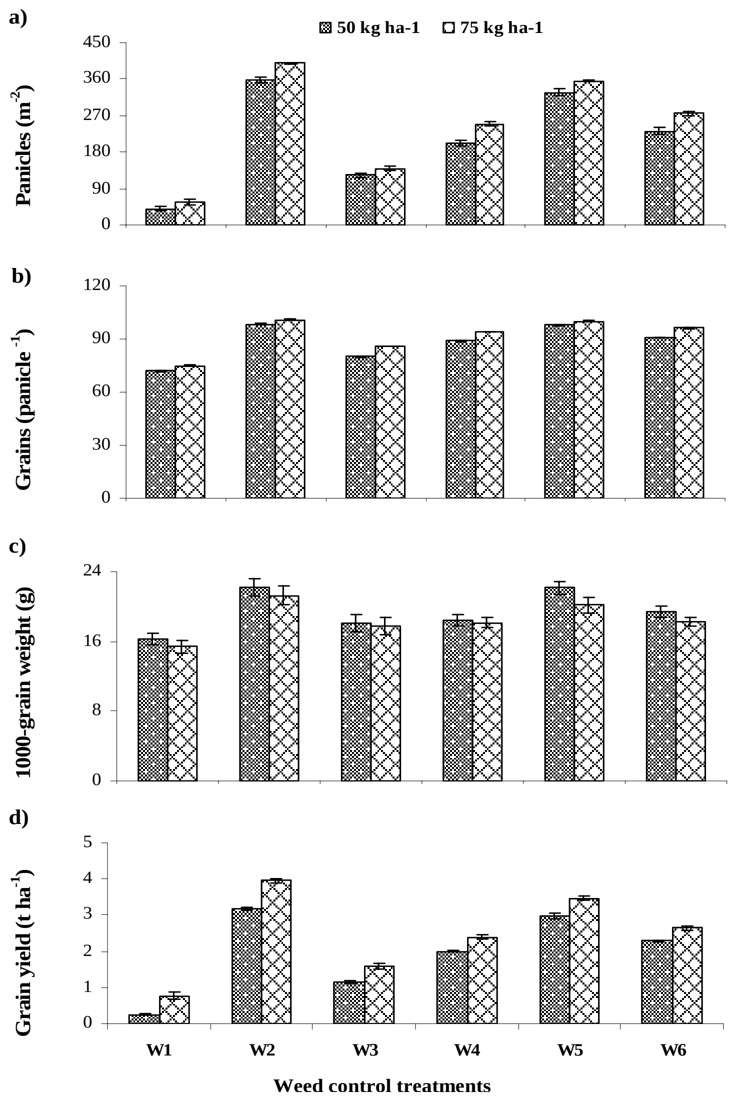


Fig. 8: Relationship of grain yield to weed density at seeding density of (a) 50 kg ha^{-1} (b) 75 kg ha^{-1} and weed dry weight (c) 50 kg ha^{-1} (d) 75 kg ha^{-1}

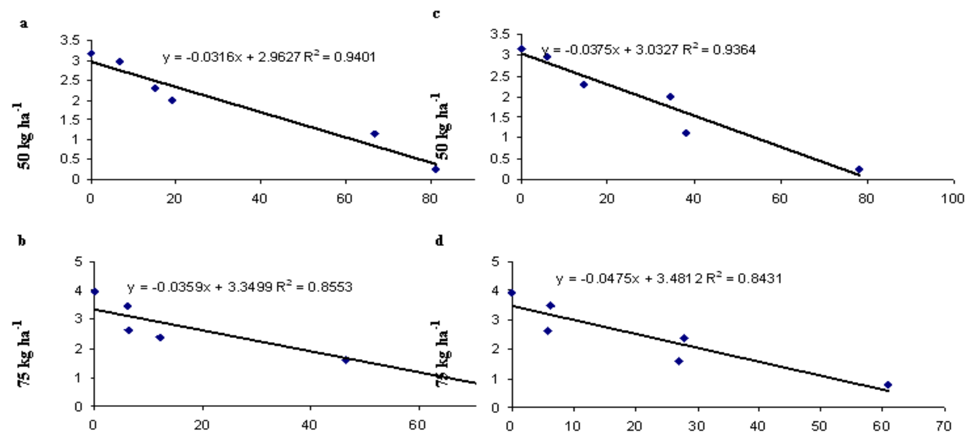
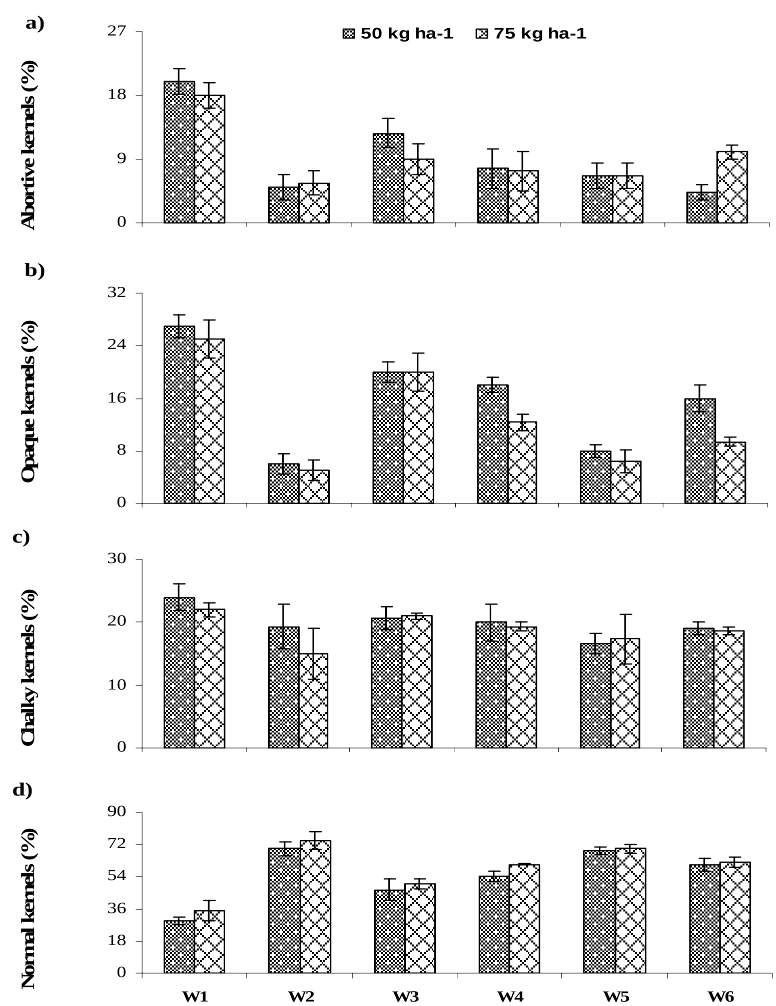
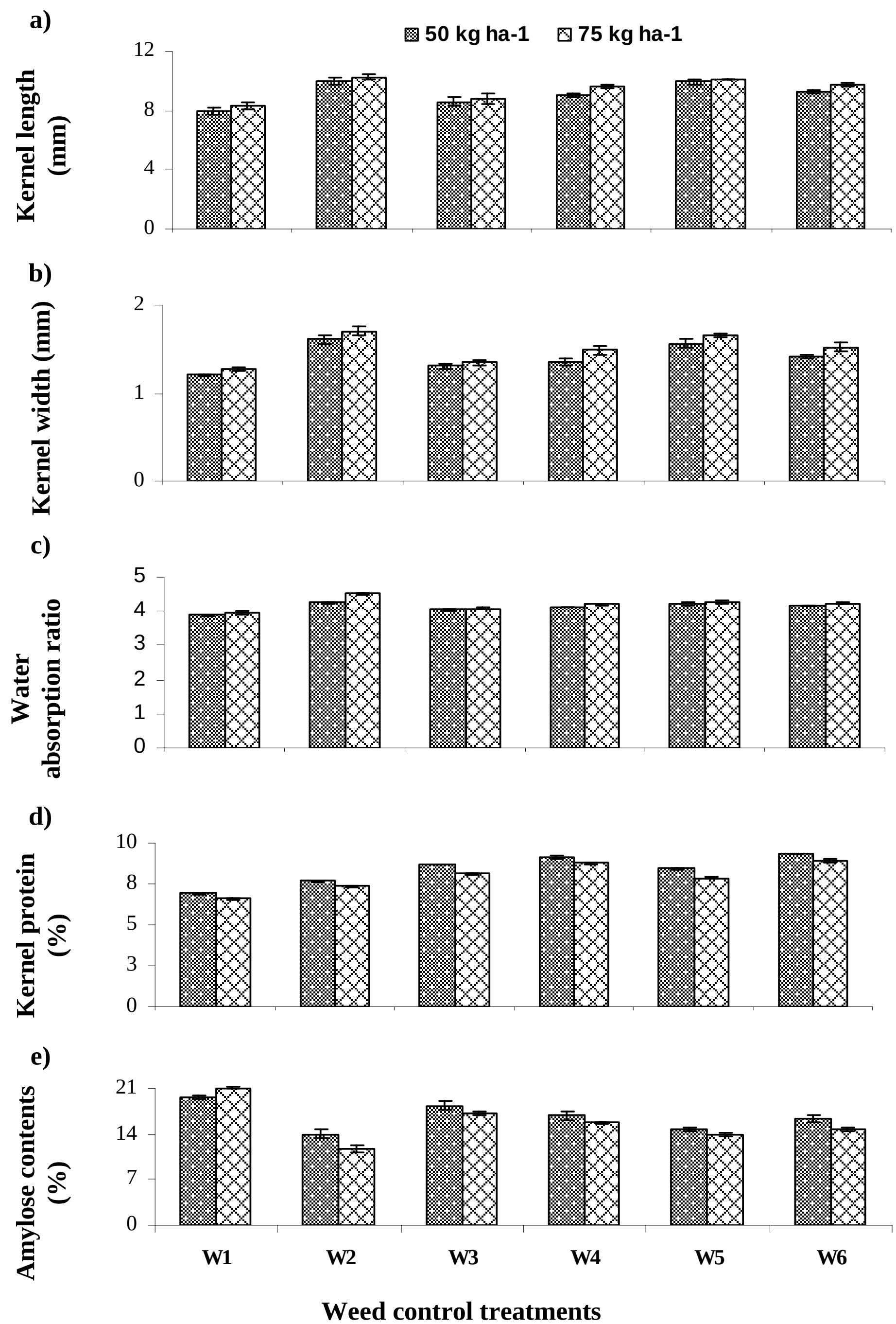


Fig. 9: Interactive effect of seeding densities and herbicide tank mixture on kernel quality attributes in dry seeded fine rice. Vertical bars above mean denote standard error of three replicates. LSD for interaction is (a) 7.180, (b) 5.237 (c) 6.881 and (d) 11.087



was highest in weed free and bispyribac sodium + ethoxysulfuron treated plots seeded at 75 kg ha^{-1}. Higher seeding density outperformed the lower one (Fig. 5) suggesting better crop growth even in the absence of any weed control measure. An insight into patterns of crop growth rate (Fig. 6) revealed that various weed control treatments improved crop growth rate over weedy check that varied as a function of seeding densities. Crop growth rate achieved a plateau at 65-85 DAS and showed a sharp decline afterwards presumably due to end of peak vegetative growth (panicle initiation) and phase transition into reproductive (heading) stage. The observed improvements

Fig. 10: Effect of herbicide tank mixture on kernel quality attributes in dry seeded fine rice sown at different densities. Vertical bars above mean denote standard error of three replicates. LSD for weed control treatments is (a) 0.599, (b) 0.096, (c) 1.278 (d) 1.070 and (e) 2.600



in these growth attributes over weedy check suggest the effectiveness of various weed control treatments in suppressing weed growth that ultimately lessened the weed-crop competition for any of the growth factors. Later on, weeds may be suppressed by early and dense canopy closure. Better resource acquisition and utilization might have contributed to prompt growth and more biomass accumulation by rice plants. Higher leaf area index and duration particularly early in the growing season led to more interception of radiation over a longer period of time that was explained by higher dry matter accumulation in such treatments. Improvement in rice growth attributes under the influence of effective weed control measures is in line with Anwar *et al.* (2011).

Rice yield and yield components: Data regarding rice yield and related traits (Fig. 7) indicated a positive influence of different weed control treatments. The obvious differences due to seeding density were noticed for some weed control treatments for number of productive tillers and grain yield. Nonetheless, grains per panicle and 1000-grain weight remained almost unaffected by seeding densities yet 1000-grain weight was less in 75 kg ha^{-1} possibly due to dilution effect (Mahajan *et al.*, 2010). However, the effect of weed control treatments was significant ($P \leq 0.05$) for these two attributes. After weed free treatment, the tank mixture of bispyribac sodium+ethoxysulfuron came up with higher grain yield. The regression analyses (Fig. 8) revealed that grain yield was negatively associated with weed density and biomass and 93% and 83% variation in yield was recorded owing to weed density and dry biomass of plots seeded at 50 and 75 kg ha^{-1}, respectively. The uncontrolled weed growth accounted for 92 and 80% yield loss at seeding density of 50 and 75 kg ha^{-1}, respectively. This reduction in yield loss at higher seeding density might be due to 66% more grain yield than 50 kg ha^{-1} under weedy conditions. Significant improvement in rice yield and reduction in yield losses caused by weeds owing to seeding densities have been reported by Phuong *et al.* (2005) and Anwar *et al.* (2011).

Kernel quality attributes: Kernel quality was significantly improved under different weed control treatments (Fig. 9 & 10). Uncontrolled weed spread (weedy check plots) enhanced abortive, chalky and opaque kernels with only <40% kernels being normal. Nonetheless, a reverse trend for these traits was observed where weeds were controlled (Fig. 9). Tank mixture of bispyribac sodium+ethoxysulfuron ranked second best treatment only after weed free plots regarding normal kernel percentage. Different weed control treatments also improved kernel dimensions significantly over weedy check, although the effect of seeding densities was non-significant (Fig. 10). Tank mixture of bispyribac sodium+ethoxysulfuron produced as good quality kernels as were harvested from weed free plots. Un-managed weeds also reduced kernel-protein content that was significantly improved by weed control treatments (Fig. 10). Maximum protein contents were noted for tank mixture of penoxsulam + ethoxysulfuron. Significantly lower amylose contents and higher water absorption ratios over weedy check were recorded for all weed control treatments (Fig. 10).

Improved kernel length in present studies indicated greater source capacity to produce photo-assimilates that were translocated and partitioned into sink. Increase in kernel quality attributes may be an out come of better production environment that imparted better nutrient and water uptake under weed control treatments with improved fertilization and reduced abortive kernels (Khaliq *et al.*, 2011). Irshad *et al.* (2008) reported that reduced weed-crop competition facilitates continuous translocation of carbohydrates to panicles. The improved kernel protein contents may have resulted due to greater fraction of available nitrogen to rice plants in the absence of weeds. The lower protein contents in weed free plots might be due to dilution effect (Mahajan *et al.*, 2010).

In crux, early post emergence application of bispyribac sodium + ethoxysulfuron tank mixture for effective weed control in DSR to secure quantity and quality of produce. The use of higher seeding density may be effective where previous history reveals higher weed infestation in the field.

REFERENCES

Ahmed, G.J.U. and M.K.A. Bhuiyan, 2010. Performance of weed management practices for different establishment methods of rice (*Oryza sativa* L.) in dry season. *Pakistan J. Weed Sci. Res*., 16: 393–402

Alsaadawi, I.S., A. Khaliq, A.A. Al-Temimi and A. Matloob, 2011 Integration of sunflower (*Helianthus annuus* L.) residues with a pre-plant herbicide enhances weed suppression in broad bean (*Vicia faba* L.). *Planta Daninha*, 29: 849–859

Anwar, P., A.S. Juraimi, A. Puteh, A. Selamat, A. Man and A. Hakim, 2011. Seeding method and rate influence on weed suppression in aerobic rice. *African J. Biotechnol.*, 10: 15259–15270

AOAC, 1990. *Official Methods of Analysis*: *Association of Official Analytical Chemists*, 15th edition. Arlington, Virginia, USA

Azmi, M., M.Z. Abdullah, B. Mislamah and B.B. Baki, 2000. Management of weedy rice (*Oryza sativa* L.): the Malaysian experience. *In:* Baki, B.B., D.V. Chin and M. Mortimer (eds.), '*Wild and Weedy Rice in Rice Ecosystems in Asia-a Review*', pp: 91–96. International Rice Research Institute, Los Baños, Philippines

Chauhan, B.S., V.P. Singh, A. Kumar and D.E. Johnson, 2011. Relations of rice seeding rates to crop and weed growth in aerobic rice. *Field Crops Res.,* 121: 105–115

Damalas, C.A., 2004. Herbicide tank mixture: commen interactions, *Int. J. Agric. Biol.*, 6: 209–212

Freed, R.D. and D.E. Scott, 1986. *MSTATC.* Crop and Soil Science Department, Michigan State University, Michigan, USA

Gibson, K.D., J.E. Hill, T.C. Foin, B.P. Caton and A.J. Fischer, 2001. Water -seeded rice cultivars differ in ability to interfere with water grass. *Agron. J*., 93: 326–332

Guillermo D. Arce, Palle Pedersen and Robert G. Hartzler, 2009. Soybean seeding rate effects on weed management. *Weed Technol*., 23: 17–22

Hunt, R., 1978. *Plant Growth Analysis*, pp: 26–38. Edward Arnold, UK

Irshad, A., Z.A. Cheema and M. Farooq, 2008. Influence of nitrogen on interference of barnyard grass (*Echinochloa crus-galli* L.) with transplanted rice. *Archives Agron. Soil Sci*., 54: 493–505

Juliano, B.O., 1971. A simplified assay for milled rice amylose. *Cer. Sci. Today*, 16: 334–338

Juliano, B.O., L.U. Onate and A.M. Mundo, 1965. Relation of starch compaction, protein content and gelatinization temperatures to cooking and eating quality of milled rice. *Food Technol*., 19: 1006–1101

Khaliq, A. and A. Matloob., 2011. Weed crop competition period in three fine rice cultivars under direct seeded rice culture. *Pakistan J. Weed Sci. Res.,* 17: 229–243

Khaliq, A., Y. Riaz and A. Matloob, 2011. Bio-economic assessment of chemical and non-chemical weed management strategies in dry seeded fine rice (*Oryza sativa* L.). *J. Plant Breed. Crop Sci*., 3: 302–310

Khan, M.A., M. Tariq, A. Amin, G. Hassan, M.A. Khan and H.U. Khan, 2009. Possibility of weed suppression by seeding rate and cultivars of wheat. *Pakistan J. Weed Sci. Res*., 15: 209–217

Mahajan, G., M.S. Gill and K. Singh, 2010. Optimizing seed rates to suppress weeds and to increase yield in aerobic-direct seeded rice in Northwestern Indo- Gangetic Plains. *J. New Seeds*, 11: 225–238

Maity, S.K. and P.K. Mukherjee, 2008. Integrated weed management in dry direct-seeded rainy season rice (*Oryza sativa*). *Indian J. Agron*., 53: 116–120

Mohler, L.C., 2001. Enhancing the competitive ability of crops. *In*: Liebman, M., C.M. Mohler and C.P. Staver (eds.), *Ecological Management of Agricultural Weeds*, pp: 270–280. Cambridge University Press, UK

Phuong, L.T., M. Denich, P.L.G. Vlek and V. Balasubramanian, 2005. Suppressing weeds in direct-seeded lowland rice: effects of methods and rates of seeding. *J. Agron. Crop Sci*., 191: 185–194

Rao, A.N., D.E. Jhonson, B. Sivaprasad, J.K. Ladha and A.M. Mortimer, 2007. Weed management in direct seeded rice. *Adv. Agron*., 93: 153–255

Saito, K., 2010. Weed pressure level and the correlation between weed competitiveness and rice yield without weed competition: An analysis of empirical data. *Field Crops Res*., 117: 1–8

Shrestha, A., B.D. Hanson, M.W. Fidelibus and M. Alcorta, 2010. Growth, phenology, and intraspecific competition between glyphosate-resistant and glyphosate-susceptible horseweeds (*Conyza canadensis*) in the San Joaquin valley of California. *Weed Sci*., 58: 147–153

Singh, S., L. Bhushan, J.K. Ladha, R.K., Gupta, A.N. Rao and B. Sivaprasad, 2006. Weed management in dry-seeded rice (*Oryza sativa*) cultivated on furrow irrigated raised bed planting system. *Crop Prot*., 25: 487–495.

Steel, R.G.D., J.H. Torrie and D. Dickey, 1997. *Principles and Procedures of Statistics: A Biometrical Approach*, 3rd edition, pp: 172–177. McGraw Hill Book Co. Inc., New York, USA

Tuong, T.P., P.P. Pablico, M. Yamauchi, R. Confesor and K. Moody, 2000. Increasing water productivity and weed suppression of wet seeded rice: effect of water management and rice genotypes. *J. Exp. Agric*., 36: 1–19

Watson, D.J., 1947. Comparative physiological studies on the growth of field crops: II. The effect of varying nutrient supply on net assimilation rate and leaf area. *Ann. Bot*., 11: 375–407

Wrubel, R.P. and Z. Gressel, 1994. Are herbicide mixtures useful for delaying the rapid evaluation of resistance? A case study. *Weed Technol*., 8: 635–648

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

(Received 09 February 2012; Accepted 05 March 2012)