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ORIGINAL ARTICLE

Weed interference period and seed rate influence on wheat productivity

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Wheat-weed competition depends on many factors including weed interference period and competitiveness of wheat which is mostly governed by seeding density of the crop. Increasing weed interference period decreases grain yield and vice versa. Seeding density is a management tool for minimizing weeding infestation and maximizing grain yield through maximum utilization of resources by the crop. Therefore, present study was undertaken to evaluate the effect of different weed interference periods and seed rates on the productivity of wheat cv. BARI Gom 26. The study was conducted during the *Rabi* season 2015-2016 at the Agronomy Field Laboratory, Bangladesh Agricultural University, Mymensingh. Treatments included five seed rates of wheat namely, 100, 120, 140, 160 and 180 kg ha^{-1} and five weed interference periods namely, season-long-weed-free, weed-free up to 20 DAS, weed-free up to 40 DAS, weed-free up to 60 DAS and season-long-weedy. The field experiment was laid out in a randomized complete block design with three replications. The results showed that weed dry weight decreased gradually with the increase in wheat seed rate. The highest (101.7 g m^{-2}) and lowest (92.19 g m^{-2}) weed dry weights were recorded with 100 and 180 kg seeds ha^{-1}, respectively. Weed dry weight also increased with increasing weed interference period. Season-long weed free resulted in the maximum weed dry weight (149.3 g m^{-2}), followed by weed-free up to 20 DAS (130.6 g m^{-2}), weed-free up to 40 DAS (121.3 g m^{-2}) and weed-free up to 60 DAS (92.5 g m^{-2}). Wheat grain yield decreased with increased weed interference period. As expected, weed-free treatment resulted in the maximum grain yield (2.78 t ha^{-1}) and the lowest one was found in weedy treatment (1.35 t ha^{-1}). The seed rate of 140 kg ha^{-1} produced the highest grain yield (2.81 t ha^{-1}). The seed rate of 160 kg ha^{-1} resulted in the lowest grain yield (2.04 t ha^{-1}). The highest grain yield (3.40 t ha^{-1}) resulted from the interaction of 140 kg seed ha^{-1} with weedy treatment which was statistically identical to the obtained from 140 kg seed ha^{-1} with weed free up to 40 DAS and 60 DAS. The lowest grain yield (1.76 t ha^{-1}) resulted from the interaction of 180 kg seed ha^{-1} with weedy treatment which was statistically identical to 180 kg seed ha^{-1} with weed free up to 20 DAS. Although weed-free regime produced the maximum yield but it is not economic to maintain weed-free condition throughout. Therefore, it can be concluded that BARI Gom 26 should be cultivated with 140 kg seeds ha^{-1} keeping weed free up to 40 DAS for obtaining higher yield.

INTRODUCTION

Wheat (*Triticum aestivum L.*) is a major cereal crop of the world and it ranks second in Bangladesh following rice. Protein content is much higher in wheat than in rice. Wheat grain contains 12% protein, 1.72% fat, 69.60% carbohydrate and 27.20% mineral matter (BARI 2001). Wheat germ is available as a separate entity because it is an important source of vitamin E. Wheat germ has only one half the glutamine and proline of flour, but the levels of alanine, arginine, asparagines, glycine, lysine and threonine are double (Cornell 2003). With the introduction of high yielding varieties in Bangladesh, the area and production of wheat have been increased substantially. The annual production of wheat in 2014-15 was 13.48 lakh tons obtained from 4.37 lakh hectares of lands (BBS 2015). Still the yield of wheat (3.5 t ha^{-1}) is not up to the satisfactory level rather it is very low compared to that of leading wheat growing countries like Holland, United Kingdom, France and Norway where the average yield of is 7.8, 7.7, 6.2 and 4.4 t ha^{-1}, respectively (FAO 2005). Wheat is grown in *Rabi* season in Bangladesh during dry winter months from November to March. In recent time, wheat have gained much popularity among the farmers of Bangladesh due to its low irrigation requirement and lower cost of production than that of *Boro* rice

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(*winter* rice) grown in the same season (BBS 2015). But higher weed infestation in wheat (because of absence of standing water layer) compared with *Boro* rice is a limiting factor for wheat cultivation and therefore proper weed management is very crucial for this crop.

Many scientists from South Asia reported weed as the major constraint to wheat cultivation. Hossain et al. (2010) noted that wheat fields are normally infested by 18 to 22 weed species belonging to 11-12 families. Among them *Oxalis* spp. (Oxalidaceae) was most important comprising 27-33% of the total weed population. Weed inflicted relative yield loss in wheat is highly variable, and may range from 17 to 51% (Hossain et al. 2010). Weed infestation may reduce yield by 45.5 to 63.9% (Reddy and Reddi 2002) in wheat while reduced up to 92% by competition from ryegrass (Dickson et al. 2011), 17 to 62% due to wild oat (Marwat et al. 2011). Moreover, because of weak root system wheat is not so competitive against weed. Crop competitiveness can be measured in two ways: as weed suppression or as the ability of crop to tolerate weed presence and maintain grain yield (Goldberd 1990). These two attributes are often but not necessary correlated (Lemerly et al. 2001). The concept of weed as unwanted plant was born when man started to grow plants deliberately for food and other purposes. Crop production is often called a fight against weeds. The edaphic and climatic conditions of Bangladesh favour the growth of weed. High competitive ability of weeds exerts a serious negative effect on crop production causing significant losses in crop yield.

The effect of weed interference can be measured by observing crop growth reduction and decreased yield. However, competitive relationship between wheat crops and weeds also depends on other factors, such as weather, plant populations, diversity of weed species and crop management practices. Therefore, pressure of undesirable weed species, create a huge competition for resources. In addition, competition may be greater when both species (crop and weeds) are morphologically and physiologically similar because of their similar requirements.

At the beginning of the growth stage, crops and weeds can co-exist for a certain period without incurring reduction in crop growth. This phase is called the period before interference (PBI), wherein the environment can provide growth of resources required by the crops and weeds. The other competition period starts at emergence and determines the length of time a crop that should grow freely in the presence of weeds so that the crop yield is not affected. It is called total period of interference prevention (TPIP). After that time, the existing weed will not compete in order to reduce weed yield because the crop can suppress the competing weed plants. Finally there is a third period, referred to as critical period of interference prevention (CPP), which is the phase in which the weed control practices should effectively be adopted in order to prevent losses in productivity (Evans et al. 2003).

Period of weed competition against wheat crops can assist in the choice of the type of management and / or control to be used. Knowledge of these periods may reduce the number of herbicide applications, improve control effectiveness and reduce possible environmental contamination and emergence of herbicide resistant weeds. However the degree of interference is strongly influenced by the characteristics of environment, the weed and the cultivated species because determining periods of interference depends on these particular conditions.

Wheat is primarily grown for its grain which is consumed as human food. Seeding rate is one of the important factors for deciding grain yield. Seeding density is an efficient management tool for minimizing weeding infestation and maximizing grain yield by increasing the interception of solar radiation within the crop canopy (Elkoca et al. 2005). Suitable plant density increases economic yield and prevents the growth of weeds (Gozubenti et al. 2004). Crop density is more important for controlling weed growth than for obtaining normal grain yield. Grain yield decreases as the weed interference period increases. Decreased grain yield caused by increased length of the weed interference period is accompanied by concurrent reduction in yield components.

Present research was therefore undertaken to evaluate the effect of weed interference period and seed rate on wheat productivity, and to study how wheat seeding density interacts with weed interference period in determining growth and yield of wheat.

MATERIALS AND METHODS

Experimental Site

The experiment was carried out at the Agronomy Field Laboratory of Bangladesh Agricultural University, Mymensingh during the period from November 2015 to March 2016. The experimental site is located at 24°75' N latitude and 90°50' E longitude at an elevation of 18 m above the mean sea level. The experimental site belongs to non-calcareous dark grey floodplain soil under the Old Brahmaputra Floodplain, Agro-ecological Zone 9 (FAO and UNDP 1988). Experimental field was a medium high land with silty clay loam soil texture having pH value 6.5. Climate of the site during *Rabi* season is characterized by moderately low temperature, scanty rainfall and plenty of sunshine. The weather information regarding temperature, rainfall, relative humidity and sunshine hours prevailing at the experimental site during the period of the study have been presenting in Table 1.

Table 1. Distribution of monthly temperature, relative humidity, sunshine hour and rainfall of the experimental site during the crop growth period

Month and year	*Air temperature (°C)			**	*	**
	Maximum	Minimum	Average	Rainfall (mm)	Relative humidity (%)	Sunshine (hrs.)
November 2015	30.00	18.10	23.40	4.30	82.20	200.00
December 2015	25.2	13.30	19.3	0.00	83.40	117.90
January 2016	23.91	12.02	17.99	0.59	84.35	126.79
February 2016	27.84	17.4	23.18	0.30	83.00	140.07
March 2016	31.14	20.16	25.57	3.38	73.19	149.73

*Monthly average, **Monthly total

Experimental Treatments

Experimental factors included in the study were five weed interference periods such as weed free (weeding throughout the season), weed free up to 20 Days after Sowing (DAS), weed free up to 40 DAS, weed free up to 60 DAS and weedy (no weeding throughout the season) and five seed rates such as 100, 120, 140, 160 and 180 kg ha^{-1}. The experiment was laid out in a randomized complete block design with three replications. The size of the each plot was 4.0 m × 2.5 m. The distance maintained between individual plots was 0.5 m and between blocks was 1.0 m.

Crop Husbandry

The experimental land was opened with a tractor drawn disc plough 15 days before sowing. The land was further ploughed and cross ploughed four times with country plough followed by laddering for breaking clods and leveling the land. The corners and levels of land were trimmed by spade, visible large clods were broken into small pieces by wooden hammer. All weeds and stubbles were removed from the land. Seeds were sown in 20 cm apart lines on 20 November 2015 as per treatment specifications. Sowing depth was maintained about 4 cm and seeds were covered with soil immediately after sowing. The plots were fertilized with urea, triple super phosphate (TSP), muriate of potash (MoP) and gypsum at the rate of 220, 180, 50 and 120 kg ha^{-1}, respectively. The whole amount of TSP, MoP and gypsum and one- third of urea were applied just before final land preparation. The rest amount of urea was applied in two equal splits at 20 and 40 DAS. Weeding operation was done manually as per experimental treatments. The crop was irrigated once at the crown root initiation stage at 20 DAS following flood irrigation. No drainage operation was required. As there were no remarkable infestation of disease and insect, hence no plant protection measure was taken.

Data Collection

Crop was harvested at maturity on 18 March 2016. Weed species grown in the experimental field were identified and weed density and dry weight were measured at harvest. Relative density (RD) of different weed groups (grass, sedge and broadleaf) was calculated by the following formula: RD (%) = (Density of a given weed group/ Total weed density) × 100. Five randomly selected hills from each plot were harvested and data on plant characters and yield attributes were taken accordingly. Wheat grain and straw yield were recorded after harvesting the whole plot. The grain yield was adjusted to moisture content of 14%.

Statistical Analysis

Analysis of variance was done with the help of computer package MSTAT-C. The mean differences among the treatments were performed by Duncan's Multiple Range Test (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Weed Composition

In total 8 weed species belonging to 6 families infested the experimental crop fields of which 3 were grasses, 4 were broadleaves and 1 was sedge. Among these species, Anguli ghash, Durba and Chapra belonged to Gramineae, Foska begun belonged to Solanaceae, Bishkatali belonged to Polygonaceae, Mutha belonged to Cyperaceae, Keshuti belonged to Compositae and Sada lazzaboti belonged to Leguminisae. Common name, scientific name, type and family of these weeds have been presented in the Table 2.

Table 2. Common name, scientific name, type, family and density of different weed species as to recorded in weedy plots

Sl. No.	Common name	Scientific name	Type	Family	Density (no. m^{-2})
1	Anguli ghash	*Digitania sanguinalis*	Grass	Gramineae	85.33
2	Foska begun	*Physalis heterophylla*	Broad leaf	Solanaceae	66.66
3	Durba	*Cynodon dactylon*	Grass	Gramineae	32
4	Chapra	*Eleusina indica*	Grass	Gramineae	22.66
5	Bishkatali	*Polygonum hydropiper*	Broad leaf	Polygonaceae	5.33
6	Mutha	*Cyperus rotundus*	Sedge	Cyperaceae	4.00
7	Keshuti	*Eclipta alba*	Broad leaf	Compositae	2.66
8	Sada lazzaboti	*Mimosa pudica*	Broad leaf	Leguminosae	2.66

Weed Density

The most dominated weed species based on density in descending order were Anguli ghash > Foska begun > Durba > Chapra > Bishkatali > Mutha > Keshuti > Sada laaboti (Table 2). Grasses were dominated over broadleaves and sedge. At first the relative density of each weed species was calculated. Then they were classified among different types i.e. grass, broadleaf and sedge and total values were calculated. Among different groups grasses contributed 63.25% to weed density followed by broadleaves (34.94%) and sedge (1.81%) (Figure 1).

Effect of Weeding Regimes and Seed Rate on Weed Dry Weight

Weed dry weight was significantly affected by weeding regime and seed rate (Table 3). The highest weed dry weight (149.30 g m^{-2}) was obtained from weedy treatment and the lowest value (92.50 g m^{-2}) was obtained from weed free up to 20 DAS (Table 3). The highest weed dry weight (104.70 g m^{-2}) was observed at the seed rate of 140 kg ha^{-1} and the lowest value (92.19 g m^{-2}) was observed from the seed rate of 180 kg ha^{-1} (Table 3). There are several reasons why there was a lower density of weed infestation in areas that had a higher seed rate. Guillermo et al. (2009) showed that areas with higher plant densities might have a competitive advantage over weeds due to fast canopy development. The interaction effect of weeding regime and seed rate on weed dry weight was found significant (Table 3).

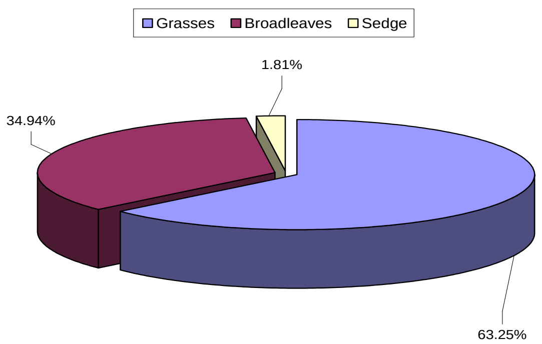

Figure 1. Relative contribution (in terms of density) of different weed groups

This result revealed that higher seed rate with specific weeding regime treatment reduced the weed dry weight than lower seed rate with that specific weeding regime. The highest weed dry weight (169.20 g m^{-2}) was found due to the interaction of seed rate at 100 kg ha^{-1} with weedy treatment which was statistically identical to the interaction of 120 kg seed ha^{-1} with weedy treatment. The lowest weed dry weight (85.55 g m^{-2}) was obtained from the interaction of 100 kg seed ha^{-1} with weed free up to 20 DAS (Table 3).

Table 3. Effect of weeding regime, seed rate and their interaction on weed dry weight

Treatment	Weed dry weight (g m^{-2})
Weeding regime	
Weed free (W_1)	0.00 e
Weed free upto 20 DAS (W_2)	92.50 d
Weed free upto 40 DAS (W_3)	121.30 c
Weed free upto 60 DAS (W_4)	130.60 b
Weedy (W_5)	149.30 a
Level of significance	**
CV (%)	7.26
Seed rate (kg ha^{-1})	
100 (S_1)	101.70 ab
120 (S_2)	98.88 b
140 (S_3)	104.70 a
160 (S_4)	96.37 bc
180 (S_5)	92.19 c
Level of significance	**
CV (%)	7.26
Seed rate × weeding regime	
S_1W_1	0.00 k
S_1W_2	85.55 j
S_1W_3	121.10 efg
S_1W_4	132.50 de
S_1W_5	169.20 a
S_2W_1	0.00 k
S_2W_2	89.09 j
S_2W_3	118.30 fg
S_2W_4	129.10 def
S_2W_5	157.90 ab
S_3W_1	0.00 k
S_3W_2	90.73 j
S_3W_3	132.90 de
S_3W_4	150.00 bc
S_3W_5	149.6 bc
S_4W_1	0.00 k
S_4W_2	104.40 hi
S_4W_3	121.20 efg
S_4W_4	126.00 efg
S_4W_5	130.20 def
S_5W_1	0.00 k
S_5W_2	92.73 ij
S_5W_3	112.90 gh
S_5W_4	115.60 gh
S_5W_5	139.70 cd
Level of significance	**
CV (%)	7.26

Mean values in a column having the same letters do not differ significantly as per DMRT. ** = Significant at 1% level of probability

Effect of Weeding Regime and Seed Rate on Plant Characters and Yield of Wheat

Plant height

Weeding regime had significant influence on plant height at 45 and 60 DAS, and at harvest but not at 15 and 30 DAS (Table 4). At 15 and 30 DAS, the tallest plant (14.40 and 29.01 cm, respectively) was observed from weed free up to 60 DAS and the lowest value (14.13 and 28.35 cm, respectively) was observed from weed free treatment. But at 45 DAS, the tallest plant (51.59 cm) was obtained from weed free up to 20 DAS and the shortest one (49.16 cm) was obtained from weedy treatment. At 60 DAS, the tallest plant (71.77 cm) was found from weed free up to 20 DAS and the shortest one (68.45 cm) was observed from weed free treatment. At harvest, the highest plant height (93.61 cm) was found from weed free up to 40 DAS and the lowest plant height (91.71 cm) was obtained from weedy treatment (Table 4). Weed competition was severe in no weeding condition and thus plant height of wheat was reduced. Bedry (2007) found that increasing weeding competition period increased plant height due to efficient weed control in wheat. Seed rate had significant influence on plant height at 15 and 30 days after sowing (DAS) but not at 45 and 60 DAS, and at harvest (Table 4). At 15 DAS, the tallest plant (14.68 cm) was found from 140 kg seed ha^{-1} and the shortest one (13.83 cm) was found from 100 kg seed ha^{-1}. At 30 DAS, the tallest plant (29.55 cm) was obtained from 140 kg seed ha^{-1} and the shortest one (27.94 cm) was obtained from 100 kg seed ha^{-1}. At 45 DAS, the highest value (51.47 cm) was found from 100 kg seed ha^{-1} and lowest value (49.28 cm) was found from 160 kg seed ha^{-1}. At 60 DAS, the highest plant (70.73 cm) was obtained from 180 kg seed ha^{-1} and the lowest value (69.33 cm) was found from 120 kg seed ha^{-1}. At harvest, the tallest plant (94.08 cm) was obtained from 160 kg seed ha^{-1} and the shortest plant (91.99 cm) was obtained from 180 kg seed ha^{-1}. At 45, 60 DAS and at harvest all the values are statistically identical (Table 4). The result showed that at different DAS, significantly highest plant height was achieved with lower seed rates due to minimum number of plants per unit area. Thickening plant density caused to increasing plant height because of inter-specific competition to more absorption of light (Rahim et al. 2012). The interaction effect of seed rate and weeding regime on plant height was significant at 15, 30, 45 and 60 DAS but not at harvest (Table 4). At 15 DAS, the tallest plant (15.13 cm) was observed from the interaction of 140 kg seed ha^{-1} with weed free up to 20 DAS. The shortest plant (13.13 cm) was obtained from the interaction of 100 kg seed ha^{-1} with weed free up to 40 DAS. At 30 DAS, the tallest plant (30.67 cm) was found due to the interaction of 180 kg seed ha^{-1} and weed free up to 40 DAS and the shortest plant (26.60 cm) was found from the interaction of 120 kg seed ha^{-1} and weed free up to 20 DAS. At 45 DAS, the tallest plant (54.33 cm) was found from the interaction of 100 kg seed ha^{-1} and weed free up to 20 DAS and the shortest plant (45.73 cm) was observed from the interaction of 120 kg seed ha^{-1} and weed free up to 60 DAS which was statistically identical to 160 kg seed ha^{-1} with weed free treatment. At 60 DAS, the tallest plant (73.87cm) was obtained from the interaction of 100 kg seed ha^{-1} and weed free treatment. The shortest plant (61.47 cm) was obtained from the interaction of 120 kg seed ha^{-1} and weed free up to 60 DAS (Table 4). The result indicates that the tallest plant could be obtained with weeding over no weeding.

Yield attributes

Weeding regime and seed rate had significant effect on number of effective tillers hill^{-1} (Table 5). The highest number of effective tillers hill^{-1} (3.40) was observed from weed free treatment which was statistically identical to weed free up to 20, 40, 60 DAS. The lowest number of effective tillers hill^{-1} (3.19) was obtained from weedy treatment (Table 5). It showed that number of effective tillers increased with increasing level of weeding from weedy to weed free treatment. Similar results were reported by Sultana et al. (2012) who observed that total number of effective tillers were affected by weed competition. Number of effective tillers hill^{-1} was not affected significantly due to seed rate (Table 5). The highest number of effective tillers hill^{-1} (3.39) was found at the seed rate of 180 kg ha^{-1} and the lowest number of effective tillers hill^{-1} (3.26) was observed from 140 kg seed ha^{-1} (Table 5). The results showed that the increasing number of effective tillers produced with increasing seed rate. Yoon et al. (1991) reported increased percentage of effective tillers with highest sowing rate which also led to increase grain yield. The interaction effect of seed rate and weeding regime on number of effective tillers hill^{-1} was statistically significant (Table 6). The highest number of effective tillers hil^{l-1} (3.70) was found due to the interaction of 120 kg seed ha^{-1} and weed free treatment which did not differ significantly with the interaction of 160 kg seed ha^{-1} and weed free up to 60 DAS, 180 kg seed ha^{-1} and weed free treatment. The lowest number of effective tillers hill^{-1} (3.00) was found due to the interaction of 120 kg seed ha^{-1} with weedy treatment that was statistically identical to 140 kg seed ha^{-1} with weed free, 160 kg seed ha^{-1} with weedy treatment (Table 6).

Table 4. Effect of weeding regime, seed rate and their interaction on plant height of wheat at different sampling dates

Treatment	Plant height (cm) at different days after sowing (DAS)				
	15	30	45	60	At harvest
Weeding regime					
Weed free (W_1)	14.13	28.35	49.51 bc	68.45 c	93.96 a
Weed free upto 20 DAS (W_2)	14.25	28.77	51.59 a	71.77 a	93.08 ab
Weed free upto 40 DAS (W_3)	14.17	28.76	51.41 ab	71.25 ab	93.61 a
Weed free upto 60 DAS (W_4)	14.40	29.01	50.29 abc	69.28 bc	92.79 ab
Weedy (W_5)	14.32	28.85	49.16 c	69.21 bc	91.71 b
Level of significance	ns	ns	*	**	*
CV (%)	3.45	4.55	4.98	4.09	2.08
Seed rate (kg ha^{-1})					
100 (S_1)	13.83 c	27.94 c	51.47	70.01	93.05
120 (S_2)	14.07 bc	28.36 bc	50.37	69.33	92.81
140 (S_3)	14.68 a	29.55 a	50.28	70.23	93.21
160 (S_4)	14.29 b	28.73 abc	49.28	69.67	94.08
180 (S_5)	14.41 ab	29.17 ab	50.57	70.73	91.99
Level of significance	**	**	ns	ns	ns
CV (%)	3.45	4.55	4.98	4.09	2.08
Seed rate × weeding regime					
S_1W_1	14.13 b-f	28.73 a-e	50.47 a-e	68.87 a-d	93.13
S_1W_2	14.27 a-f	28.87 a-e	54.33 a	73.87 a	93.80
S_1W_3	13.13 g	26.55 e	51.40 abc	68.40 a-d	93.73
S_1W_4	14.20 a-f	28.41 a-e	52.60 ab	73.13 ab	93.80
S_1W_5	13.40 fg	27.13 de	48.53 b-e	65.80 de	90.80
S_2W_1	14.60 a-e	29.33 a-d	50.40 a-e	69.87 a-d	94.13
S_2W_2	13.07 g	26.60 e	47.43 cde	69.80 a-d	93.33
S_2W_3	14.20 a-f	28.80 a-e	54.00 a	73.40 ab	93.67
S_2W_4	13.87 c-g	27.87 b-e	45.73 e	61.47 e	91.27
S_2W_5	14.60 a-e	29.20 a-d	54.27 a	72.13 abc	91.67
S_3W_1	14.47 a-e	28.87 a-e	50.67 a-d	68.40 a-d	93.67
S_3W_2	15.13 a	30.40 ab	52.60 ab	72.80 abc	95.13
S_3W_3	14.33 a-f	28.93 a-e	49.47 a-e	68.00 bcd	92.73
S_3W_4	14.60 a-e	29.33 a-d	50.07 a-e	72.13 abc	93.00
S_3W_5	14.87 ab	30.20 abc	48.60 b-e	69.80 a-d	91.53
S_4W_1	13.67 efg	27.13 de	45.73 e	67.87 bcd	95.60
S_4W_2	14.67 a-d	29.60 a-d	51.33 abc	70.33 a-d	91.47
S_4W_3	14.40 a-e	28.87 a-e	50.73 a-d	73.33 ab	95.53
S_4W_4	14.33 a-f	29.27 a-d	50.47 a-e	68.07 bcd	95.20
S_4W_5	14.40 a-e	28.80 a-e	48.13 b-e	68.73 a-d	92.60
S_5W_1	13.80 d-g	27.67 cde	50.27 a-e	67.27 cd	93.27
S_5W_2	14.13 b-f	28.40 a-e	52.27 abc	72.07 abc	91.67
S_5W_3	14.80 abc	30.67 a	51.47 abc	73.13 ab	92.40
S_5W_4	15.00 ab	30.20 abc	52.60 ab	71.60 abc	90.67
S_5W_5	14.33 a-f	28.91 a-e	46.27 de	69.60 a-d	91.93
Level of significance	**	**	**	**	ns
CV (%)	3.45	4.55	4.98	4.09	2.08

Mean values in a column having the same letters do not differ significantly as per DMRT.
** = Significant at 1% level of probability, * = Significant at 5% level of probability, ns = Not significant

Table 5. Effect of weeding regime and seed rate on different agronomic characters of wheat

Treatment	No. of effective tillers hill^{-1}	Spike length (cm)	No. of total spikelets spike^{-1}	Number of grains spike^{-1}	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Weeding regime									
Weed free	3.40 a	10.10	19.47 b	52.93 a	43.26	2.78 a	4.08 a	6.87 a	40.42 a
Weed free upto 20 DAS	3.33 a	10.06	19.93 a	44.60 c	43.28	2.40 c	3.70 c	6.10 c	39.16 a
Weed free upto 40 DAS	3.33 a	10.03	19.33 b	48.33 b	43.27	2.54 bc	3.84 bc	6.38 bc	39.61 a
Weed free upto 60 DAS	3.39 a	10.08	19.27 b	52.20 a	43.28	2.67 ab	3.97 ab	6.64 ab	40.08 a
Weedy	3.19 b	9.96	19.33 b	42.47 c	43.27	1.35 d	2.65 d	4.00 d	33.59 b
Level of significance	**	NS	*	**	NS	**	**	**	**
CV (%)	4.10	1.84	3.06	6.74	3.25	8.51	7.22	7.85	4.29
Seed rate (kg ha^{-1})									
100	3.33	9.97	19.73 a	46.93 b	43.27	2.23 c	3.56 c	5.80 c	37.89 b
120	3.33	10.09	19.47 ab	49.87 a	43.25	2.54 b	3.84 b	6.39 b	39.17 a
140	3.26	10.07	19.14 b	51.80 a	43.27	2.81 a	4.11 a	6.92 a	39.80 a
160	3.33	10.12	19.67 a	46.00 b	43.26	2.04 d	3.37 d	5.41 d	37.39 b
180	3.39	9.97	19.33 ab	45.93 b	43.30	2.12 cd	3.35 d	5.47 cd	38.62 ab
Level of significance	ns	ns	*	**	ns	**	**	**	**
CV (%)	4.10	1.84	3.06	6.74	3.25	8.51	7.22	7.85	4.29

Mean values in a column having the same letters do not differ significantly as per DMRT.
DAS = Days after sowing, ** = Significant at 1% level of probability, * = Significant at 5% level of probability, ns = Not significant, CV= Co-efficient of Variation

Table 6. Interaction effect of weeding regime and seed rate on different agronomic characters of wheat

Seed rate × weeding regime	No. of effective tillers hill^{-1}	Spike length (cm)	No. of total spikelets spike^{-1}	Number of grains spike^{-1}	Weight of 1000 grains (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
S_1W_1	3.33 b	9.92 cde	19.33 bcd	52.00	43.28	2.73 def	4.06 c-f	6.80 c-f	40.15
S_1W_2	3.33 b	10.00 a-e	20.67 a	41.33	43.28	2.30 g-j	3.63 f-i	5.93 f-i	38.86
S_1W_3	3.33 b	10.17 a-e	19.67 a-d	49.00	43.29	2.43 f-i	3.76 e-i	6.20 e-i	39.11
S_1W_4	3.33 b	9.90 cde	19.33 bcd	52.33	43.24	2.53 e-h	3.86 d-h	6.40 e-h	39.67
S_1W_5	3.33 b	9.88 cde	19.67 a-d	40.00	43.28	1.17 l	2.50 l	3.66 l	31.63
S_2W_1	3.70 a	10.06 a-e	19.00 cde	54.00	43.25	3.03 a-d	4.33 a-d	7.36 a-d	41.23
S_2W_2	3.33 b	9.99 a-e	19.67 abcd	48.33	43.28	2.60 efg	3.90 d-g	6.50 d-g	40.06
S_2W_3	3.33 b	10.12 a-e	20.00 abc	50.00	43.23	2.83 cde	4.13 b-e	6.96 b-e	40.57
S_2W_4	3.33 b	10.35 a	19.00 cde	53.33	43.23	3.03 bcd	4.33 a-d	7.36 a-d	41.13
S_2W_5	3.00 c	9.95 cde	19.67 a-d	43.67	43.28	1.23 l	2.53 kl	3.76 l	32.85
S_3W_1	3.00 c	10.33 ab	19.67 a-d	57.33	43.26	3.40 a	4.70 a	8.10 a	41.99
S_3W_2	3.33 b	10.12 a-e	19.67 a-d	48.00	43.30	3.03 bcd	4.33 a-d	7.36 a-d	41.10
S_3W_3	3.33 b	9.84 de	18.00 e	51.33	43.28	3.13 abc	4.43 abc	7.56 abc	41.46
S_3W_4	3.33 b	10.21 a-d	19.67 a-d	56.00	43.25	3.26 ab	4.56 ab	7.83 ab	41.68
S_3W_5	3.33 b	9.87 de	18.67 de	46.33	43.27	1.23 l	2.53	3.76 l	32.79
S_4W_1	3.33 b	10.11 a-e	19.67 a-d	51.00	43.25	2.43 f-i	3.76 e-i	6.20 e-i	39.26
S_4W_2	3.33 b	10.26 abc	20.33 ab	42.67	43.28	2.03 jk	3.36 hij	5.40 ij	37.58
S_4W_3	3.33 b	9.98 b-e	19.67 a-d	46.33	43.26	2.10 ijk	3.43 g-j	5.53 hij	37.89
S_4W_4	3.66 a	10.12 a-e	19.00 cde	49.67	43.25	2.27 g-j	3.60 f-i	5.86 ghi	38.59
S_4W_5	3.00 c	10.13 a-e	19.67 a-d	40.33	43.27	1.36 l	2.70 kl	4.06 kl	33.64
S_5W_1	3.67 a	10.09 a-e	19.67 a-d	50.33	43.26	2.33 g-j	3.56 ghi	5.90 ghi	39.49
S_5W_2	3.33 b	9.91 cde	19.33 bcd	42.67	43.28	2.03 jk	3.26 ij	5.30 ij	38.21
S_5W_3	3.33 b	10.03 a-e	19.33 bcd	45.00	43.28	2.20 hij	3.43 g-j	5.63 ghi	39.03
S_5W_4	3.33 b	9.83 e	19.33 bcd	49.67	43.40	2.26 g-j	3.50 ghi	5.76 ghi	39.31
S_5W_5	3.33 b	10.01 a-e	19.00 cde	42.00	43.27	1.76 k	3.00 jk	4.76 jk	37.04
Level of sig.	**	*	*	ns	ns	**	**	**	ns
CV (%)	4.10	1.84	3.06	6.74	3.25	8.51	7.22	7.85	4.29

Mean values in a column having the same letters do not differ significantly as per DMRT.
** = Significant at 1% level of probability, ns = Not significant,
S_1 = 100 kg ha^{-1}, S_2 = 120 kg ha^{-1}, S_3 = 140 kg ha^{-1}, S_4 = 160 kg ha^{-1} and S_5 = 180 kg ha^{-1}, W_1 = Weed free, W_2 = Weed free upto 20 days after sowing (DAS), W_3 = Weed free upto 40 DAS, W_4 = Weed free upto 60 DAS and W_5 = Weedy

Spike length was not affected significantly by weeding regime and seed rate (Table 5). Numerically the longest spike (10.10 cm) was observed from weed free treatment and the shortest spike (9.96 cm) was found from weedy treatment (Table 5). The result showed the reduction of spike length with increasing weed competition and it might be resulted from reduced flag leaf which ultimately caused less photosynthesis and less assimilates than that required for production of normal spike length. Numerically the longest spike (10.12 cm) was produced due to seed rate of 160 kg ha^{-1}. The shortest spike (9.97 cm) was observed at the seed rate of 180 kg ha^{-1} (Table 5). Gafar (2007) stated that increasing sowing density from 200 up to 400 seeds m^{-2} significantly decreased spike length. The length of spike was significantly influenced by the interaction of seed rate and weeding regime (Table 6). The longest spike (10.50) was obtained due to the interaction of 120 kg seed ha^{-1} with weed free up to 20, 40, 60 DAS. The shortest spike (9.83) was found due to the interaction of 180 seed kg ha^{-1} with weed free up to 60 DAS (Table 6).

Weeding regime and seed rate both had significant effect on total number of spike (Table 5). The highest number of total spike (19.93) was observed at weed free up to 20 DAS treatment. The lowest number of total spike (19.27) was obtained from weed free up to 60 DAS treatment (Table 5). This result may be attributed to vigorous plant growth with less competition for light, nutrients and free space in weed free treatment. This result is supported with the findings of Okafor (1987) and Karim and Mamun (1988) who reported that number of spikelets spike^{-1} was reduced due to competitive stress of weeds. The highest number of total spike (19.73) was observed from the treatment 100 kg seed ha^{-1} and the lowest number of total spike (19.14) was observed from 140 kg seed ha^{-1} (Table 5). From the above study we found that the lowest seed rate produced the highest number of spikelets spike^{-1} due to lower planting density. Similar results were also found by Talukder (2004). The interaction effect of seed rate and weeding regime had significant effect on number of total spike (Table 6). The highest number of total spike (20.67) was obtained due to the interaction of 100 kg seed ha^{-1} with weed free up to 20 DAS. The lowest number of total spike (18.00) was found due to the interaction of 140 kg seed ha^{-1} with weed free up to 40 DAS treatment (Table 6).

During our observation it was found that weeding regime and seed rate both had significant effect on number of grains spike^{-1} (Table 5). The highest number of grains spike^{-1} (52.93) was obtained from weed free treatment. The lowest number of grains spike^{-1} (42.47) was found from weedy treatment (Table 5). In this study, weed free treatment produced the highest number of grains spike^{-1} which might be attributed due to vigorous growth of wheat plant without crop-weed competition. Singh and Singh (1996) observed that number of grains spike^{-1} reduced up to 40% in wheat due to weed competition. The highest number of grains spike^{-1} (51.80) was observed from 140 kg seed ha^{-1}. The lowest number of effective spikelet spike^{-1} (45.93) was obtained from 180 kg seed ha^{-1} (Table 5). The highest and lowest grains spike^{-1} observed at lowest and highest plant densities, respectively (Rahim et al. 2012). Number of grains spike^{-1} was non-significantly affected by the interaction of seed rate and weeding regime (Table 6). The highest number of grain spike^{-1} (57.33) was found due to the interaction of seed rate at 140 kg ha^{-1} with weed free treatment. The lowest number of grains spike^{-1} (40.00) was found due to the interaction of seed rate at 100 kg ha^{-1} with weedy treatment (Table 6).

Weight of 1000 grains of wheat was not significantly influenced due to weeding regime and seed rate (Table 5). Numerically the highest 1000 grains weight (43.28 g) was obtained from weed free up to 20, 60 DAS treatment. The lowest 1000 grains weight (43.26 g) was obtained from weed free treatment (Table 5). Numerically, the highest weight of 1000 grains (43.30 g) was obtained from the seed rate of 180 kg ha^{-1}. The seed rate of 120 kg ha^{-1} produced the lowest weight of 1000 grains (43.25 g) (Table 5). The interaction effect of seed rate and weeding regime on weight of 1000 grains of wheat was non-significant (Table 6). The highest weight of 1000 grains (43.40 g) was resulted from the interaction of 180 kg seed ha^{-1} with weed free up to 60 DAS treatment. The lowest weight of 1000 grains (43.23 g) was obtained from the interaction of 120 kg seed ha^{-1} with weed free up to 40, 60 DAS (Table 6).

Yield and harvest index

Grain yield was significantly influenced by weeding regime and seed rate (Table 5 and Figure 2). The highest grain yield (2.78 t ha^{-1}) was obtained from weed free treatment and the lowest grain (1.35 t ha^{-1}) yield was found from weedy treatment (Figure 2). The weeds competed with the wheat crop plants for nutrition, air, water, sunlight and space, thus reduced yield. The highest grain yield obtained due to higher number of total and effective tillers hill^{-1} and higher number of grains spike^{-1}. Weed free condition facilitated the crop for better absorption of nutrients, moisture and solar radiation for higher yield. Hossain et al. (2001) also reported that weed free condition gave higher grain yield of wheat than weedy treatment. The highest grain yield (2.81 t ha^{-1}) was observed in the seed rate of 140 kg ha^{-1} and the lowest one (2.04 t ha^{-1}) was obtained from 160 kg seed ha^{-1} (Figure 3). The increased seed rate from 100 to 120 and 140 kg ha^{-1} resulted in grain yield increase by 13.9 and 26.0%, respectively due to higher number of effective tillers hill^{-1}. Again, the seed rate from 100 to 160 and 180 kg ha^{-1} resulted in yield decrease by 0.32 and 0.14% respectively. Oztork et al. (2006) reported that the reducing seed rate may result in more tillers, spikes plant^{-1} and more spikelets spike^{-1} but in many cases reduced grain yield. The interaction effect of seed rate and weeding regime on grain yield was statistically significant (Table 6). The highest grain yield (3.40 t ha^{-1}) was obtained from the interaction of 140 kg seed ha^{-1} with weed free treatment. The lowest grain yield (1.17 t ha^{-1}) was obtained from the interaction of 100 kg seed ha^{-1} with weedy treatment (Table 6).

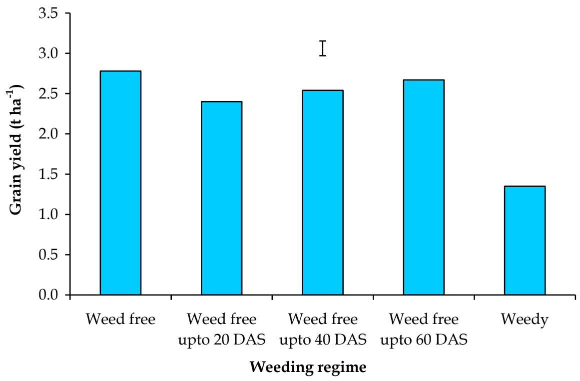

Figure 2. Effect of weeding regime on grain yield of wheat (DAS = days after sowing)

Weeding regime and seed rate both had significant effect on straw yield and biological yield (Table 5). The highest straw yield (4.08 t ha^{-1}) was found from weed free treatment and the lowest one (2.65 t ha^{-1}) was found from weedy treatment (Figure 4). Rahman (1985), Mamun and Salim (1989) and Singh and Singh (1996) also observed reduction in straw yield in wheat due to weed competition. The highest straw yield (4.11 t ha^{-1}) was obtained from the seed rate of 140 kg ha^{-1} and the lowest one (3.35 t ha^{-1}) was obtained from the seed rate of

180 kg ha^{-1} (Figure 5). Straw yield was significantly affected by the interaction of seed rate and weeding regime (Table 6). The highest value (3.51 t ha^{-1}) was obtained from the interaction of 140 kg seed ha^{-1} with weed free treatment. On the other hand, the lowest value (2.50 t h^{-1}) was obtained from the interaction of 100 kg seed ha^{-1} with weedy treatment (Table 6). The highest biological yield (4.96 t ha^{-1}) was obtained from weed free treatment which was statistically identical to weed free up to 60 DAS treatment. The lowest biological yield (4.00 t ha^{-1}) was obtained from weedy treatment (Table 5). The highest biological yield (6.92 t ha^{-1}) was obtained from 140 kg seed ha^{-1} and the lowest biological yield (5.41 t ha^{-1}) was observed from 160 kg seed ha^{-1} (Table 5). Biological yield was significantly affected by the interaction of seed rate and weeding regime (Table 6). The highest biological yield (8.10 t ha^{-1}) was found due to the interaction of 140 kg seed ha^{-1} with weed free treatment. The lowest biological yield (3.66 t ha^{-1}) was obtained due to the interaction of seed rate at 100 kg ha^{-1} with weedy treatment (Table 6).

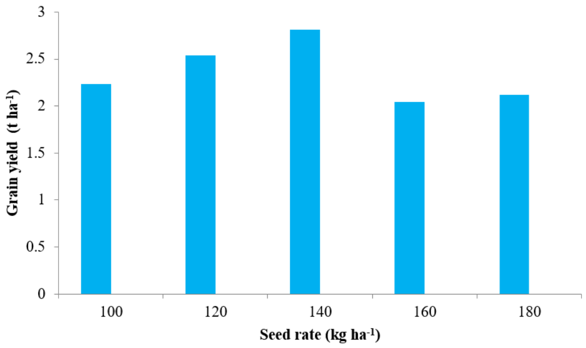

Figure 3. Effect of seed rate on grain yield of wheat

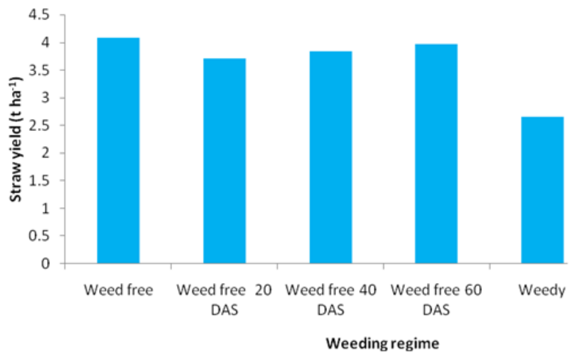

Figure 4. Effect of weeding regime on straw yield of wheat (DAS = days after sowing)

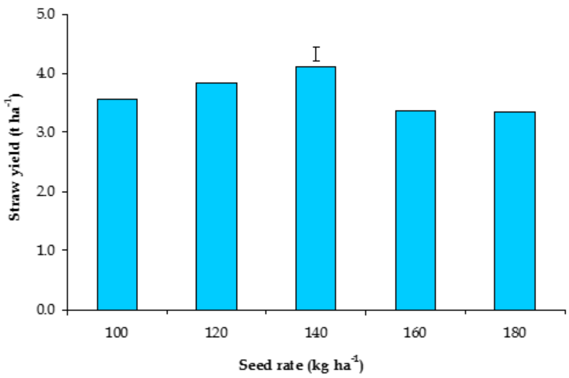

Figure 5. Effect of seed rate on straw yield of wheat

Weeding regime had significant effect on harvest index (Table 5). The highest harvest index (40.42%) was obtained from weed free treatment which was statistically identical to weed free up to 20, 40 and 60 DAS. and the lowest value (33.59%) was obtained from weedy treatment (Table 5). Seed rate had no significant effect on harvest index (Table 5). The highest harvest index (39.80%) was obtained from 140 kg seed ha^{-1}. The lowest harvest index (37.39%) was obtained from 160 kg seed ha^{-1} (Table 5). The interaction effect of seed rate and weeding regime had no significant effect on harvest index (Table 6). The highest harvest index (41.68%) was found due to the interaction of seed rate at 140 kg ha^{-1} with weed free up to 60 DAS treatment. The lowest harvest index (31.63%) was obtained from the interaction of 100 kg seed ha^{-1} with weedy treatment (Table 6).

CONCLUSIONS

It is evident from this study that wheat productivity is largely influenced by seeding density and weed interference period. Seed rate of 140 kg ha^{-1} appeared as the optimum for higher yield of BARI Gom 26. Season- long weed free condition and weed free up to 60 days after seeding resulted in similar grain yield of wheat. Season-long weed free condition is necessary at lower seeding rate like 120 kg ha^{-1} for higher yield. But, in case of higher seeding rate like 140 kg ha^{-1} weed free condition up to 40 days after seeding is enough to ensure higher yield. Therefore, form economic view point 140 kg seed ha^{-1} and weed free condition up to 40 DAS could be recommended for higher productivity of BARI Gom 26.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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