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CAUSES OF YIELD REDUCTION BY DELAYED PLANTING OF HEXAPLOID WHEAT IN PAKISTAN

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Abstract

Soil moisture availability at planting time of wheat (*Triticum aestivum* L.) is critical and can delay sowing if moisture is insufficient in a typical rainfed area. Shortening of vegetative growth (post emergence to pre flowering) by delay sowing can cause yield losses. We compared growth and yield of four wheat varieties viz., Inqilab 91, Bakhtawar 92, Nowshera 96 and Fakhre Sarhad planted at different dates; starting from Oct. 24 to Dec.11 with 15 days interval at the Research Farm, KP Agricultutal University Peshawar, Pakistan. Uniform cultural practices were applied during the crop growth. Fakhre Sarhad ranked the best ($p<0.05$) variety, followed by Nowshera 96, Bakhtawar 92 and Inqilab 91 for seed yield. However, each delay in sowing from Oct. 24 onwards decreased ($p<0.05$) seed yield. Emergence and tiller number by late sowing decreased. Rate and duration of linear growth stage (LGS) along with time of peak periods also differed for the varieties and sowing dates. The LGS duration among varieties differed from 28 to 54 for Inqilab 91, 30 to 60 for Bakhtawar 92, 48 to 75 for Nowshera 96 and 45 to 65 for Fakhre Sarhad by delaying sowing time which created significant differences in seed and biomass production. It was observed that crop growth rate and its duration in the LGS are in close association with dry matter and seed losses. Breeding efforts need to improve LGS of wheat variety to be recommended as rainfed variety for the area.

Introduction

Increasing wheat (*Triticum aestivum* L.) demand with increase in population is natural for Khyber Pakhtunkhuwa (KP), Pakistan. However, KP is contributing >60% rainfed wheat cultivation on cropped land. Wheat is generally sown over a period of 6-8 weeks extending from October to late December. Area's where soil moisture is limited wheat is planted subject to the availability of natural precipitation. However, early planting cause excessive vegetative growth (Joshua *et al*., 2002). Early planted wheat may lose winter dormancy earlier and has great potential for late spring freeze injury (Miller, 1992). Wheat planted at optimum date has relatively greater yield potential than that planted late in the season by high tillers, heads and kernel weight (Thill *et al*., 1978). Late-planted wheat also develops under different temperature and day-length, which shortens the phyllochron interval (Cao & Moss, 1994), and requires high seeding rates to compensate tiller density (Shah *et al*., 1994). However, research has proved the advantage of adequate Phosphorus (P) application to late sowing (Blue *et al*., 1990).

Wheat is either planted in rotation with maize or as mono crop under rainfed condition where water is expected after monsoon. Hybrid maize in rotation with wheat had also delayed wheat sowing in the season. Unavailability of rainfall also delays wheat cultivation which results in low seed and biomass production (Shah & Akmal, 2002). Root, stem and leaf of a wheat plant are competitive sinks for assimilates at vegetative stage and their partitioning influences growth performance (Danks *et al*., 1983). Green leaves are the major assimilates contributing organ (Edwards & Walker, 1983) and their damages through leaf rust (*Puccinia triticina*) is common on both irrigated and rainfed areas. Adjustment of planting time could be an alternative to overcome rust disease, although effectiveness often depends on specific environmental conditions and cultivar selection (Guy & Oplinger, 1989; Milus, 1994). Wheat yield performance is outcome of the primary and secondary yield contributing traits of which tiller initiation is associated to leaf number that obviously contribute in the production (Mulholland *et al*., 1997). Nevertheless, grain yield depends on the period of grain weight gain - the longer the vegetative phase (planting to heading) - the greater would be the grain yield (Alvaro *et al*., 2008). Wheat production also depends on sink capacity i.e., initiation of floral structure during vegetative period and photosynthetic capacity e.g., the grain filling duration (Bauer *et al*., 1985). Contribution of pre-anthesis reserves to seed is estimated from 5-10% in wheat and about 20% in barley (Evan & Wardlaw, 1976) but after anthesis initiation, assimilates of flag leaf mainly contribute to grain's dry matter accumulation (Makunga *et al*., 1978).

Study to identify reasons of yield loss by late sowing is limited but essential for a sound breeding program. The comparison of different varieties to change planting date may let us know the reason to address in future breeding for improvement in variety to increase production.

Materials and Methods

The experiment was conducted at Research Farm of the Agricultural University at Peshawar, Pakistan. The experimental site is about 120 km north of the Indian oceans at an altitude of 350 m and a latitude of 34.01^{O} N. Mountains surround Peshawar valley on all sides and two rivers flow in to provide water for irrigation. Soil of the experiment was clay loam, low in organic matter (1.15%) and alkaline (pH 7.85). Total nitrogen content of the soil was 0.09%. Wheat varieties (Inqilab 91, Bakhtawar 92, Nowshera 96 and Fakhre Sarhad) were sown on different dates (October 24, November 10, November 24 and December 11). Inqilab 91 is a high yielding variety (Ashraf & Bashir, 2003). Bakhtawar 92 can be planted relatively late. Nowshera 96 and Fakhre Sarhad are new releases with resistance to rust and smut. Certified seeds of all the varieties were used and selection based on relatively higher acreage under cultivation. Average day and night temperatures of the region were 29±4 and 14±3^{o}C, respectively. The maximum and minimum temperature and seasonal rainfall during the crop growth period is shown in Fig. 1.

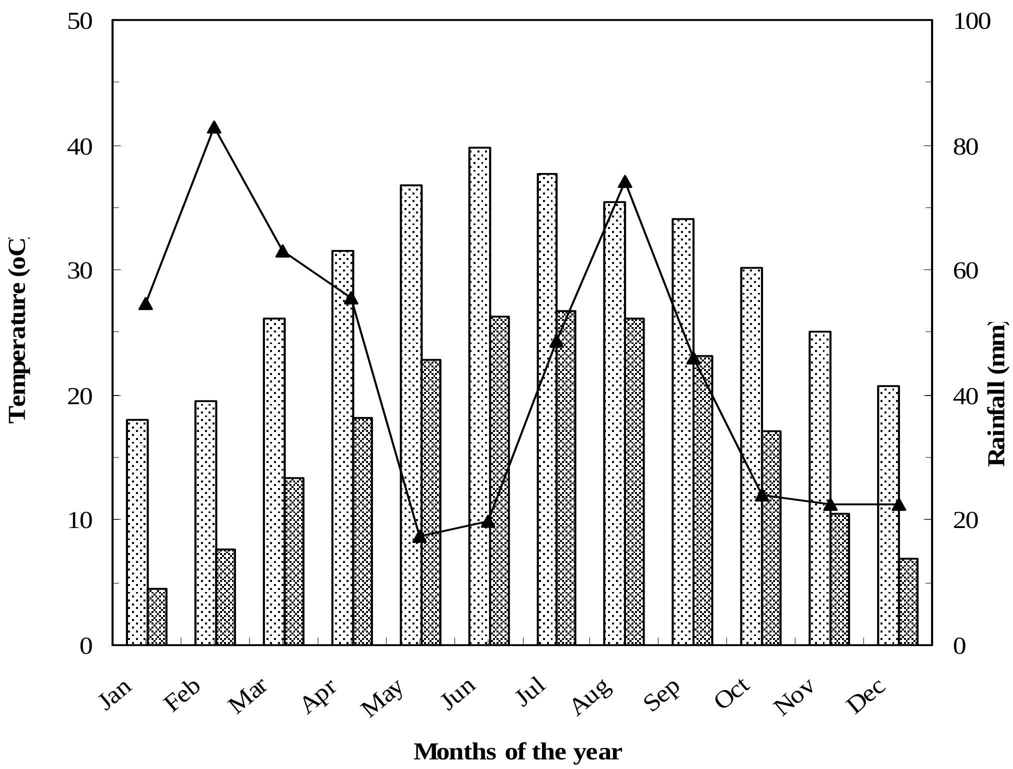

Fig. 1. Monthly maximum (light colored bars) and minimum (dark colored bars) temperatures averaged over 5 years. Line indicates monthly rainfall at the experimental site.

Emergence per unit area was counted manually using half m² ring randomly at two locations. Days to complete emergence were calculated when >80% seedlings emerged from sowing. Likewise, days to flowering and maturity were calculated to estimate vegetative and reproductive periods, respectively. To estimate crop growth rate (CGR), half meter row from two locations were periodically harvested. The material was oven dried at 70^oC. The dry matter was fitted against time using Richard's equation (Richards, 1969). Periodic crop growth rate (g m^{-2} d^{-1}) was derived from differences in dry matters of the two samples over that time. Crop growth curve is sigmoid (Cannell, 2003) and CGR in the linear phase is stable. Slopes of regression can be used as mean CGR. Duration of the linear growth phase (days) can be estimated as differences in final and starting periods (days) when growth was relatively stable (D). The growth in linear phase (GLP) of a variety planted on different date could be estimated as [GLP = slope of regression (g d^{-1}) x duration of linear growth phase in days]. Tillers per unit area were manually counted. Grain and above-ground biomass yield were separately measured by harvesting two central rows in an experimental unit.

The experiment was conducted in randomized complete block design, split plot arrangements in three replications. Planting dates were assigned to main plots and varieties to the subplots. Each sub-plot consisted of ten rows 5m length and 30cm apart leaving one blank row. Field was prepared by cultivator and leveled subsequently. Nitrogen and phosphorus were applied as urea and Diammonium phosphate at 120 and 60 kg ha^{-1}, respectively. Excluding natural precipitation, four irrigations were applied as per crop water demand. Weeding was done manually once 45 days after sowing (DAS). The data was statistically analyzed using recommended model (Steel & Torrie, 1981) and means were compared through LSD ($p<0.05$).

Results

Emergence per unit area decreased when wheat planting was delayed in season from Oct. 24 onwards for all varieties (Fig. 2) but with a different magnitude. Fitting a simple regression equation between emergence and the planting date, we could estimate the loss in emergence by the delay planting for each wheat variety through slopes of the regression equation. Emergence of Bakhtawar 92 decreased with the highest rate of about 0.44 seedling m^{-2} day^{-1} ($r^2 = 0.99$). The remaining three varieties varied little with showing 0.18 ($r^2 = 0.94$), 0.20 ($r^2 = 0.96$) and 0.24 ($r^2 = 0.66$) seedling losses m^{-2} d^{-1} for Inqilab 91, Nowshera 96 and Fakhre Sarhad, respectively. Emergence per unit area usually determined seedling density i.e., the tiller number per unit area, which is the primary yield contributor of dry matter and seed yield.

Decrease in emergence by late planting also reduced tiller number (Fig. 3) of all varieties but with different magnitudes. Inqilab 91 showed a strong (Oct. 24 – Nov. 10) to moderate reduction (Nov. 10 – Nov. 24). Bakhtawar 92 showed relatively a stable ($p<0.05$) decrease for every subsequent delay in planting from Oct. 24 onwards. Nowshera 96 was initially stable (Oct 24 to Nov. 10) but exhibited a strong significant reduction thereafter (Nov. 10 to Dec. 11). Fakhre Sarhad reduced ($p<0.05$) tiller in the initial 15 days delay (Oct. 24 to Nov. 10) but thereafter remained relatively stable.

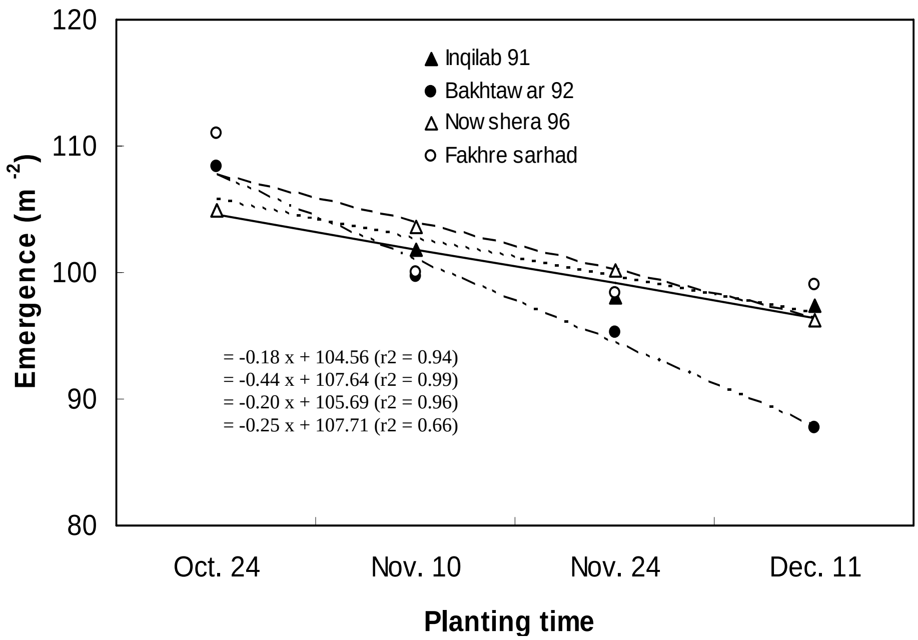

Fig. 2. Emergence per unit area depending on planting date for the different wheat varieties.

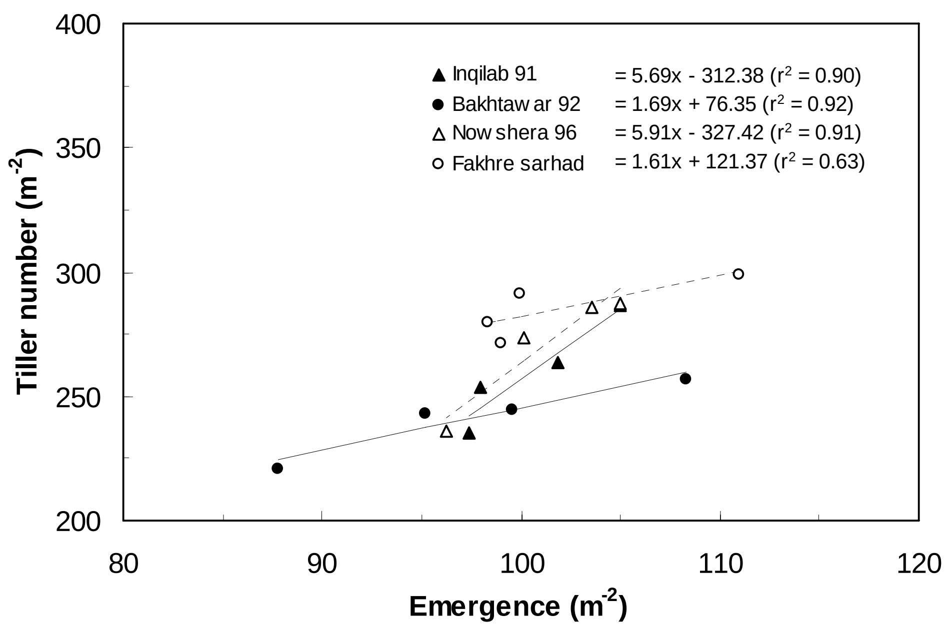

Fig. 3. Relationship between tiller number and emergence per unit area of different wheat varieties planted on different dates.

Dry Matter increased in a sigmoid relationship with increasing DAS (Fig. 4). The DM of different wheat varieties planted on different dates, was smoothed through Richard's function. Coefficients of the regression equations are provided in Table 1. Delay of planting changed the shapes of the growth curves within the variety as well as among the varieties but in different fashions (Fig. 4). DM productions of all planting dates were initially uniform for the variety but thereafter varied during LGP. The LGP, where crop growth rate is constant ($r^2 = 1.00$), was observed from 75 to 125, 86 to 140, 72 to 100, and 75 to 110 DAS when the varieties Inqilab 91 was planted on Oct. 24, Nov, 10, Nov. 24 and Dec. 11, respectively. The LGP of variety Bakhtawar 92 was reported from 74 to 127, 75 to 135, 60 to 110 and 85 to 115 DAS for the planting dates Oct. 24, Nov. 10, Nov. 24 and Dec. 11, respectively. Variety Nowshera 96 responded with linear growth from 78 to 140, 75 to 150, 70 to 120, 70 to 118 DAS for the sowing dates Oct. 24, Nov. 10, Nov. 24 and Dec. 11, respectively. The LGP of Fakhre Sarhad ranged from 80 to 145, 85 to 140, 80 to 125 and 80 to 122 DAS when planted on Oct. 24, Nov. 10, Nov. 24 and Dec. 11, respectively. Loss in DM between 1st and 2nd planting date as well as 3rd and 4th planting date of the Inqilab 91 and Nowshera 96 were relatively moderate but were stronger between the 2nd and 3rd plantings. The other 2 varieties responded relatively stable variations of crop growth for the 4 sowing dates.

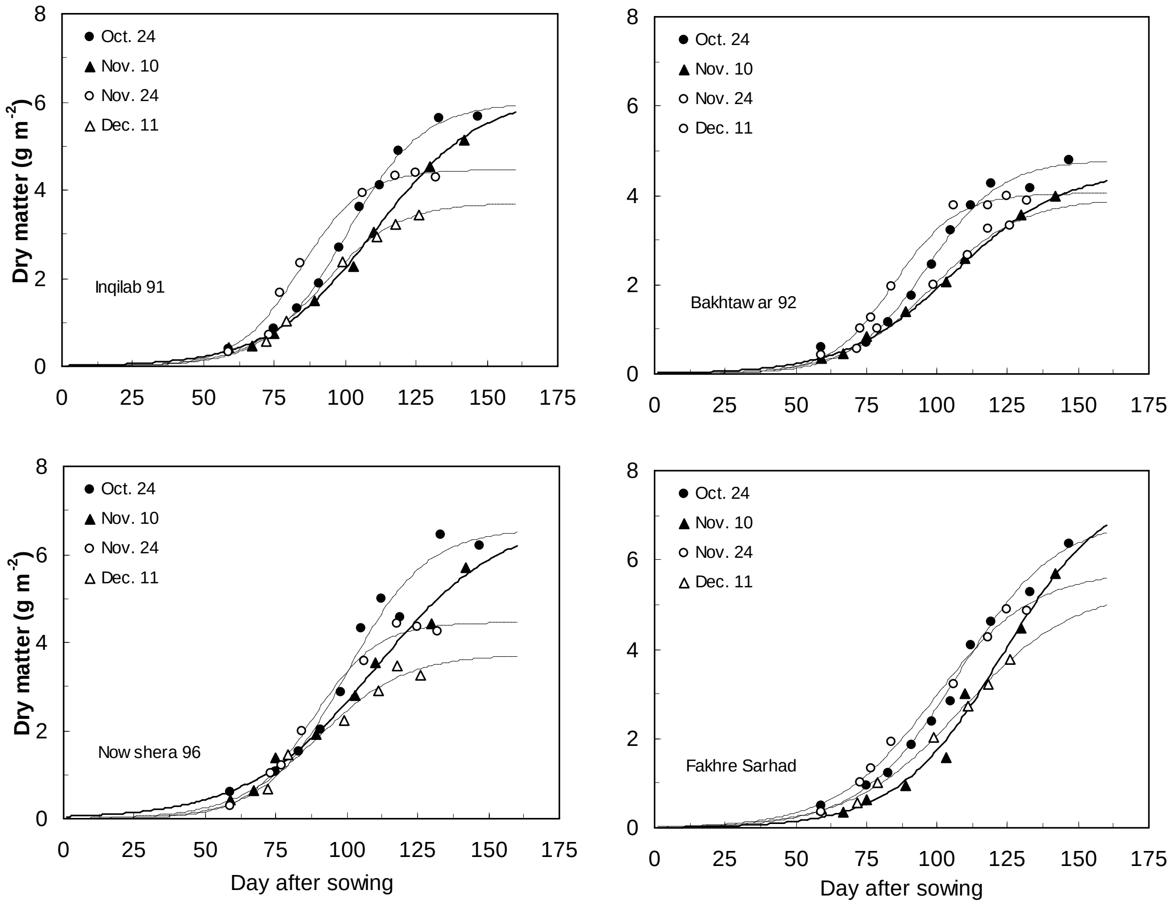

Fig. 4. Dry matter production after planting of the 4 wheat varieties subjected to different planting date.

Table 1. Coefficient of the regression derived using Richards function for smoothing dry matter against days after sowing for wheat varieties planted on four different dates.

Variety	Planting date	a	b	c	r^2	SD
Inqilab 91	Oct. 24	5.98	1854.03	-0.075	0.99	0.09
	Nov. 10	6.16	389.03	-0.054	0.99	0.07
	Nov. 24	4.46	2131.13	-0.091	0.99	0.17
	Dec. 11	3.72	1009.9	-0.075	0.98	0.26
Bkhtawar 92	Oct. 24	4.79	1684.5	-0.077	0.99	0.24
	Nov. 10	4.58	251.33	-0.052	0.99	0.12
	Nov. 24	4.05	2216.24	-0.91	0.99	0.16
	Dec. 11	3.43	549.2	-0.064	0.98	0.19
Nowshera 96	Oct. 24	6.59	1245.37	-0.071	0.99	0.07
	Nov. 10	6.85	142.03	-0.045	0.98	0.13
	Nov. 24	4.46	2216.6	-0.088	0.99	0.26
	Dec. 11	3.73	382.99	-0.066	0.98	0.16
Fakhre Sarhad	Oct. 24	6.93	517.38	-0.058	0.95	0.24
	Nov. 10	7.69	759.71	-0.054	0.96	0.18
	Nov. 24	5.76	278.94	-0.057	0.97	0.11
	Dec. 11	5.36	260.19	-0.051	0.94	0.27

SD = Standard deviation

The CGR of all varieties showed a bell shape (Fig. 5). The maximum CGR was observed in the middle of the crop growth but this maximum range and its timing differed both within and among the varieties when planting dates changed from Oct. 24 to Dec. 11. Peak values of the CGR (0.11, 0.08, 0.10 and 0.07 g DM d^{-1}) for the variety Inqilab 91 were observed in about 105, 120, 90 and 95 DAS for Oct. 24, Nov. 10, Nov. 24 and Dec. 11 planting dates, respectively. Bakhtawar 92 exhibited the highest CGR (0.09, 0.06, 0.09 and 0.06 g DM m^{-2} d^{-1}) after about 105, 110, 90 and 95 DAS, respectively for the planting dates Oct. 24, Nov. 10, Nov. 24 and Dec. 11. Nowshera 96 showed the highest CGR (0.11, 08, 0.09 and 0.06 g DM m^{-2} d^{-1}) after about 105, 120, 90 and 100 DAS when planted on Oct. 24, Nov. 10, Nov. 24 and Dec. 11, respectively. Likewise, Fakhre

Sarhad showed the highest CGR (0.09, 0.10, 0.08 and 0.07 g DM m^{-2} d^{-1}) after about 105, 125, 105 and 120 DAS when planted on Oct. 24, Nov. 10, Nov. 24 and Dec. 11, respectively. Difference in the duration of the linear growth phase and rate of the crop growth influenced grain and DM yield (Table 2). Every subsequent delay of the planting date decreased ($p<0.05$) both grain and DM. Fakhre Sarhad produced more grains ($p<0.05$) than any other variety. Nowshera 96 ranked the next in yield followed by Inqilab 91 and Bakhtawar 92. Interaction of varieties with sowing dates were also found significant ($p<0.05$).

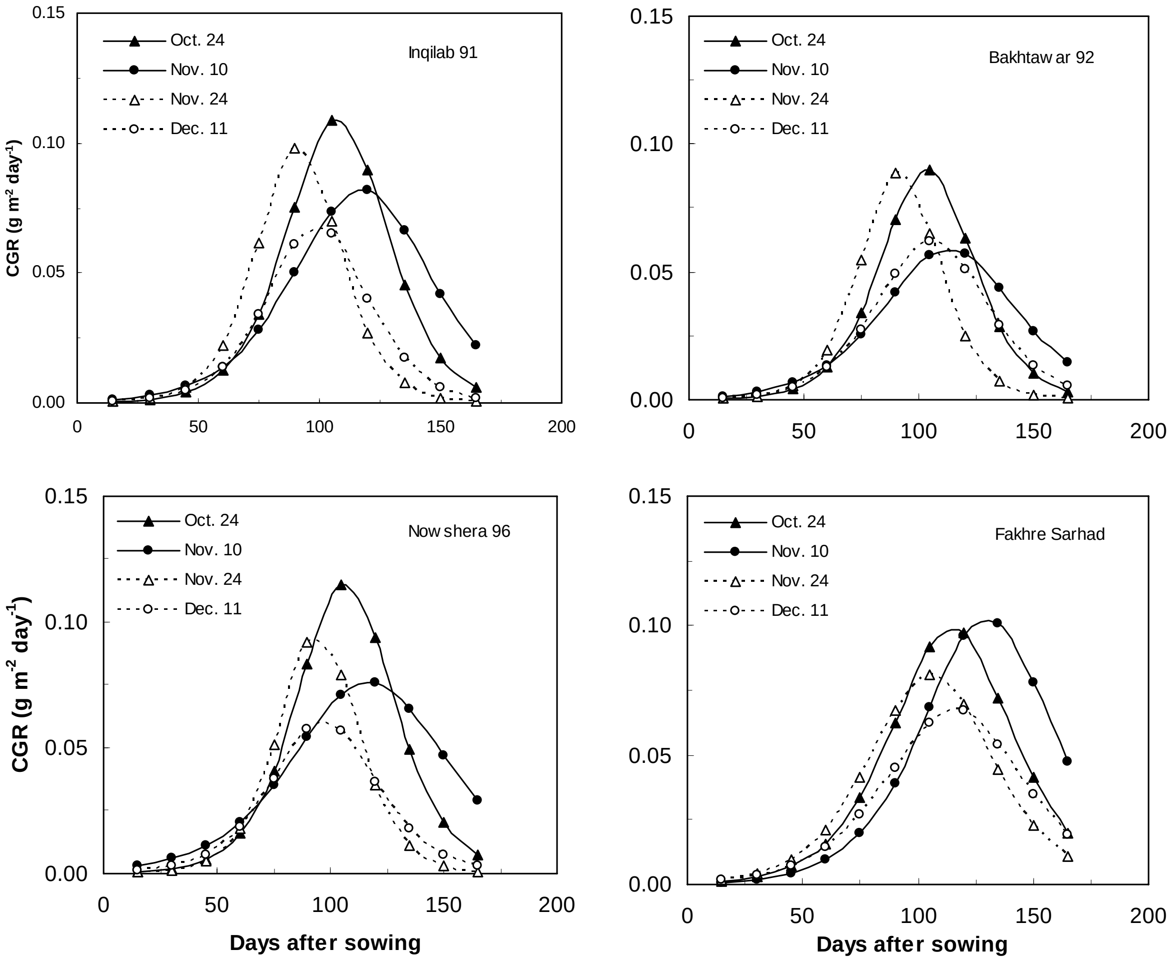

Fig. 5. Mean crop growth rates (CGR) of different wheat varieties planted on different dates.

Table 2. Dry matter and seed yield (kg ha^{-1}) of the wheat varieties planted on different dates at Agricultural University Peshawar, Pakistan.

Varieties	Planting dates				Mean
	Oct. 24	Nov. 10	Nov. 24	Dec. 11	
Seed yield					
1. Inqilab 91	44430 d	40270 h	35000 k	28198 n	36974 c
2. Bakhtawar 92	42760 g	37458 j	32375 m	23208 p	33950 d
3. Nowshera 96	50965 b	44168 e	38058 i	27765 o	40238 b
4. Fakhre Sarhad	55013 a	50695 c	43083 f	34298 l	45772 a
Mean	**48292 a**	**43148 b**	**37129 c**	**28367 d**	
Dry matter					
1. Inqilab 91	12220 e	11663 g	10140 j	9443 l	10866 d
2. Bakhtawar 92	12220 e	11675 g	11528 h	8475 m	10974 c
3. Nowshera 96	12503 c	12378 d	11938 f	9583 k	11600 b
4. Fakhre Sarhad	13058 a	12778 b	12768 b	10555 i	12289 a
Mean	**12500 a**	**12123 b**	**11593 c**	**9514 d**	

	Varieties	Sowing dates	Interaction
LSD ($p<0.05$) for grain yields	8.19	8.19	16.38
LSD ($p<0.05$) for dry matter yield	6.08	6.08	12.16

The life cycle was shortened due to a reduction of both vegetative and reproductive growth periods under the late sowing for all the varieties. The grain as well as DM yields were linearly related to the length of GLP with little differences between the varieties (Fig. 6, Table 2). The relationship of the accumulated difference in grain and dry matter losses actually observed (Table 2) and estimated through regression (Fig. 6) for the different varieties planted on the different dates were closely related for both grains (r^2 = 0.98) and for dry matter (r^2 = 0.90) yield. This shows that GLP could be used as an alternative to estimate yield losses of a wheat variety when its planting delayed from optimum to late in the season.

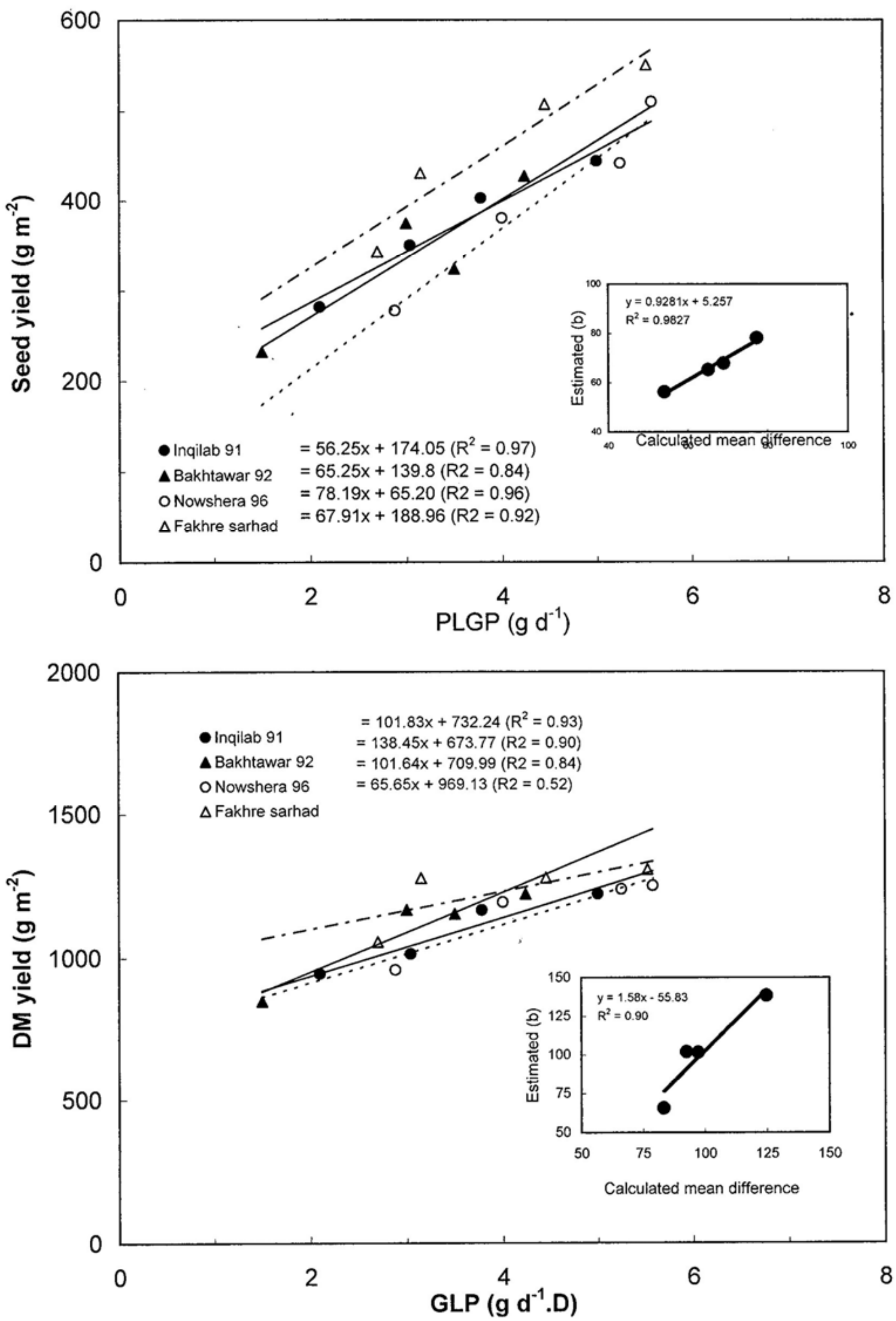

Fig. 6. Grain production and dry matter yield depending on the length of growth in linear phase (GLP) of different wheat varieties planted on different dates. Boxes show the relationship of the accumulated difference in grain and dry matter losses actually observed (Table 2) and estimated through the regressions.

Discussion

Rates of emergence decreased in all varieties but to a varying degree by late sowing. Decrease in especially the day temperature was critical environmental factor (Amato *et al*., 1992) affecting emergence (Fig. 2). Under uniform cultural and environmental conditions, Bakhtawar 92 was sensitive than the other varieties. Data indicated that different varieties differed in production and needs to be cultivated with different inputs in the area. Temperature after sowing is a critical factor for wheat (Akmal & Hirasawa, 2004). Crop sensitivity to varying emergence is one cause of yield loss (Liu *et al*., 2004) and can be optimized through optimum planting time. Nevertheless, proper variety identification for late sowing is also important to be optimized yield particularly: (a) in rainfed areas where wheat planting depends on availability of natural precipitation and (b) under irrigated areas and/or where wheat is planted in rotation with hybrid maize that due to the lengthy growing season delay wheat sowing in rotation. However, poor emergence was observed in late planted wheat of all varieties which can be compensated through increased seeding rate for higher tillers (Fig. 2). We assumed that wheat tiller production associated with temperature that decreases from early to late planting. However, the varieties respond differently to change in the temperature. It has also observed that tiller number of the varieties and emergence rate synchronized but in different fashions (Fig. 3). Tiller number of variety Bakhtawar 92 against emergence reduced in a linear fashion when planted from Oct. 24 to Dec. 11. Contrary to that, this relationship for the variety Fakhre Sarhad remains relatively stable. The rest of the varieties (Inqilab 91 and Nowshera 96) showed a highly sensitive response with strong decreases in tiller number and emergence relationship (Planting Oct. 24 to Dec. 11). Here one reason might be that the increase in tiller number was subject to space and light at the plant base.

Delay planting decreased emergence and might have adversely affected potentiality of tiller production at low temperature by late sowing (e.g., January) when temperatures favor growth due to assimilates partitioning towards stem formation and plant height might have dominated the density by restricting light availability at the plant base (Robson *et al*., 1988; Van Loo, 1993). Differences in emergence and tiller density by late sowing affected biomass production (Fig. 4). The crop growth curve is usually sigmoid but duration of the linear growth phase (LGP) can be the next important aspect of yield loss by late planting. The canopy intercepts the maximum light during this period (Akmal &Janssens, 2004). Delayed sowing decreased LGP and hence production of all varieties. Difference among the varieties in production has been reported (Ashraf &Basher, 2003; Shah & Akmal, 2002) due to reduced canopy leaf area expansion rate and varieties interaction within environments. However, differences in attenuation in peak CGR of varieties varied with planting dates and this different CGR would let us know how much sensitive a variety is for sowing date. The relatively longer LGP of early (Oct. 24 and Nov. 10) than late (Nov. 24 and Dec. 11) sowing dates of Inqilab 91 and Nowshera 96 confines their cultivation in areas where temperature fluctuates during the season. Contrary to that mild difference in LGP of the rest of the two varieties make them preferable in areas where planting is subjected to unavoidable circumstances (e.g. natural precipitation, cropping pattern, etc.). Planting wheat late than normal time allows crop to built canopy earlier and intercept maximum light in the season (Fig. 4). The relatively longer sunny period by timely sowing enables more sunlight for the vegetative growth. Moreover, in time sowing allowed crop to starts reproductive growth after sufficient vegetative development which supply sufficient assimilates for grain establishment to yield high (Table 2). Delay planting has decreased vegetative growth period and starts flower initiation in time by change of temperature when compared with early sowing (Mar.-Apr.) and resulted higher seed yield by early sowing. Increasing temperature and photoperiod have adversely affected grain growth (Boykin *et al*., 1995) and resulted low seed yield. In our study, every delay in sowing has reduced growth duration which has resulted lower biomass and seed (Table 2). Differences in growth duration of wheat varieties are not unusual (Bindraban *et al*., 1998) but varieties with relatively longer vegetative period yields higher due to longer seed filling duration to encourage high seed number with heavier weight per spike. The reason might be sufficient carbohydrates supply to spike (Binderban *et al*., 1998). Late sowing has decreased ($P<0.05$) production of all the varieties by limiting their vegetative and reproductive durations. We therefore tried to establish a relationship that shows slopes of regression was almost the same that obtained from aggregate differences observed among the varieties for planting them on different dates. Dry matter and seed yield over vegetative and reproductive durations were almost linear with decreasing trends for all the varieties. We tried to establish similar relationship for seed and dry matter with growth duration (vegetative + reproductive) but did not reach for slopes that could be equals to the aggregate losses in production for the varieties planted on different dates. The slopes of the linear growth and its total duration against seed and dry matter was relatively found more appropriate in changing magnitudes of both seed yield and dry matter of the varieties when their planting was exercised between Oct. 24 and Dec. 11 with 15 days interval. The growth rate in linear phase of the development and the total duration of a variety is significant factors to examine yield loss when planting delayed from early to late in season. Moreover, if planting in time is not possible due to any unavoidable circumstances, varieties with high yield return can be sustained for breeding efforts to improve biomass production rate with emphasis on the linear growth phase though its duration decreased by late sowing.

Conclusion

From this study it can be concluded that where wheat is grown primarily for seed, relatively early planting ensures optimum emergence though sufficient tiller number per unit area. Each week delay of wheat sowing in November, when seed germination is possible due to soil temperature, reduced length of the crop vegetative and reproductive stages. This affect rate of crop growth and cause yield reduction. Wheat, where planted as a major seasonal crop, should be planted relatively early in the season to get the optimum emergence which ensure the required density. Areas, where temperature fluctuates and/or relatively unstable during the linear growth phase, may decrease tiller production and hence needs adjustment for planting geometry i.e., optimum tiller density through higher seeding rate under the late sowing condition in the season. Delay planting, if cannot be avoided due to unavailability of rainfall or land for sowing due to cropping system, needs to be compensated by selecting appropriate variety which relatively has moderate fluctuations of growth in the linear phase. Variety with decreased linear growth under late planting can be improved through breeding by increasing growth rate in the linear phase. Further research needs to conduct for identifying causes of yield reduction by late sowing.

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