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Biomass, Harvest Index and Yield in Relation to Changes in Photo-thermal Regimes in Soybean (*Glycine max* L. Merrill.) Genotypes

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ABSTRACT

Fifteen photo- and thermo-insensitive early maturing genotypes and five promising main season normal maturing genotypes of soybean which were determinate in growth and photo-thermo sensitivity were evaluated for their agronomic performance under a wide range of photoperiod and temperature conditions manipulated through five sowing dates (February 23, March 20, April 14, May 9 and June 3). Genotypes, sowing dates and their interactions with environments were highly significant for the traits studied. The significant GE interactions for biomass production, harvest index (HI) and grain yield (GY) indicated that the tested genotypes ranked differently across diverse environments for these characters. In early maturing genotypes, longer day-length and higher temperature produced bold seeds and high HI but fewer yields. Main season genotypes produced higher biomass and GY than that of early maturing genotypes in all the sowings. Early maturing genotypes viz. E7 and E19 had higher GY whereas SL 295 and Pb. No. 1 recorded higher GY among main season genotypes over all the sowing dates. Biomass and HI were important determinants of GY as evident from their significant positive regression coefficients with GY. It is concluded that for main season genotypes (May and June sowing) GY can be increased by increasing HI and enhancement of biomass production in early maturing-photo and thermo insensitive in February-March sowing could lead in yield improvement. Study also demonstrated that early maturing photo-thermo insensitive genotypes of soybean could be grown successfully during spring/summer (February to June).

Keywords: Grain yield components, genotype × environment interaction, photo-insensitiveness, sowing dates

INTRODUCTION

Soybean (*Glycine max* L. Merrill.), believed to have originated in China, is a nitrogen fixing legume crop that may be a good component of a general plan to improve cropping system efficiency. For this purpose, crop suitability to specific environments must be established, as the economic yield of the crop will depend largely on its adaptability to various environments. So, the understanding of the growth dynamics and of the growth realized in the grain component is important to improve the crop management.

Soybean is a short-day plant, and photoperiod and temperature control the duration of both pre- and post-flowering phases (Kantolic and Slafer 2007). Its growth depends on the ability of different genotypes to capture light and the efficiency of conversion of intercepted light into biomass (Confalone *et al.* 2010). Photo-thermal sensitivity in soybean influences to a considerable extent the area of its adaptation and the time of maturity of cultivars (Hartwig and Kihl 1979).

Temperature along with photoperiod affects the flowering time but temperature along with humidity affects initiation and normal development of pods (Singh and Khehra 1988). Roberts *et al.* (1996) had also emphasized the importance of photoperiod-insensitivity in the improvement of soybean crop after characterizing soybean genotypes in conjunction with an analysis of the world-wide range of photo-thermal environments in which soybean crops are grown. Most of the Indian soybean cultivars (> 95%) were found to be highly sensitive to photoperiod that limits their cultivation in only localized area (Bhatia *et al.* 2003).

In soybean three loci E_1/e_1, E_2/e_2 and E_3/e_3 affect the photoperiod sensitivity of the duration from the sowing to first flowering (Upadhyay *et al.* 1994a, 1994b), and from first flowering to the end of flowering (Asumadu *et al.*1998; Summerfield *et al.* 1998). The genotypes differing in one or more alleles show negligible differences in vegetative and reproductive durations in short days but substantial differences in long days (Upadhyay *et al.* 1994a, 1994b; Asumadu *et al.* 1998; Summerfield *et al.* 1998). Not surprisingly, the greater the reproductive duration of a genotype in long days the more biomass was accumulated by maturity (Asumadu *et al.* 1998). However, the variation in duration accounted for only about 70% of the variation in the biomass accumulated at maturity (Hunt 1982).

Different soybean varieties behave differently under different photoperiod and temperature conditions. Photoperiod affects vegetative growth, flowering and seed maturity while temperature influences time of flowering, rate of growth, normal pod development and pod retention (Piper *et al.* 1996). Both of these parameters i.e. photoperiod and temperature can be manipulated by varying sowing dates under field conditions.

The seed yield of grain legumes is the result of two interconnected processes: plant growth and development of sink strength which will determine the proportion of growth partitioned to grain, and the harvest index (HI). Components of yield, seed numbers and seed weight provide some clues as to the environmental effects on yield-forming processes (Ayaz *et al.* 2004). Duration of vegetative and reproductive development is reported to vary in response to different planting dates. Vegetative growth of soybean has been reported to be associated with seed yield. Therefore, sufficient vegetative dry matter is required to support and

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attain higher yield (Specht *et al.* 1984).

HI, a ratio between seed yield and total dry matter is a useful index to understand the optimum balance between grain yield (GY) and total dry matter for different sowing dates. Correlation and regression analysis were usually used to determine the relationship between seed yield, biomass and HI (Mayer *et al.* 1991; Morrison *et al.* 1999, 2000; Cui *et al.* 2005). Little information is available about optimum vegetative growth for attaining higher GY under Punjab conditions. Therefore, present study has been planned to investigate the effect of photoperiod and temperature as manipulated by planting dates on biomass accumulation, HI and GY in early maturing photoperiod insensitive and normal maturing photoperiod sensitive soybean genotypes.

MATERIALS AND METHODS

Fifteen photo and thermo-insensitive early maturing genotypes and five promising main season genotypes of soybean which are determinate in growth and photoperiod sensitive were evaluated at Punjab Agricultural University, Ludhiana under different sowing dates. The experiment was sown in a randomized complete block design with three replications at five different sowing dates spaced 25 days apart viz. February 23, March 20, April 14, May 9 and June 3, 2004. Experimental site is located at 30°-40′ North Latitude and 75°-40′ East Longitude at a mean height of 240 m above sea level. Photoperiod and temperature during crop period are given in **Figs. 1**, **2**. Each sowing date was considered a separate experiment. Each genotype was planted in a single row of 2 m length with row to row spacing of 45 cm. Observations were recorded on five randomly taken competitive plants in each replication for plant height, number of branches at flowering, biomass at flowering, number of pods per plant, total biomass, 100-seed weight, GY and HI. Mean values of five plants were used for further statistical analysis. Analysis of variance was performed for each sowing date separately and combined analysis over all the sowing dates. Multiple regression analysis was performed to describe the relationships among the traits using the stability analysis developed by Eberhart and Russell (1966). Grain yield per plant was selected as a dependent variable and other traits were selected as independent variables. BMM and MVM software were used for stability and multiple regression analyses, respectively. Significance was tested at 0.05 and 0.01 levels.

RESULTS AND DISCUSSION

Experiments conducted in this study were designed to provide a wide range of environmental conditions to better understand the growth and yield response of soybean genotypes. Plants were exposed to large variations in temperature and photoperiod, both of which increased as the sowing date was delayed, producing a reduction of crop cycle from first to last date of sowing.

Analysis of variance

The variance due to genotypes was highly significant for all the characters in all the sowing dates; however, differences among early genotypes were non-significant for some of the characters particularly for days to flowering and days to full grain development in all the sowings (February to June), indicating photoperiod insensitivity of early maturing genotypes. Differences among main season genotypes were significant for most of the characters in different sowings. The combined analysis of variance over environments revealed that genotypes, sowing dates and their interactions were significant for plant height at flowering, biomass at flowering, number of branches per plant, biomass at maturity, 100-seed weight, GY and HI which indicates that interaction of genotypes with environment was of considerable importance in determining biomass, HI, yield and yield components. These results are in agreement with Comstock and Moll (1963).

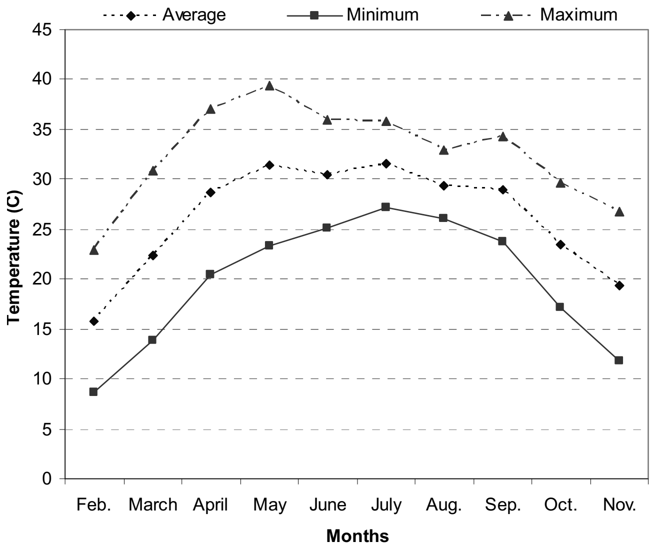

Fig. 1 Temperature (°C) from Feb. 2004 to Nov. 2004. Source: Meteorological observatory, Punjab Agricultural University, Ludhiana (India).

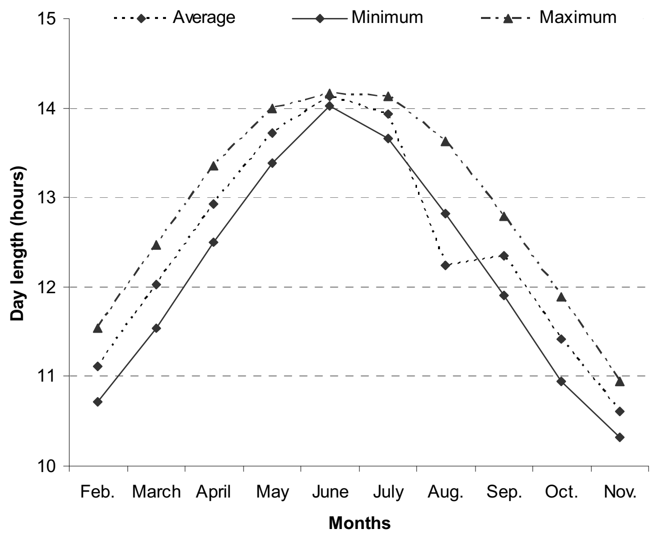

Fig. 2 Day length from Feb. 2004 to Nov. 2004.

Biomass accumulation for different sowing dates

Biomass accumulation at flowering and total biomass at maturity is considered to be important parameters for determining GY in soybean. All the early selection lines had higher biomass accumulation at flowering in February sowing than that in other sowings (**Table 1**) suggesting that growth rate of early selection lines was maximum in February whereas main season genotypes had higher biomass accumulation in June sowing i.e. at their optimum time of sowing which shows that main season genotypes are adapted to grow better at higher temperature. Higher biomass accumulation in February for early genotypes was due to longer vegetative period as flowering in February was delayed due to low temperature. In general, main season genotypes had higher biomass production at flowering as compared to early maturing, photo-thermo insensitive genotypes.

Mean biomass at maturity for early genotypes was 18.95 g in February, 22.15 g in March, 25.41 g in April, 26.05 g in May and 22.75 g in June sowing (**Table 1**). Main season genotypes produced biomass of 35.17, 35.33, 36.86, 46.30 and 43.78 g for the five sowings, respectively. Main season genotypes due to their longer growth period produced more biomass at maturity than early genotypes. Biomass production was highest in May sowing both for early and main season genotypes. This may be due to optimum temperature conditions favouring vegetative growth.

Table 1 Effect of sowing dates on total biomass accumulated, harvest index and other related plant attributes. Observations were recorded on five randomly taken competitive plants in each replication.

Genotype	Plant height (cm)					No. of branches at flowering					Biomass at flowering (g)					No. of pods/plant				
	Feb	Mar	Apr	May	June	Feb	Mar	Apr	May	June	Feb	Mar	Apr	May	June	Feb	Mar	Apr	May	June
E5	19.3	15.8	12.3	12.8	20.3	5.0	2.9	3.8	2.1	2.7	11.2	4.4	5.9	3.4	5.1	39.7	31.8	39.0	38.3	49.9
E6	17.4	13.7	12.3	9.7	18.3	4.8	4.0	3.5	2.1	3.2	8.7	6.7	5.5	2.1	5.5	39.9	53.9	42.6	47.0	50.3
E7	18.6	15.2	10.9	13.2	18.9	6.1	4.5	3.2	2.6	3.6	12.9	6.9	3.7	2.6	5.6	51.4	45.8	36.8	33.1	51.2
E8	23.1	18.3	14.5	13.3	20.3	5.8	3.1	3.8	2.7	3.3	12.9	5.4	5.9	3.8	6.2	47.6	34.3	34.3	36.6	47.9
E9	22.1	18.6	12.3	15.5	22.3	5.8	3.6	3.7	3.2	4.7	13.4	6.3	5.9	6.2	8.8	45.6	42.0	36.6	37.3	39.0
E10	19.7	17.1	11.3	13.5	25.5	5.3	3.3	2.8	2.5	3.5	7.4	4.2	4.6	3.3	7.0	38.8	35.4	31.7	38.6	53.8
E11	18.9	15.9	11.8	14.8	20.7	3.9	3.6	3.3	2.5	4.4	6.6	4.9	4.7	4.8	6.6	43.6	43.9	38.3	34.4	32.4
E12	20.9	15.9	11.2	13.5	17.8	4.1	3.6	3.2	2.6	2.6	7.1	4.7	4.3	3.9	4.5	33.2	49.2	39.3	42.5	32.4
E13	20.1	16.9	13.6	13.7	19.4	3.0	3.4	4.6	3.0	3.0	5.1	5.7	6.1	4.1	4.5	41.8	46.1	39.3	50.5	61.7
E14	18.7	16.3	12.7	14.7	24.6	5.4	3.4	4.4	2.8	3.9	10.8	6.3	8.3	5.7	8.9	49.1	49.7	28.6	37.8	34.7
E15	19.5	14.8	10.4	12.3	18.5	5.5	4.3	4.2	2.3	3.5	10.7	5.3	8.0	3.2	5.9	40.0	44.8	44.0	37.6	34.6
E16	16.6	14.7	9.8	11.2	17.4	4.5	3.1	2.4	2.2	3.2	4.9	4.6	3.2	2.9	4.7	47.7	30.4	37.4	31.7	47.9
E17	19.6	15.4	13.2	13.0	22.1	5.0	3.2	3.7	2.6	3.8	11.6	4.1	4.3	3.0	6.4	41.9	40.7	36.4	44.8	31.9
E18	19.1	16.5	14.3	12.3	22.4	5.9	3.8	3.6	2.9	3.4	8.0	5.5	5.7	5.2	7.9	43.3	49.1	40.4	59.5	54.4
E19	17.8	14.4	12.3	14.6	19.8	5.4	3.6	4.0	3.8	3.7	7.9	6.1	5.1	5.7	6.2	37.7	37.5	38.7	35.4	47.9
SL295	30.8	35.9	28.7	29.4	43.4	8.3	4.1	3.5	3.2	2.6	14.2	13.8	13.1	13.1	19.2	66.2	76.1	78.6	86.6	104.0
SL443	22.1	25.7	26.2	28.2	34.1	8.1	5.8	3.4	3.3	3.5	12.1	14.5	12.8	14.1	18.7	63.8	86.8	80.1	87.7	101.6
SL459	28.7	33.1	31.8	30.6	37.7	7.8	4.1	3.3	3.7	3.3	11.7	10.7	12.5	12.3	17.3	36.8	61.9	66.2	94.3	103.9
Pb. No. 1	30.7	33.0	26.5	33.5	38.2	8.7	5.2	3.2	3.5	3.2	20.6	16.1	13.9	14.5	22.2	77.4	52.3	90.3	109.3	120.7
E4	25.0	21.9	26.0	29.5	32.9	3.8	3.0	3.3	3.0	2.2	8.4	3.3	9.8	11.7	16.7	35.3	50.2	44.6	102.3	103.3
Early genotypes																				
Mean	19.4	16.0	12.2	13.2	20.6	5.0	3.6	3.6	2.7	3.5	9.3	5.4	5.4	4.0	6.2	42.8	42.3	37.6	40.3	44.7
Range	16.6-23.1	13.7-18.6	9.8-14.5	9.7-15.5	17.4-25.5	3.0-6.1	2.9-4.5	2.4-4.6	2.1-3.8	2.6-4.7	4.9-13.4	4.1-6.9	3.2-8.3	2.1-6.2	4.5-8.9	33.2-51.4	30.4-53.9	28.6-44.0	31.7-59.5	31.9-61.7
Main season genotypes																				
Mean	27.5	29.9	27.8	30.2	37.2	7.3	4.4	3.3	3.3	3.0	13.4	11.7	12.4	13.1	18.8	55.9	65.5	72.0	96.0	106.7
Range	22.1-30.8	21.9-35.9	26.0-31.8	28.2-33.5	32.9-43.4	3.8-8.7	3.0-5.8	3.2-3.5	3.0-3.7	2.2-3.5	8.4-20.6	3.3-16.1	9.8-13.9	11.7-14.5	16.7-22.2	35.3-77.4	50.2-86.8	44.6-90.3	86.6-109.3	101.6-120.7

Table 1 (Cont.)

Genotype	Total biomass (g)					100-seed weight (g)					Grain yield (g)					Harvest index (%)				
	Feb	Mar	Apr	May	June	Feb	Mar	Apr	May	June	Feb	Mar	Apr	May	June	Feb	Mar	Apr	May	June
E5	17.1	19.2	23.9	22.4	23.9	13.6	15.1	12.0	12.6	12.5	8.5	8.3	9.4	9.4	10.7	50.0	43.3	39.4	42.1	44.8
E6	17.4	26.0	27.7	17.1	22.9	10.6	14.0	12.8	12.5	12.7	8.7	10.7	10.4	6.4	11.1	50.1	41.2	37.6	37.7	48.4
E7	25.9	28.7	26.6	27.3	29.2	13.6	15.0	12.1	12.4	11.7	12.5	12.5	10.4	10.5	12.1	48.1	43.5	39.1	38.6	41.4
E8	22.4	18.5	25.4	22.6	29.6	15.4	15.1	12.1	12.3	13.9	11.3	8.7	10.0	8.5	13.3	50.7	46.9	39.3	37.7	44.8
E9	19.7	24.3	23.6	25.2	19.7	14.1	14.4	12.8	13.1	11.5	10.9	12.1	8.4	9.4	8.5	55.6	49.7	35.5	37.4	43.1
E10	17.4	18.1	23.5	31.1	26.9	15.4	14.9	13.3	13.0	11.7	9.2	8.0	9.2	11.3	10.9	52.8	44.1	39.1	36.3	40.6
E11	19.9	18.1	21.0	20.3	15.5	13.9	14.8	9.5	11.8	10.9	11.1	9.1	8.2	8.3	6.7	55.5	50.3	39.1	40.8	43.5
E12	11.2	32.2	29.0	37.7	17.4	13.7	15.9	13.4	12.7	11.4	6.6	15.4	10.3	13.6	7.3	58.5	47.8	35.6	36.1	42.1
E13	14.8	25.2	24.5	24.8	27.5	12.5	14.5	10.1	11.1	10.2	6.7	11.3	9.4	8.8	12.2	45.4	45.0	38.3	35.5	44.4
E14	23.8	26.7	20.9	28.6	24.7	16.3	16.7	11.7	13.5	12.5	11.1	12.6	7.1	10.0	9.7	46.6	47.2	34.0	34.9	39.2
E15	20.7	21.4	30.3	26.7	17.5	13.9	13.7	12.1	12.5	12.3	10.4	8.3	11.4	10.8	8.4	50.3	38.6	37.7	40.5	47.9
E16	20.9	19.4	24.0	20.6	23.8	13.0	13.9	11.4	12.4	12.3	10.6	8.8	8.7	7.4	9.9	50.6	45.5	36.1	36.1	41.5
E17	20.7	19.5	23.3	22.3	16.5	13.6	15.4	12.3	11.5	10.9	9.3	10.0	8.5	8.7	6.9	44.9	51.1	36.5	39.1	42.0
E18	17.6	21.6	27.6	30.0	27.5	13.9	14.9	11.4	13.1	12.0	8.3	10.6	10.5	11.6	12.7	47.3	49.3	37.9	38.6	46.2
E19	20.9	22.5	30.1	32.2	22.6	16.0	15.0	13.2	12.3	10.8	11.7	10.8	11.5	12.7	9.7	56.1	48.0	38.2	39.5	43.1
SL295	39.3	40.9	37.6	53.5	48.0	10.9	10.2	9.8	10.0	11.3	14.5	16.4	15.1	21.5	22.6	36.9	40.1	40.2	40.3	47.0
SL443	33.0	48.9	40.2	41.6	43.9	9.5	9.3	9.2	9.1	10.9	11.8	20.0	14.0	16.2	20.1	35.7	40.9	34.7	38.9	45.9
SL459	25.7	34.4	40.1	43.4	40.3	9.5	7.6	8.0	8.2	8.8	10.9	13.4	15.4	17.7	17.4	42.5	39.0	38.5	40.7	43.1
Pb. No. 1	53.6	27.5	39.5	49.5	53.2	8.7	9.5	8.6	8.0	8.8	14.3	11.4	14.7	20.7	23.9	26.7	41.4	37.2	41.9	44.9
E4	24.2	24.9	26.9	43.5	33.5	7.5	7.6	7.2	7.5	7.6	9.8	9.7	10.4	18.2	15.7	40.2	38.8	38.5	41.7	47.0
Early genotypes																				
Mean	19.4	22.8	25.4	25.9	23.0	14.0	14.9	12.0	12.5	11.8	9.8	10.5	9.6	9.8	10.0	50.8	46.1	37.6	38.1	43.5
Range	11.2-25.9	18.1-32.2	20.9-30.3	17.1-37.7	15.5-29.6	10.6-16.3	13.7-16.7	9.5-13.4	11.1-13.5	10.2-13.9	6.6-12.5	8.0-15.4	7.1-11.5	6.4-13.6	6.7-13.3	44.9-58.5	38.6-51.1	34.0-39.4	34.9-42.1	39.2-48.4
Main season genotypes																				
Mean	35.2	35.3	36.9	46.3	43.8	9.2	8.8	8.5	8.6	9.5	12.3	14.2	13.9	18.9	19.9	36.4	40.0	37.8	40.7	45.6
Range	24.2-53.6	24.9-48.9	26.9-40.2	41.6-53.5	33.5-53.2	7.5-10.9	7.6-10.2	7.2-9.8	7.5-10.0	7.6-11.3	9.8-14.5	9.7-20.0	10.4-15.4	16.2-21.5	15.7-23.9	26.7-42.5	38.8-41.4	34.7-40.2	38.9-41.9	43.1-47.0

Grain yield and yield contributing traits as affected by sowing dates

There was considerable variability in GY across sowing dates. The effect of sowing date on GY varied with genotypes. Main season genotypes always produced more grains than early genotypes because main season genotypes accumulated sufficient vegetative matter before flowering to support more grains per plant. Early maturing genotypes were extremely early in flowering (30-35 days) which resulted in less biomass accumulation and ultimately low yield as compared to main season genotypes. Hartwig (1954) suggested that the vegetative period should be at least 45 days to optimize seed yields. Highest GY in main season genotypes was obtained in June sowing (19.94 g/plant) followed by May sowing (18.86 g/plant). The reason for this is that in May and June sowings number of pods was higher as compared to other sowings. Early maturing genotypes being insensitive to photoperiod and temperature variations in different sowing dates had less variation for GY that ranged between 9.55 g/plant (April sowing) to 10.48 g/plant (March sowing). These findings were not in conformation to the results obtained by Kantolic and Slafer (2007) who found that the sensitivity to photoperiod remained high during the reproductive period and was highly and positively coupled with the process of generation of yield. The exposure to extended photoperiods increased the seed yield per unit area and plants exposed cycles of extended photoperiods tended to establish more seeds than those exposed to fewer cycles. Similarly Kumar *et al.* (2008) also iterated in their studies that prediction of growth stages beyond podding was less accurate in soybean because of difficulties associated with indeterminate nature of crop. They also reported decrease in GY with delayed sowing that again uncorroborated our findings. Among main season genotypes SL 295 and Pb. No. 1 had highest GY over all sowings whereas among early maturing genotypes, E7 and E19 had higher yield.

Early genotypes showed higher HI in February and March sowing whereas main season genotypes had highest HI in June sowing due to their adaptability to specific environmental conditions. HI for early genotypes ranged from 37.57% (April sowing) to 51.59% (February sowing). Among the main season genotypes highest HI (45.57%) was recorded in June sowing and lowest value (36.41%) was in February sowing In February sowing, nine out of 15 early genotypes had HI more than 50% whereas main season genotypes never showed more than 47% HI.

Like GY, pod production by early genotypes did not vary much over sowing dates. On an average early genotypes produced 37.6 pods/plant (March sowing) to 44.7 pods/plant (June sowing). The range for number of pods/plant was wide for normal season genotypes viz. 33.2 to 77.43 in February, 30.4 to 86.77 in March, 28.57 to 90.33 in April, 31.7 to 109.33 in May and 31.9 to 120.67 in June sowing (**Table 1**). Different genotypes produced varying number of pods at different sowing dates which may be attributed to varying degree of flowering period and flower drop by different genotypes. These results were in conformation to previous findings of Egli *et al.* (1985) who revealed that variation in pod and seed number may be more closely related to variations in crop growth rate than to variations in the allocation of assimilate between vegetative and reproductive plant parts. Likewise, Egli (2005) suggested the role of the length of the flowering period that varied among cultivars, growth habits (indeterminate and determinate) and environments. The reproductive success of flowers produced early in the period is usually greater than those produced later. Lowest number of pods was observed in February sowing and highest in the month of June.

100-Seed weight was much higher in early genotypes than main season genotypes in all the sowings. The mean 100-seed weight for early genotypes was 13.98 g in February, 14.89 g in March, 12.02 g in April, 12.45 g in May and 11.82 g in June sowing whereas these values for main season genotypes were 9.22, 8.85, 8.54, 8.55 and 9.49 g in February, March, April, May and June sowing, respectively. Reduction in seed weight in main season genotypes as compared to early genotypes suggests the effect of day length and temperature on grain filling. In early maturing genotypes grain filling period was exposed to high temperature and longer photoperiod of May and June. Main season genotypes being sensitive to photoperiod and temperature flowered in August irrespective of sowing date, thus, grain filling period in these genotypes fall in comparatively low temperature of September and October. Previous studies (Zheng *et al.* 2009) showed that elevated mean daily temperature during seed filling period had a discernible positive impact on grain filling in soybean. Their results also indicated that 22% variation in year to year yield changes (1987-2007) could be explained by average maximum temperature warming during seed filling period in soybean.

Table 2 Estimates of t-values of different traits with respect to grain yield.

Character	t-value
Plant height	1.37
No. of branches at flowering	0.72
Biomass at flowering	1.16
No. of pods/plant	0.03
Total biomass	12.64*
100-seed weight	0.07
Harvest index	4.42*

* Different letters within a column indicate significant differences according to the *t*-test (P = 0.05). Observations were recorded on five randomly taken competitive plants in each replication

All the genotypes showed maximum plant height in June sowing because high temperature and longer day length prevailed during early plant growth in June sowing. Camara *et al.* (1995) reported that long photoperiod and/or high temperature resulted in taller soybean plants. Generally plants of photosensitive genotypes were taller than photo-insensitive genotypes in all the sowings. Branching at flowering was maximum in February sowing and minimum in May sowing. This was due to the fact that in February sowing, all the genotypes remained in vegetative phase for longer period. Decline in branching after February sowing in early as well as main season genotypes suggests that low environmental temperature and shorter day length favours branching, which was in coincidence with the previous results obtained from the experiments of Kantolic and Slafer (2001) who reported that all the cultivars sown on 12th February showed increased branching but did not support any decline in branching as no sowing was attempted after February. They also reported an increase in branch number below the node where the first open flower was recorded validating our results that branch number was influenced more by pre- than post-flowering conditions. Han *et al.* (2006) investigated the post-flowering photoperiod effects on both vegetative growth and reproductive development and found that number of branches per plant were higher in long day condition over short day condition, in contrast to our results.

Components contributing to grain yield

Multiple regression analysis was performed on the raw data (**Table 2**). All the yield contributing traits viz. plant height, biomass, number of branches, number of pods/plant, 100-seed weight, biomass at maturity and HI are independently related to yield with total biomass and HI having significant and positive relationship with GY. The significant *t*-values for biomass (12.64) and HI (4.42) showed that these are the important determinants of GY. Also high values for regression coefficients for biomass at maturity (0.39) and HI (0.19) support our results. Path coefficient analysis of soybean yield and yield components showed that HI and plant dry matter were the most important yield-determining traits (Shukla *et al.* 1998). Results from multiple regression analysis are in agreement with the significant correlations observed for seed yield with biomass and HI. Rao *et al.* (2002) evaluated 12 soybean genotypes, including three from Japan, for their agronomic performance, genotype × environment (GE) interactions, and yield stability at four locations in the USA from 1994 to 1997. Genotypic differences for the traits like seed yield, biomass, HI, and 100-seed dry weight were examined and found to be significant. The genotype effects were significantly larger than the location × year effects for plant height, seed weight, and HI, but not for biomass or GY. Biomass and HI were important determinants of seed yield. They also observed a positive correlation of seed yield with biomass production and HI, thus testifying our results.

CONCLUSION

The present study showed that both genotypes and sowing dates had significant effects on biomass accumulation, seed yield, yield components and HI in soybean. From multiple regression analysis, it can be concluded that total biomass and HI had a significant effect on GY. Thus, GY can be improved by increasing biomass production and or increasing HI. Study also indicated that main season genotypes had higher biomass resulting in more GY as compared to early maturing genotypes. On the other hand early maturing genotypes recorded higher HI but low biomass than main season genotypes particularly in February and March sowing. Further, for the main season genotypes yield could be increased by increasing HI because already they have sufficient biomass. Morrison *et al*. (1999) found that there was no significant change in biomass produced by old and new cultivars but HI increased linearly by 0.47% per year. However, for early maturing genotypes GY can be increased by increasing biomass production because they have less biomass production to support higher yield. It also demonstrated the possibility of growing soybean during spring/ summer.

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