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Influence of Planting Dates and Plant Densities on Photosynthesis Capacity, Grain and Biological Yield of Soybean [*Glycine max* (L.) Merr.] in Karaj, Iran

Mazahero Daroish, Zeinali Hassan and Madani Ahad
Department of Agronomy and Plant Breeding,
Agriculture College of Tehran University, Iran

Abstract: The experiment was carried out to study importance of photosynthesis capacity (NAR, CGR and LAI) during seed filling period and its relationship with grain and biological yield. Maximum grain yield of 437.2 g m^{-2} was attained by early planted crop (May 10). The rate of decrease in grain yield was noted about 22.5 g m^{-2} reduction with one week delay in sowing. Grain yield increased 38% with increase in plant density from 20 to 60 plants m^{-2} and maximum grain yield of 433.0 g m^{-2} was recorded at 60 plants m^{-2}. Significant Relationship ($r = 0.93$, $p<0.01$) between biological yield at early seed filling stage (R_5) and grain yield indicate that greater total dry matter results in greater seed yield if the total dry matter is produced before seed filling period. No NAR differences were observed among planting dates during vegetative stage and early reproductive stage (early flowering to early seed filling) and LAI during vegetative stage (emergence to early flowering) was 16.66% greater for late sowing date, therefore more dry matter accumulation at early seed filling stage (R_5) for early planted soybean is commonly due to greate LAI during early reproductive period (R_1 to R_5). No NAR differences were observed among plant densities during vegetative stage (emergence to early flowering), therefore more dry matter accumulation at early seed filling stage (R_5) for highest plant density is commonly due to greater LAI during emergence to early seed filling and greater NAR during early reproductive stage (R_1 to R_5). NAR (source activity) during seed filling period was a poor predictor of grain yield while, LAI (source size) at early seed filling stage (R_5) strongly affected CGR, total dry accumulation and grain yield.

Key words: *Glycine max* (L.) Merr, photosynthesis capacity, seed filling period, plant density, planting date

INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] has the ability to produce similar yields across a broad range of management systems and planting dates and plant populations[1]. Greater NAR in low compared with normal plant populations during the late vegetative and early reproductive periods is some times a contributing factor to CGR and grain yield equilibration across plant densities[2]. Hunt[3] demonstrated that the compensatory growth and alterations in plant development among cultivars, management systems and planting dates had no impact on soybean yield. Soybean yield is determined by the genetic yield potential and the interactions with environmental conditions and is correlated with the number of seeds and seed size[4]. Genetic and cultural strategies for increasing soybean yield might be improved by identifying growth periods where potential yield is limited by assimilatory capacity[5]. Schou *et al.*[6] concluded that yield is more influenced by changes in source strength during R_1 to R_7 compared with emergence to R_1 period. Several studies suggest that yield is more source restricted during the early compared late reproductive period[7,8]. The early reproductive period (R_1 to shortly past R_5) is most sensitive to altered source strength and CGR since it is the time in which the final pod numbers are formed[1]. Hayati[9] proposed that greater total dry matter results in greater seed yield if total dry matter is produced before seed initiation. In contrast, Weber *et al.*[10] founded that both total dry matter and LAI were poor predictors of seed yield. Wells[11] examined various plant density and row width combinations and showed that similar grain yield occurred despite significant difference in total dry matter yield over the growing season.

Overproduction of vegetative dry matter does not always reduce seed yields, but improved partitioning of dry weight could result in higher seed yields[12]. Total dry matter is influenced by CGR, relative growth rate, relative leaf area growth rate and net assimilation rate[13]. Crop growth rate is a prime dynamic growth factor to study since it reflects canopy assimilatory capacity and

Corresponding Author: Madani Ahad, Department of Agronomy and Plant Breeding, Agriculture College of Tehran University, Iran

effects total dry matter levels and equilibrates rate[9]. Shibles and Weber[14] demonstrated that optimal CGR and yield resulted when LAI was sufficient (3 to 3.5) to achieve an optimal light interception of 95% by R5. However, subsequent studies showed that the relationship between LAI and optimal CGR varied with environmental conditions[3,13].

MATERIALS AND METHODS

The experiment was carried out at the agriculture research farm of Tehran University in Karaj during 2003. The site is located at 35°25′ N latitude, 71°25′ E longitudes and an altitude of 1321 m above sea level. Karaj is located about 30 km west of Tehran thus has a semi-arid (375 mm rainfall yearly) climate. The soil of experimental site was clay loam with a clay type of montmorillionite, low in nitrogen (0.04-0.05%), low in organic matter (0.9-1%) and alkaline in reaction with a pH of 7.8 and Ec=0.44 dS m^{-1}.

The experiment was laid out in Randomized Complete Block Design with a split plot arrangement have four replication. Four planting dates (May 10, May 25, June 10 and June 25) were allotted to main plots and tree plant densities (20, 40 and 60 plant m^{-2}) were allotted to sub plots. A sub plot size of 3×6 m, having 6 rows 6 m long was used. Sowing was done in hills. Two to five seeds per hill were planted and thinning was done to leave 1, 2 and 3 plants $hill^{-1}$ corresponding to 20, 40 and 60 plants m^{-2}. Normal cultural practice was followed uniformly for all experimental units. The plots were hand weeded in different vegetative stages. Irrigation was applied at weekly interval. Areas of 4 m^2 (2 m from 4 middle rows) were hand harvested from each sub plot to estimate grain and biological yield. Sections of 1 m^2 (0.5 m from 4 middle rows) from each plot were hand harvested at early flowering (R_1), early seed filling period (R_5) and late seed filling period (R_6) to determine leaf area, leaf dry weight and Total Dry Matter (TDM). Dry weight samples were oven-dried at 60°C to a constant weight to determine growth on a dry weight basis. Leaf area index was measured at early flowering (R_1), early seed filling period (R_5) and late seed filling period (R_6) with a leaf area meter. Crop Growth Rate (CGR) and Net Assimilation Rate (NAR) during vegetative stage (emergence to R_1), early reproductive stage (R_1 to R_5) and seed filling period (R_5 to R_6) were calculated by following equations:

$$CGR = (W_2\text{-}W_1)/(T_2\text{-}T_1)\,(1/S)$$
$$NAR = (W_2\text{-}W_1)/(T_2\text{-}T_1)\,(\ln A_2\text{-}\ln A_1)/(A_2\text{-}A_1)$$

Where:

S = The ground area on which the dry weights have been estimated (m^2)

T_2-T_1 = Time interval between two successive harvests (week for NAR, day for CGR)

W_2-W_1 = Total dry matter difference between two successive harvests (g)

A_2-A_1 = Leaf area difference between two successive harvests (m^2)

Data were statistically analyzed using analysis of variance technique appropriate for randomize complete block design with plant densities split on planting dates and Duncan ($p<0.05$) test was employed for mean separation when F-values were significant.

RESULTS AND DISCUSSION

Grain yield: The statistical analysis of data indicates that planting dates and plant densities had significant effect on grain yield (Table 1). Maximum grain yield of 437.2 g m^{-2} was attained by early planted crop. Grain yield decreased significantly with delay in planting (Table 2). The rate of decrease in grain yield was noted about 22.5 g m^{-2} reduction (5.1% reduction) with one week delay in sowing. Grain yield increased 38% with increase in plant density from 20 to 60 plants m^{-2} and maximum grain yield of 433.0 g m^{-2} was recorded at 60 plants m^{-2} (Table 2). Interaction between plant densities and planting dates was significant (Table 1 and 2) hence there was not significant difference between grain yield of early planted crop at lowest plant density (May 10 at 20 plants m^{-2}) with late planted crop at highest plant density (June 25 at 60 plants m^{-2}). It is due to that the rate of decrease in grain yield with delay in sowing from May 10 to June 25 for lowest plant density (30.85% reduction) was 2.9 time more than highest plant density (10.5% reduction) also the rate of increase in grain yield with increase in plant density from 20 to 60 plants m^{-2} for early planted crop (48.02% reduction) was 3.64 time more than late planted crop (13.17% reduction). Two latest sowing dates (June 10 and June 25) obtained similar grain yield across all of plant densities. It may results from equilibration of CGR during early reproductive period which cause an equivalent numbers pods per square meter[15].

Biological yield at early seed filling period (total dry matter accumulation at R_5): The statistical analysis of data indicates that planting dates and plant densities had significant effect on biological yield (Table 1). Maximum

Table 1: Mean squares of planting dates and plant densities effects on grain yield ($g\ m^{-2}$) and biological yield ($g\ m^{-2}$) at R_5

SOV	d.f	Grain yield ($g\ m^{-2}$)	Biological yield at R_5 ($g\ m^{-2}$)
Replication	3	1069.256*	12000.123*
Planting date	3	49344.700**	343521.221**
Error (Ea)	9	267.314	300.415
Planting density	2	109555.437**	803252.326**
Planting date ×plant density	6	3586.766**	310256.233**
Error (Eb)	24	379.946	500.211

**, * and NS indicate significance at 0.01, 0.05 and lack of significance at 0.05, respectively, R_5: early seed filling period

Table 2: Mean comparison of grain yield ($g\ m^{-2}$) as affected by planting dates and plant densities

	Planting densities (plant m^{-2})			
Planting dates	20	40	60	Mean
May 10	385.3c	448.3ab	478.2a	437.2a
May 25	275.3e	329.1d	428.0b	344.1b
June 10	212.2f	279.0e	410.5bc	300.6c
June 25	200.2f	290.3e	415.2bc	301.9c
Mean	268.3c	336.7b	433.0a	

*Means of the same category followed by different letters are significantly different at 0.05 % level of probability using Duncan Test

Table 3: Mean comparison of biological yield at R_5 ($g\ m^{-2}$) as affected by planting dates and plant densities

	Planting densities (plant m^{-2})			
Planting dates	20	40	60	Mean
May 10	1277b	1387ab	1514a	1393a
May 25	902d	1087c	1489a	1160b
June 10	930d	937d	1320b	1062c
June 25	808d	918d	1310b	1012c
Mean	979c	1082b	1408a	

* Means of the same category followed by different letters are significantly different at 0.05 % level of probability using Duncan Test
R_5: Early seed filling period

biological yield of 1393 $g\ m^{-2}$ was attained by early planted crop. Grain yield decreased significantly with delay in planting (Table 3). Planting date influenced dry matter accumulation at R_5 because of cooler temperature that delayed reproductive growth stages. Egli and Guffy[13] founded that maximum dry matter accumulation occurred for early planting (May 1) at R_5 which was 5% higher than late planting date while, Jeffers and Shibles[15] reported that late planted soybean had 7% higher dry matter accumulation at harvest than early planted, which may be attributed to the establishment difficulties at early planting date.

The rate of decrease in biological yield was noted about 63 $g\ m^{-2}$ reduction (4.5% reduction) with one week delay in sowing. Biological yield increased 30.4% with increase in plant density from 20 to 60 plants m^{-2} and maximum biological yield of 1408 $g\ m^{-2}$ was recorded at 60 plants m^{-2} (Table 3).

Interaction between plant densities and planting dates was significant (Table 1 and 3) and there was not significant difference between grain yield of early planted crop at lowest plant density (May10 at 20 plant m^2) with late planted crop at highest plant

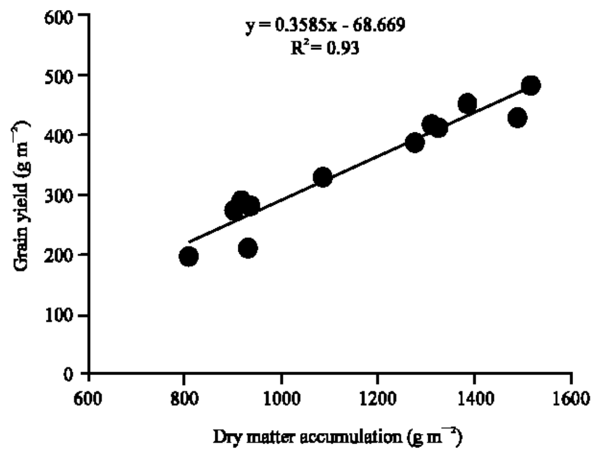

Fig. 1: Relationship between dry matter accumulation at early seed filling (R_5 and gran yield)

density (June 25 at 60 plant m^2) . It is due to that the rate of decrease in biological yield with delay in sowing from may 10 to June 25 for lowest plant density (36.7% reduction) was 2.7 time more than highest plant density (13.4 % reduction). Significant relationship (r = 0.93**) between biological yield at early seed filling period and grain yield indicate that greater total dry matter results in greater seed yield if the total dry matter is produced before filling period (Fig. 1). Several researchers have also maintained the importance of dry matter accumulation to soybean yield. However, most studies, like Hayati *et al.*[9] have shown that yield is best correlated with an increase in dry mater accumulation and photosynthesis at R_5.

Leaf area index (LAI) at early seed filling period (R_5): The statistical analysis of data indicates that planting dates and plant densities had significant effect on leaf area index at R_5 (Table 4). Maximum LAI of 6.13 was attained by early planted crop. LAI decreased significantly with delay in planting (Table 5). Since most LAI development during the early reproductive period occurs on branches, greater partitioning of total dry matter in to branches by early planted crop could result greater LAI at R_5 for early planted soybean[7]. Egli *et al.*[8,13] showed that at R_5 fraction dry matter in leaves and LAI was 56% and 38% higher for the early planting date compared with the late planting date.

Table 4: Mean squares of planting dates and plant densities effects on LAI at R_5, CGR (g m^{-2} day^{-1}) and NAR (g m^{-2} $week^{-1}$) during R_5 to R_6

SOV	d.f	LAI at R_5	CGR during R_5 to R_6(g m^{-2} day)	NAR during R_5 to R_6 (gr m^{-2} week)
Replication	3	0.24*	0.188*	0.203*
Planting date	3	4.037**	6.863**	7.123**
Error (Ea)	9	0.06	0.047	0.052
Planting density	2	10.838**	19.239**	17.123**
Planting date ×plant density	6	0.236*	0.342**	0.422**
Error (Eb)	24	0.092	0.064	0.085

**, * and NS indicate significance at 0.01, 0.05 and lack of significance at 0.05, respectively, R_5: Early seed filling period; R_5 to R_6: seed filling period

Table 5: Mean comparison of LAI at R_5 as affected by planting dates and plant densities

Planting dates	Planting densities (plant m^{-2}) 20	40	60	Mean
May 10	5.53cd	6.03b	6.83a	6.13a
May 25	4.89e	5.39d	6.19b	5.49b
June 10	4.31f	5.20de	6.00b	5.17c
June 25	3.60g	4.79e	5.89bc	4.76d
Mean	4.58c	5.35b	6.23a	

* Means of the same category followed by different letters are significantly different at 0.05 % level of probability using Duncan test
R_5: early seed filling period

The rate of decrease in LAI was noted about 0.23 m^2 reduction (3.7% reduction) with one week delay in sowing and LAI at R_5 was 22.3% greater for early planting date (May 10) compared with late planting date (June 25). Leaf expansion rate between emergence to R_5 (LAI at R_5/days from emergence to R_5) was similar (0.1 m^2 day^{-1}) for all planting dates (data not shown) despite significant differences in LAI. LAI increased about 26.4% with increase in plant density from 20 to 60 plants m^{-2} and maximum LAI of 6.23 was recorded at 60 plants m^{-2} (Table 5).

Interaction between plant densities and planting dates was significant (Table 4 and 5) and there was not significant difference between LAI of early planted crop at lowest plant density (May 10 at 20 plants m^{-2}) with late planted crop at highest plant density (June 25 at 60 plants m^{-2}). It is due to that the rate of decrease in LAI with delay in sowing from May 10 to June 25 for lowest plant density (34.9% reduction) was 2.5 time more than highest plant density (13.76% reduction).

LAI peaked around early seed filling stage (R_5) for all planting dates before declining (Fig. 2). The early planted soybean achieved enough LAI for optimal light interception at 60 days after emergence compared with 45 days for the late planted soybean (data not showed). LAI during vegetative stage (emergence to R_1) was 16.66 % greater for late planting date compared with the early planting date likely because the temperature was warmer. However, LAI during early reproductive stage (R_1 to R_5) and seed filling period (R_5 to R_6) Averaged 35.23% and 31.22% lower for delayed planting (Fig. 2). It seems that greater radiation absorption during the seed filling period, especially when LAI values are below the critical value for 95% radiation interception results to more grain yield. These data correspond well with previous observations by Board and Harvile[5] that reported that optimal light interaction during vegetative (emergence to R_1) and early reproductive (R_1 to R_5) period was not required to maximized yield. It seems that greater LAI during the seed filling period in consistent with the maintenance of dry matter accumulation later into the seed filling period and grain yield. James E. Board[9] also reported that total defoliation at the three-fourths point of seed filling also reduced yield. No LAI differences were observed among plant densities at early seed filling stage (R_5). However, before seed filling period (emergence to R_5) and during seed filling period (R_5 to R_6), LAI was 33.11% and 17% higher for early planting (Fig. 3). LAI (source size) at early seed filling period (R_5) strongly affects CGR, total dry accumulation and grain yield (Fig. 4 and 5). Pederson[12] reported that dry matter accumulation peaked around R_5 for all management systems before declining and the decline in dry matter was consistent with the onset of leaf senescence and coincided with the decline in LAI.

Crop growth rate (CGR) during seed filling period (R_5 to R_6): Crop growth rate is the rate of change of total plant dry biomass over time. The statistical analysis of data indicates that planting dates and plant densities had significant effect on CGR during seed filling period (Table 4). Maximum CGR of 5.21 g m^{-2} day^{-1} was attained by early planted crop. Joseph and Pederson[10] reported that delayed planting results a more rapid CGR after emergence than early planting likely because the temperature was warmer but at R_5, CGR for delayed planting was 61% lower than early planting date.

CGR decreased significantly with delay in planting (Table 6). The rate of decrease in CGR was noted about

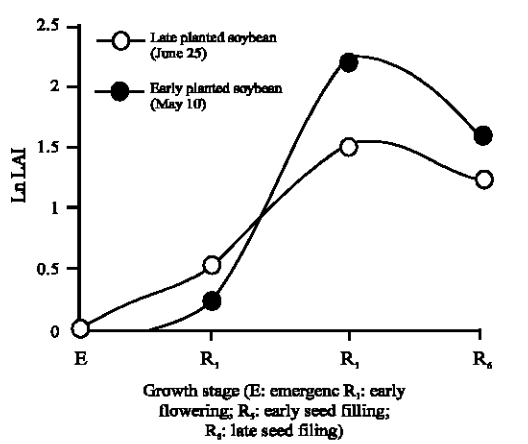

Fig. 2: LAI at various growth stages as affected by planting dates

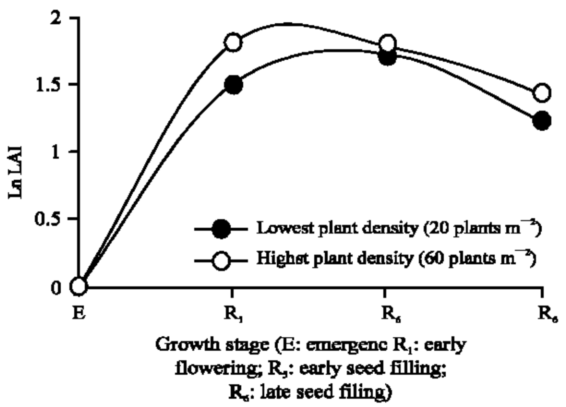

Fig. 3: LAI at various growth stages as affected by plant densities

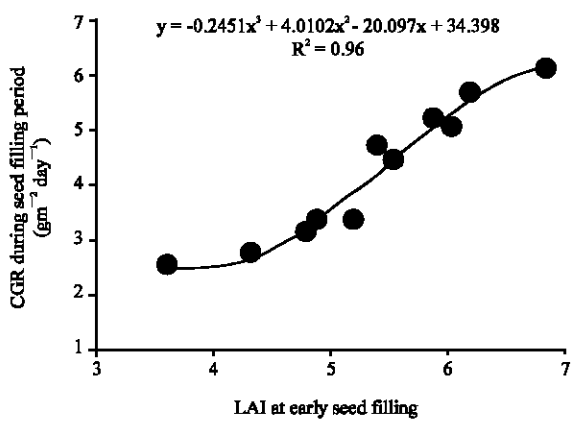

Fig. 4: Relationship between LAI at early seed filling (R_5 and CGR during seed filling period (R_5 to T_6)

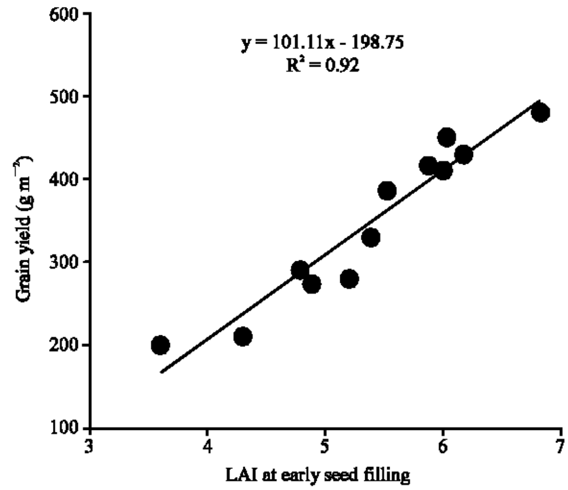

Fig. 5: Relationship between LAI at early seed filling (R_5) and grain yield

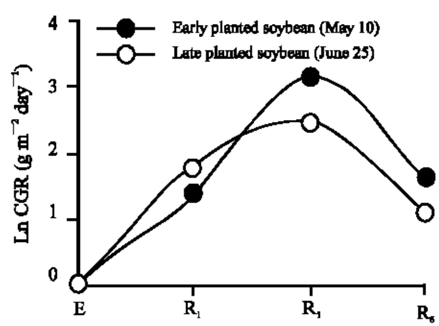

Fig. 6: CGR at various growth stages as affected by planting dates

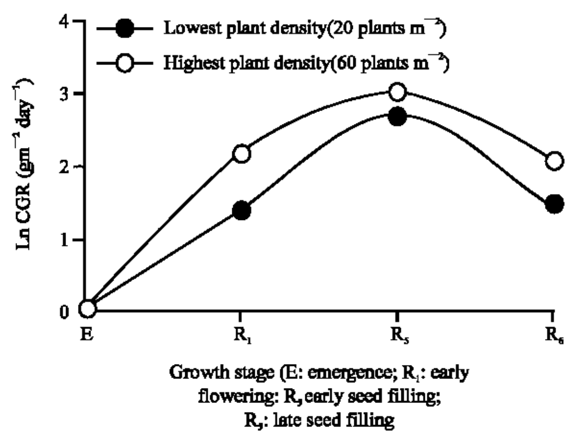

Fig. 7: CGR at various growth stages as affected by plant densities

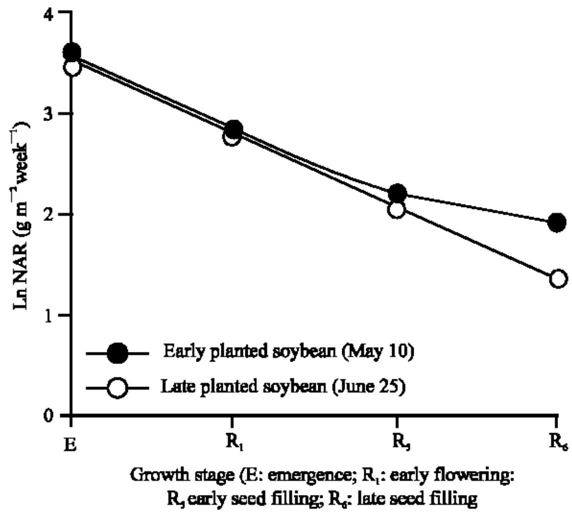

Fig. 8: NAR at various growth stages as affected by planting dates

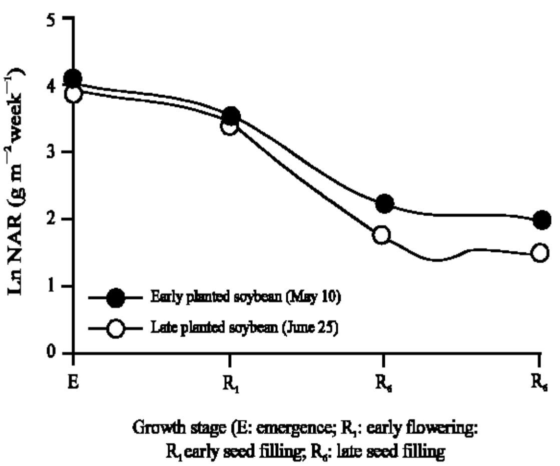

Fig. 9: NAR at various growth stages as affected by plants densities

0.26 g m^{-2} day^{-1} reduction (5% reduction) with one week delay in sowing and CGR during seed filling period was 30.1% greater for early (May 10) planting date compared with late (June 25) sowing date (Fig. 6). CGR increased about 39% with increase in plant density from 20 to 60 plants m^{-2} and maximum CGR of 5.51 g m^{-2} day^{-1} was recorded at 60 plants m^{-2} (Table 6).

Interaction between plant densities and planting dates was significant (Table 4 and 6) and there was not significant difference between CGR of early planted crop at lowest plant density (May 10 at 20 plants m^{-2}) with late planted crop at highest plant density (June 25 at 60 plants m^{-2}). It is due to that the rate of decrease in CGR with delay in sowing from May 10 to June 25 for lowest plant density (42.6% reduction) was 2.88 time more than highest plant density (13.76% reduction).

Delayed planting resulted in a more rapid CGR after emergence than early planting. During vegetative stage (emergence to flowering), CGR for the delayed planting was 33% higher than early planting date likely because the temperature was warmer (Fig. 6). During early reproductive stage (R_1 to R_5) and seed filling period (R_5 to R_6), CGR for the early planting was 25% and 30.1% higher than late planting (Fig. 8). Capenter *et al.*[7] reported that CGR during late reproductive period (R_5 to R_8) was highly associated with total dry matter and grin yield. No CGR differences were observed among plant densities at early seed filling stage (R_5). leaf area expansion rate has been reported to be greater in spares vs. dense stands[16,17], suggesting that more rapid LAI development during the early reproductive period per unit LAI may also contribute to CGR equilibration at R_5 across plant populations. However, before seed filling period (emergence to R_5) and during seed filling period (R_5 to R_6), CGR was 49.11% and 25% higher for highest plant density (Fig. 7).

Net Assimilation Rate (NAR) during seed filling period (R_5 to R_6): Net assimilation rate is a measure of the change in total plant dry biomass per unit leaf area per unit time. The statistical analysis of data indicates that planting dates and plant densities had significant effect on NAR during seed filling period (Table 4). Maximum NAR of 5.91 g m^{-2} $week^{-1}$ was attained by early planted crop. NAR decreased significantly with delay in planting (Table 7). The rate of decrease in NAR was noted about 0.11 g m^{-2} $week^{-1}$ reduction (1.88% reduction) with one week delay in sowing. NAR during seed filling period (R_5 to R_6) was 11.33% greater for early (May 10) planting date compared with late (June 25) sowing date (Fig. 8). It may due to that for early planted soybean, this period (R_5 to R_6) occurs when there is most solar radiation (middle of summer). No NAR differences were observed among planting dates during early vegetative period (emergence to R_1) and early reproductive period (R_1 to R_5) (Fig. 9). NAR decreased about 18.42% with increase in plant density from 20 to 60 plants m-^{2} and maximum NAR of 6.08 g m^{-2} $week^{-1}$ was recorded at 20 plants m^{-2} (Table 7). Greater light interception per unit Lai was associated with this NAR advantage for low plant population[17].

Interaction between plant densities and planting dates was significant (Table 4 and 7) and hence there was

Table 6: Mean comparison of CGR during R_5 to R_6 (g m^{-2} day^{-1}) as affected by planting dates and plant densities

Planting dates	Planting densities (plants m^{-2}) 20	40	60	Mean
May 10	4.46bcd	5.06ab	6.10a	5.21a
May 25	3.36cde	4.70bc	5.66ab	4.67b
June 10	2.76e	3.36de	5.10ab	3.76c
June 25	2.56e	3.16e	5.20ab	3.64c
Mean	3.36c	4.07b	5.51a	

* Means of the same category followed by different letters are significantly different at 0.05 % level of probability using Duncan test
R_5 to R_6: seed filling period

Table 7: Mean comparison of NAR during R5 to R6 (g m^{-2} $week^{-1}$) as affected by planting dates and plant densities.

Planting dates	Planting densities (plants m^{-2}) 20	40	60	Mean
May 10	6.23a	5.88ab	5.64b	5.91a
May 25	6.37a	6.09ab	4.76c	5.74a
June 10	5.95ab	4.48c	4.48c	4.97c
June 25	6.16ab	4.62c	4.96c	5.24b
Mean	6.08a	5.26b	4.96c	

Means of the same category followed by different letters are significantly different at 0.05 % level of probability using Duncan test
R_5 to R_6; seed filling period

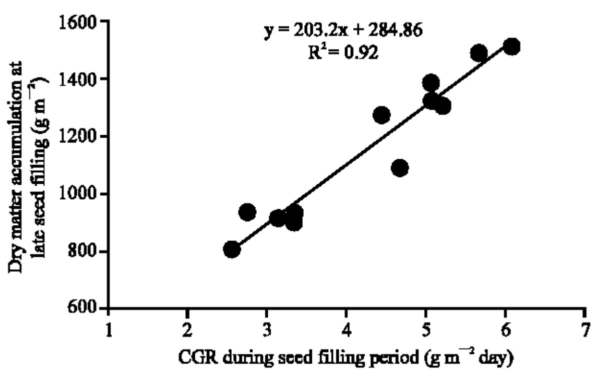

Fig. 10: Relationship between CGR during seed filling period (R_5 to R_6) and dry matter accumulation at late seed filling (R_5)

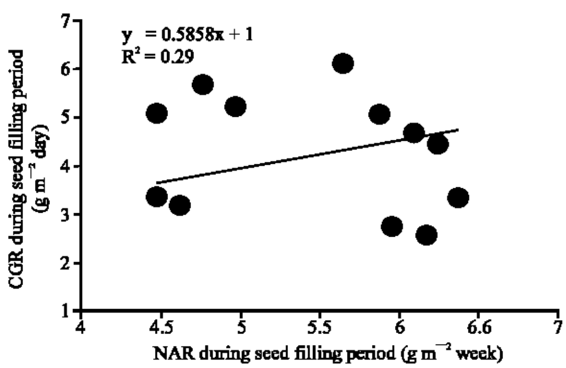

Fig. 11: Relationship between NAR and CGR during seed filling period (R_5 to R_6)

not significant difference between NAR of planting dates at lowest plant density, while the difference between planting dates was significant at middle and highest plant

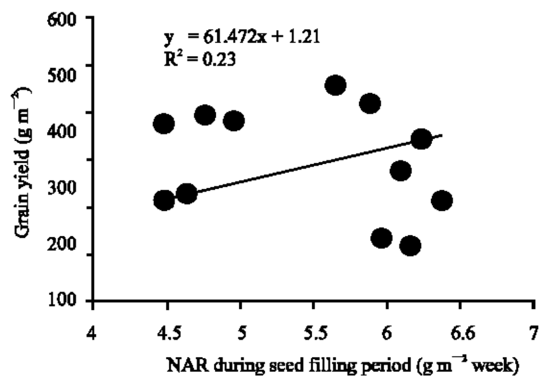

Fig. 12: Relationship between NAR during seed filling period (R_5 to R_6)

densities. It is due to that the rate of decrease in NAR with delay in sowing from May 10 to June 25 for highest plant density (12% reduction) was 10.71 time more than lowest plant density (1.12% reduction).

No NAR differences were observed among plant densities during vegetative stage (emergence to R_1). However, during flowering to late seed filling (R_1 to R_6), NAR was 27.66% higher for lowest plant density (Fig. 9).

CGR affects dry matter levels and grain yield through LAI and NAR (Fig. 10), but Significant Relationship ($r = 0.96$, $p<0.01$) between CGR during seed filling period and LAI at early seed filling period (R_5) and non-significant relationship between CGR and NAR during seed filling period (R_5 to R_6) propose that an increase in CGR and dry matter is more commonly due to an increase in LAI rather than an increase in NAR (Fig. 4 and 11). So NAR (source activity) during seed filling period is a poor predictor of grain yield (Fig. 12).

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