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***Full Length Article***

# Seed Growth Rate, Seed Filling Period and Yield Responses of Soybean (*Glycine max*) to Plant Densities at Specific Reproductive Growth Stages

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## Abstract

There is limited information on the seed growth parameters to different plant densities and their effect on plant yield. The purpose of this study was to investigate the effect of plant population density on changes of rate and duration of seed growth at specific reproductive growth stages, and to examine relationships between seed growth rate (SGR), seed filling period (SFP) and yield components in soybean. In first experiment, three soybean varieties included; AGS 190 (vegetable type), Palmetto and Deing (grain types) were grown at 20, 30 and 40 plants $m^{-2}$. In the second experiment, AGS190, and grain types of Argomolio and Willis were grown at 20, 30 or 50 plants $m^{-2}$. Results indicated that differences in plant density did not affect the SGR or SFP during any reproductive growth stages. Dry matter accumulation rate in seed was highest during reproductive growth stages of R6-R7. This period of growth for seed development was highest in SGR and SFP. As plant density increased, seed number of individual plant decreased. Seed number adjustments and SGR patterns interpreted the stability of final seed size within variety, despite the changes of plant density. Seed growth rate and seed filling period correlated inversely with seed number per plant and positively with final seed size. In conclusion, number of plants per unit area and number of seeds per plant are important features to determine yield potential, not seed growth rate in soybean. 

**Keywords:** Reproductive growth stage; Seed growth rate; Seed filling period; Plant density; Soybean

## Introduction

Growth and reproduction are two important processes in plants. Plant produces biomass, which eventually allocates to various structures and function. The biomass accumulation and its allocation relationship is the core of plant life-history strategies (Parvez *et al*., 2004; Weiner *et al.*, 2009). Plant growth and reproduction are influenced by the spatial distribution of plants in a crop community (Malek *et al.*, 2012). Variation in plant density result in variable growth and seed yield responses (Robinson and Wilcox, 1998; Taj *et al*., 2003; Wajid *et al*., 2004). Plants produced at highest densities are taller, more sparsely branched, lodged more, and set fewer pods and seed than plants at lower densities (Mondal *et al*., 2012). Plant density effects are highly pronounced in crops, where seed yield per plant decreased linearly as plant density intensified. The reduction in seed yield was attributed mostly to the reduction in number of seeds per plant and seeds per pod rather than of seeds size (Malek *et al*., 2012; Mondal *et al*., 2012).

The yield of soybean can be divided into several components, such as number of plants per unit area, number of pods per unit area, seed size and seed yield per plant. Seed yield of soybeans is the result of plant growth processes which as a final sequence are expressed in the yield components. Seed number and seed yield of individual plants responded negatively to increase of plant density. Gan *et al*. (2002) reported that increasing plant population density by two times significantly decreased both biomass and yield of individual plants for semi-determinate and indeterminate tropical soybean varieties. Similarly, yield per plant decreased as population density increased as reported by Ball *et al*. (2000a). The lack of productivity of individual plants was attributed to excessive leaf area, low dry weight increment per unit area of leaf and a strong effect of increased plant population density on rate of leaf senescence (Malek *et al*., 2012).

Seed size is the final component of yield, and there is a differential response of seed size to seed filling period (SFP) and seed growth rate (SGR) (Egli, 1999). Seed filling period which specified by the time for beginning seed fill to pod yellowing, and seed growth rate which defined by the accumulation of seed dry matter during its linear phase of growth both varies among varieties (Guffy *et al*., 1991).

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Many researchers have found a correlation between the duration of SFP and seed yield (Gay *et al*., 1980; Smith and Nelson, 1986; Munier-Jolain *et al*., 1998). However, assimilate supply after R4; the beginning of the SFP, may affect yield. A study on four Japanese soybean varieties showed that difference in dry matter accumulation between old and modern genotypes was most apparent after the beginning of SFP (Shiraiwa and Hashikawa, 1995).

Seed growth rate is positively correlated with final seed size (FSS), but rarely with yield, because of an inverse correlation with seed number and seed size (Egli, 1999; Mondal *et al*., 2011). Plant density strongly affects leaf area and thereby light interception and canopy photosynthesis in soybean (Wells, 1991; Singer, 2001). Carpenter and Board (1997) reported that as plant population of soybean declines, similar yields may achieve through maintenance of crop growth rate during early reproductive period (R1) and greater dry matter partitioning to economic yield.

Physiological understanding of seed development is essential. However, no reports have been found regarding to SGR and SFP responses during R3 to R7 reproductive growth stages of soybean to changes in plant density. Thus, the objective of this study was to investigate the effect of plant population density on changes of rate and duration of seed growth at specific reproductive growth stages, and its relationships with yield components in soybean.

## Materials and Methods

### Experiments Site and Design

Field experiments were conducted in 2010 and 2011 at Universiti Putra Malaysia (UPM), Serdang Selangor, Malaysia. The research site (3°00´ N, 101°42´ E, altitude 43 m) is tropical zone with an average annual precipitation of 2800 mm, an annual maximum temperature of 34°C and 93% relative humidity. The climatic data related to the research locations were taken from the UPM weather station. The textural class of the soil is fine sandy loam to fine sandy clay loam. Three soybean varieties included; AGS 190 (vegetable type), Palmetto and Deing (grain types) were planted in June 2010 and AGS190, and grain types of Argomolio and Willis were planted in May 2011. The plots were over seeded and emerging seedlings were thinned to a uniform stand of 20, 30 or 40 plants per $m^2$ and 20, 30 or 50 plants per $m^2$ for the year 2010 and 2011, respectively. Each plot consisted of seven rows, 5 m length with an inter row spacing of 0.5 m. The field experimental design in both years was randomized complete block design (RCBD) with three replications.

### Crop Management Practices

Supplementary irrigation was applied in both years to reduce water stress when necessary, and weeds were manually controlled. An equally balanced NPK compound fertilizer (15: 15: 15) of 75 kg per hectare was applied on two batches before seeding as basal and at twenty one days after seedling emergence. Organic fertilizer in the form of chicken manure of 15 tons per hectare was applied during land preparation in 2010.

### Plant Sampling and Analysis

Plant developmental growth stages were monitored every 2-3 days according to Fehr and Caviness (1977) on 10 marked plants. Seed growth rate (SGR) was determined from dry weight of seeds detached from 25 pods taken randomly from each plot starting at the beginning pod stage (R3), with a final sampling at physiological maturity (R7). The pods were sampled for the first time at R3 growth stage when pod length reached 1 cm. Seed growth rate within specific growth stages was calculated based on the equation as:

$SGR = (Sdwt_2 - Sdwt_1)/(t_2 - t_1)$ - (Guffy *et al.*, 1991).

Where $Sdwt_1$ and $Sdwt_2$ are seed dry weight between two growth stages, and t is day corresponding to Sdwt determination. The $t_2 - t_1$ is the time interval between two growth stages, it represents SFP between these growth stages.

Ten plants from each plot were chosen randomly in the middle of the plot to measure seed number and seed yield per plant at R7. Seeds were oven-dried at 75-80°C until a constant weight before weighing. For estimating of seed yield per unit area (g $m^{-1}$), plants in one square meter in the middle of each plot were harvested at harvest maturity (R8), and stored in paper envelopes at room temperature. Seed yield per unit area was recorded based on12-13% seed moisture. Hundred seed weight and final seed size (FSS) were also recorded based on12-13% seed moisture.

### Statistical Analysis

The data were analyzed by ANOVA (analysis of variance), and least significant difference was calculated to test significant difference among treatment means. Furthermore, correlation analysis was performed among studied parameters using SAS version 9.2 (SAS Institute Inc., 2010).

## Results

### Seed Growth Rate

The effect of genotypes on seed growth rate (SGR) at all reproductive growth stages was significant but no significant difference on SGR among the plant densities of all genotypes (Tables 1 and 2). Results showed that SGR decreased with increasing plant density in all the varieties. In 2010, SGR was initially small with an average across planting density of 0.12 mg per seed per day during R3-R4 and 0.39 mg per seed per day during R4-R5 for AGS190.

**Table 1:** The effects of plant density on seed growth rate at specific reproductive growth stages in 2010

| Variety | Density (plants $m^{-2}$) | Specific reproductive growth stage R3-R4 | R4-R5 | R5-R6 | R6-R7 | linear phase R5-R7 |
|---|---|---|---|---|---|---|
| | | mg $seed^{-1}$ $d^{-1}$ | | | | |
| AGS190 | 20 | 0.116 | 0.365 | 6.672 | 8.034 | 7.600 |
| | 30 | 0.131 | 0.406 | 6.324 | 8.002 | 7.467 |
| | 40 | 0.122 | 0.412 | 6.607 | 7.700 | 7.333 |
| Palmetto | 20 | 0.132 | 0.139 | 3.608 | 8.746 | 6.433 |
| | 30 | 0.121 | 0.181 | 3.493 | 8.703 | 6.367 |
| | 40 | 0.133 | 0.177 | 3.340 | 8.504 | 6.133 |
| Deing | 20 | 0.047 | 0.228 | 2.960 | 3.745 | 3.500 |
| | 30 | 0.054 | 0.247 | 2.835 | 3.616 | 3.367 |
| | 40 | 0.060 | 0.241 | 2.828 | 3.560 | 3.333 |
| LSD at 0.05 | | 0.016 | 0.036 | 0.250 | 0.380 | 0.162 |
| CV % | | 15.37 | 13.44 | 5.83 | 5.65 | 2.84 |
| Source of variance | df. | F- value | | | | |
| Variety | 2 | 63.94*** | 95.73*** | 552.22*** | 455.41*** | 1500.29*** |
| Density | 2 | $0.45^{ns}$ | $2.63^{ns}$ | $1.54^{ns}$ | $1.07^{ns}$ | 5.12* |
| Variety×Density | 4 | $0.68^{ns}$ | $0.20^{ns}$ | $0.62^{ns}$ | $0.08^{ns}$ | $0.31^{ns}$ |

ns: no significant; *,*** Significant differences at P ≤ 0.05, 0.001, respectively

**Table 2:** The effects of plant density on seed growth rate at specific reproductive growth stages in 2011

| Variety | Density (plants $m^{-2}$) | Specific reproductive growth stage R3-R4 | R4-R5 | R5-R6 | R6-R7 | linear phase R5-R7 |
|---|---|---|---|---|---|---|
| | | mg $seed^{-1}$ $d^{-1}$ | | | | |
| AGS190 | 20 | 0.119 | 0.406 | 6.830 | 9.026 | 8.300 |
| | 30 | 0.106 | 0.341 | 6.758 | 8.881 | 8.167 |
| | 50 | 0.111 | 0.339 | 6.412 | 8.347 | 7.733 |
| Argomolio | 20 | 0.030 | 0.161 | 3.360 | 6.640 | 5.367 |
| | 30 | 0.032 | 0.141 | 3.319 | 6.586 | 5.300 |
| | 50 | 0.025 | 0.131 | 3.203 | 6.626 | 5.267 |
| Willis | 20 | 0.039 | 0.169 | 2.871 | 4.655 | 3.900 |
| | 30 | 0.039 | 0.174 | 2.564 | 4.670 | 3.767 |
| | 50 | 0.039 | 0.171 | 2.873 | 4.345 | 3.733 |
| LSD at 0.05 | | 0.007 | 0.043 | 0.377 | 0.286 | 0.112 |
| CV% | | 10.88 | 18.96 | 8.88 | 4.31 | 1.95 |
| Source of variance | df. | F- value | | | | |
| Variety | 2 | 431.79*** | 69.16*** | 283.69*** | 483.75*** | 3382.25*** |
| Density | 2 | $1.13^{ns}$ | $1.39^{ns}$ | $0.62^{ns}$ | $3.49^{ns}$ | 14.13*** |
| Variety×Density | 4 | $1.29^{ns}$ | $0.68^{ns}$ | $0.62^{ns}$ | $1.23^{ns}$ | 4.76** |

ns: no significant difference; **, *** Significant differences at P ≤ 0.01, 0.001, respectively

The SGR was rapidly increased during R5-R6 and R6-R7 growth stages. For Palmetto and Deing varieties, seed growth rate was <0.25 mg per seed per day during R3-R4 and R4-R5 growth stages (Table 1). Rapid increase in SGR was observed during R6-R7 for Palmetto.

In 2011, almost similar SGR were observed for R3-R4 and R4-R5 growth stages for AGS190 even at higher planting density of 50 plants per $m^2$. Similar trend in rapid increase in SGR during R5-R6 and R6-R7 growth stages was recorded in all varieties (Table 2). Seed growth rate showed significant differences among varieties and planting densities in both years when analyzed by combining R5-R6 and R6-R7 together; the linear phase (R5-R7) (Table 1).

**Table 3:** The effects of plant density on seed filling period at specific reproductive growth stages in 2010

| Variety | Density (plants $m^{-2}$) | Specific period of growth stage R3-R4 | R4-R5 | R5-R6 | R6-R7 | V0-R8 |
|---|---|---|---|---|---|---|
| | | days | | | | |
| AGS190 | 20 | 4.3 | 4.7 | 13.3 | 28.0 | 107.0 |
| | 30 | 4.7 | 5.0 | 13.3 | 28.3 | 106.0 |
| | 40 | 4.7 | 4.7 | 13.3 | 28.3 | 105.3 |
| Palmetto | 20 | 5.3 | 7.3 | 8.7 | 10.7 | 87.3 |
| | 30 | 5.7 | 7.3 | 8.9 | 10.7 | 86.0 |
| | 40 | 5.7 | 7.7 | 9.0 | 10.7 | 85.0 |
| Deing | 20 | 6.3 | 7.3 | 5.0 | 11.3 | 84.3 |
| | 30 | 6.3 | 7.3 | 5.3 | 11.3 | 84.0 |
| | 40 | 6.3 | 7.3 | 5.3 | 11.3 | 83.0 |
| LSD at 0.05 | | 0.561 | 0.573 | 0.441 | 0.573 | 0.601 |
| CV % | | 10.24 | 8.79 | 4.84 | 3.42 | 0.65 |
| Source of variance | df. | F- value | | | | |
| Variety | 2 | 22.7*** | 62.31*** | 765.1*** | 2710.1*** | 3756.0*** |
| Density | 2 | $0.47^{ns}$ | $0.11^{ns}$ | $0.57^{ns}$ | $0.11^{ns}$ | 19.69*** |
| Variety×Density | 4 | $0.12^{ns}$ | $0.28^{ns}$ | $0.29^{ns}$ | $0.11^{ns}$ | $0.77^{ns}$ |

ns: no significant; *** Significant differences at P ≤ 0.001

**Table 4:** The effects of plant density on seed filling period at specific reproductive growth stages in 2011

| Variety | Density (plants $m^{-2}$) | Specific period of growth stage R3-R4 | R4-R5 | R5-R6 | R6-R7 | V0-R8 |
|---|---|---|---|---|---|---|
| | | | | Days | | |
| AGS190 | 20 | 4.3 | 4.3 | 13.7 | 28.0 | 106 |
| | 30 | 4.7 | 4.7 | 13.7 | 28.7 | 105.7 |
| | 50 | 4.7 | 4.7 | 13.7 | 28.7 | 104.7 |
| Argomolio | 20 | 4.3 | 5.3 | 10.3 | 16.3 | 88.0 |
| | 30 | 4.7 | 5.3 | 10.7 | 16.7 | 88.3 |
| | 50 | 4.7 | 5.7 | 10.7 | 16.7 | 87.7 |
| Willis | 20 | 4.7 | 4.7 | 9.3 | 13.0 | 89.3 |
| | 30 | 4.7 | 4.7 | 9.3 | 13.3 | 88.7 |
| | 50 | 4.7 | 4.3 | 9.3 | 13.3 | 87.7 |
| LSD at 0.05 | | ns | 0.608 | 0.585 | 0.451 | 0.509 |
| CV % | | 12.75 | 12.54 | 5.23 | 2.33 | 0.54 |
| Source of variance | df. | F- value | | | | |
| Variety | 2 | $0.11^{ns}$ | 6.40** | 131.1*** | 2828.9*** | 3747.9*** |
| Density | 2 | $0.43^{ns}$ | $0.10^{ns}$ | $0.11^{ns}$ | $2.91^{ns}$ | 13.18*** |
| Variety× Density | 4 | $0.11^{ns}$ | $0.40^{ns}$ | $0.11^{ns}$ | $0.18^{ns}$ | $1.65^{ns}$ |

ns: no significant difference; **, *** Significant differences at P ≤ 0.01, 0.001, respectively; V0-R8 = growth stage from planting to maturity

## Seed Filling Period and Maturity

Soybean varieties had maturity dates ranging between 83 and 107.3 days (Tables 3 and 4). The AGS190 variety had the longer growing season (105-107.3 days) and Deing variety had the fewest days to maturity (83-84.3 days). However, increasing planting density had no significant effect on SFP reported during specific reproductive growth stages; R3-R4, R4-R5, R5-R6 and R6-R7 for all varieties, but there were significant differences between varieties on SFP of these growth stages in both years. Seed filling period during the linear phase of seed growth (R5-R7) has an average across planting density of 16.5, 19.6, 22.5, 27.1and

**Table 5:** The effects of plant density on yield and yield components in 2010

| Variety | Density (plants $m^{-2}$) | Seed no. $plant^{-1}$ | FSS (mg $seed^{-1}$) | Seed yield (g $plant^{-1}$) | Seed yield (g $m^{-2}$) |
|---|---|---|---|---|---|
| AGS190 | 20 | 89.5 | 316.1 | 28.3 | 481.1 |
| | 30 | 50.1 | 313.9 | 15.7 | 377.4 |
| | 40 | 31.1 | 308.4 | 9.5 | 286.5 |
| Palmetto | 20 | 218.3 | 125.8 | 27.5 | 466.7 |
| | 30 | 159.9 | 124.8 | 19.9 | 478.8 |
| | 40 | 97.5 | 122.9 | 12.0 | 359.7 |
| Deing | 20 | 330.7 | 59.0 | 19.5 | 331.7 |
| | 30 | 248.7 | 58.1 | 14.3 | 346.6 |
| | 40 | 161.7 | 57.7 | 9.4 | 279.8 |
| LSD at 0.05 | | 10.007 | 4.524 | 1.324 | 32.750 |
| CV % | | 6.495 | 2.741 | 7.635 | 8.654 |
| Source of variance | df. | F- value | | | |
| Variety | 2 | 812.94*** | 7658.67*** | 38.34*** | 28.09*** |
| Density | 2 | 302.32*** | 1.82 $^{ns}$ | 281.96*** | 32.19*** |
| Variety×Density | 4 | 23.51*** | 0.45 $^{ns}$ | 10.19*** | 4.87** |

ns: no significant difference; FSS: final seed size; **, *** Significant differences at $P \leq 0.01$, 0.001, respectively

**Table 6:** The effects of plant density on yield and yield components in 2011

| Variety | Density (plants $m^{-2}$) | Seed no. $plant^{-1}$ | FSS (mg $seed^{-1}$) | Seed yield (g $plant^{-1}$) | Seed yield (g $m^{-2}$) |
|---|---|---|---|---|---|
| AGS190 | 20 | 60.3 | 348.7 | 21.0 | 413.9 |
| | 30 | 33.1 | 348.5 | 11.5 | 325.2 |
| | 50 | 22.3 | 328.8 | 7.3 | 311.3 |
| Argomolio | 20 | 198.8 | 144.6 | 28.8 | 494.5 |
| | 30 | 129.9 | 145.8 | 19.0 | 465.9 |
| | 50 | 77.2 | 144.9 | 11.2 | 414.9 |
| Willis | 20 | 241.1 | 88.8 | 21.4 | 376.6 |
| | 30 | 149.8 | 86.9 | 13.0 | 312.5 |
| | 50 | 82.7 | 85.4 | 7.1 | 275.2 |
| LSD at 0.05 | | 9.683 | 2.699 | 1.655 | 29.652 |
| CV % | | 8.764 | 1.411 | 10.624 | 7.875 |
| Source of variance | df. | F- value | | | |
| Variety | 2 | 384.88*** | 22029.6*** | 40.49*** | 53.19*** |
| Density | 2 | 272.22*** | 23.23*** | 192.66*** | 23.41*** |
| Variety×Density | 4 | 30.45*** | 15.93*** | 1.49 $^{ns}$ | 0.82 $^{ns}$ |

ns: no significant difference; FSS: final seed size; *** Significant differences at $P \leq 0.001$

41.5 days for Deing, Palmetto, Willis, Argomolio and AGS190, respectively (Tables 3 and 4).

## Seed Yield and Yield Components

Results showed that increased plant density significantly decreased seed number and thereby seed yield of individual plant. Seed number per plant at high density reduced by 65.3, 37.9% in 2010 and 63.0, 32.6% in 2011 for AGS190, 55.3, 39.9% for Palmetto, 51.1, 35.0% for Deing, 61.2, 40.6% for Argomolio and 65.7, 44.8% for Willis compared to low and medium densities, respectively. Seed yield per plant in both years showed similar trend as in seed number per plant, i.e., seed yield per plant decreased as plant population density increased (Tables 5 and 6). In addition,

**Table 7:** Correlation coefficients between seed growth rate and seed filling period with seed number per plant, final seed size and yield, averaged across varieties and plant densities in 2010.

| | Density (plant $m^{-2}$) | Seed no. $plant^{-1}$ | FSS (mg $seed^{-1}$) | Seed yield (g $plant^{-1}$) |
|---|---|---|---|---|
| SFP | 20 | -0.927*** | 0.989*** | 0.628** |
| | 30 | -0.931*** | 0.987*** | -0.174 $^{ns}$ |
| | 40 | -0.911*** | 0.987*** | -0.249 $^{ns}$ |
| SGR | 20 | -0.949*** | 0.869** | 0.948*** |
| | 30 | -0.945*** | 0.860** | 0.462 $^{ns}$ |
| | 40 | -0.958*** | 0.877** | 0.168 $^{ns}$ |

ns: no significant difference; FSS: final seed size; **, *** significant differences at $P \leq 0.01$, 0.001, respectively

**Table 8**: Correlation coefficients between seed growth rate and seed filling period with seed number per plant, final seed size and yield, averaged across varieties and plant densities in 2011.

| Variables | Density (plant $m^{-2}$) | Seed no. $plant^{-1}$ | FSS (mg $seed^{-1}$) | Seed yield (g $plant^{-1}$) |
|---|---|---|---|---|
| SFP | 20 | -0.987*** | 0.999*** | -0.275 $^{ns}$ |
| | 30 | -0.967*** | 0.998*** | -0.433 $^{ns}$ |
| | 50 | -0.971*** | 0.999*** | -0.224 $^{ns}$ |
| SGR | 20 | -0.987*** | 0.991*** | -0.120 $^{ns}$ |
| | 30 | -0.963*** | 0.990*** | -0.337 $^{ns}$ |
| | 50 | -0.932*** | 0.986*** | -0.063 $^{ns}$ |

ns: no significant difference; FSS: final seed size; *** significant differences at $P \leq 0.001$

plant density significantly affected seed yield per unit area for all varieties. By increased plant density to ≥ 40 plants per $m^2$, seed yield lowered by 40.4, 24.1% in 2010 and 24.8, 4.3% in 2011 for AGS190, 16.1, 10.9% for Argomolio, and 26.9, 11.9% for Willis compared to 20 and 30 plants per $m^2$, respectively. However, the highest seed yield for Palmetto and Deing was recorded at planting density of 30 plants per $m^2$ and the lowest seed yield at planting of 40 plants per $m^2$.

Final seed size showed significant differences between varieties. AGS190 had the largest seed size in both years but Deing and Willis had the smallest seed size. In 2010, the average final seed size of AGS190 variety across planting density was higher by 60.2 and 81% compared to Palmetto and Deing, respectively. While in 2011, the average final seed size of AGS190 was higher by 57.6 and 74.6% compared to Argomolio and Willis, respectively.

## Relationships between SGR, SFP and Yield and Yield Components

Negative and significant relationships were observed between the SFP and seed number per plant, between the SGR and seed number per plant in both years (Tables 7 and 8). Significant positive correlations were found between the SFP and final seed size, the SGR and final seed size of both years. However, there was no relation between SFP and seed yield. Nonetheless, positive and significant relationships were reported between the SGR and seed yield per plant at plant density 20 plants per $m^2$ but not significant at 30 and 40 plants per $m^2$ in the first year. However, the relationships were negative but no significant between SGR and seed yield per plant during the second year.

## Discussion

Plant density had great influence on the yield attribute i.e. number of seeds per plant. Seed number and seed yield of individual plants responded negatively to increased plant density. Yield per plant decreased as plant density increased (Ball *et al*., 2000a). Experimental results in both years showed that yield components decreased with increase in plant density. Higher plant population caused a significant decline in productivity per plant in soybean (Jones *et al*., 2002) which supports the present results. Yield per unit area is highly correlated with seed number per plant and consequently correlated with seed number per meter square. The reduction in yield caused by high population density was due to low seed number per unit area. The number of seeds per plant was greater in wide spacing than close that might be due to increase leaf area per plant contributing to higher solar radiation interception. This higher solar radiation interception may produce higher assimilates that contributed to higher pod set per plant (Mondal *et al*., 2012). Wide plant spacing had less number of plants per unit area and therefore less competition for nutrients, wider feeding area and adequate sunlight penetration for more efficient photosynthesis in plants thereby producing more number of pods as well seeds per plant against crop sown at narrow spacing (Malek *et al*., 2012). In the present experiment, similar reasons may be responsible and low density plants produced more number of pods as well seeds per plant. Similar results are also reported by many workers in legumes (Egli, 1988; Ball *et al*., 2000a; Mondal *et al*., 2012).

Although number of seeds per plant decreased with increasing plant density but the seed size was not affected by plant density. These results are supported by many workers that plant density affects number of pods per plant and seeds per pod but not the seed size in legumes (Ball *et al*., 2000b; Mondal *et al*., 2012; Malek *et al*., 2012). This indicates that seed size is genetic character. Therefore, the reduction in assimilate availability by increasing planting density resulted in reduced seed number per pod whereas the dry matter accumulation in filling seeds was not reduced. Munier-Jolain *et al*. (1998) opined under limited assimilates supply affected abortion in seeds of young pods but not significantly affect seed size. This indicates involvement of an effect compensatory mechanism that help in keeping original seed size by supplying sufficient assimilates from the leaves and due to this reason, the seed size was not reduced proportionately to the degree of plant density. Similar reason might occur in case of seed growth rate. In present experiment, the number of seeds per plant decreased with increasing plant density whereas seed growth rate remains unaffected by variation in planting density during the seed filling period. The reduction in assimilate availability by dense plants does not reduce the growth rate of filling seeds, but lack of assimilate induces seed abortions in younger pods and shortened seed filling, probably because of remaining assimilate remobilization necessary to maintain the growth rate of filling seeds (Sinclair and de Witt, 1976).

However, significant differences were observed in length of seed filling period and seed growth rate among the studied varieties. Bold seeded variety showed longer grain filling period and greater seed growth rate than the small seeded ones. The maintenance of the genetic differences in seed growth rate is controlled primarily by the number cells in the cotyledons or endosperm for the seed, not by the supply of assimilates from the plant or by the process involving in transferring assimilates from the phloem (Thorne, 1980). The large size seed had large cotyledons and thicker raceme which helps in supplying more assimilates from leaves to seeds (Egli, 1999; Mondal *et al*., 2011). Egli (1999) reported that large seeds usually having higher SGRs. In the present experiment, AGS190, the bold seeded variety showed higher seed growth rate and seed filling period than the small seeded ones for its larger cotyledons. The variation in the length of the SFP among varieties determined seed size but not positively associated with seed yield. Among varieties, seed size and seed number per plant were highly related to seed yield per plant. However, the variations of seed size were less among densities within each variety.

Again, seed size was positively and significantly correlated with seed filling period and seed growth rate but negatively with seed number per plant suggesting that the factor controlling seed yield depend on seed number and seed size, not seed growth rate. As plant density increased seed number of individual plant decreased, whereas the SGR and SFP were relatively stable within each variety. The stability of SGR was probably due to adjustments in the number of seeds produced by the individual plant (Egli, 1998).

In conclusion, seed growth rate (dry matter accumulation rate in seed) was the highest during reproductive growth stages of R6-R7. Differences in plant density did not affect the SGR or SFP during the specific reproductive growth stages. As plant density increased seed number of individual plant decreased. Seed number adjustments and SGR patterns interpreted the stability of final sees size within variety, despite the changes of plant density. Among varieties, SGR and SFP correlated inversely with seed number per plant and positively with final seed size. In crux, number of plants per unit area and number of seeds per plant is important feature to determine yield potential, not seed growth rate in soybean.

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