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Full Length Research Paper

Physiology of seed yield in soybean: Growth and dry matter production

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A field study was conducted to assess the growth parameters controlling the dry matter and seed yield of soybean. The result shows that growth rate was slow during vegetative phase in all genotypes. A relatively smaller portion of total dry mass (TDM) was produced before flower initiation and the bulk of it after anthesis. Maximum absolute growth rate (AGR) was observed during pod filling stage in all genotypes due to maximum leaf area (LA) development and leaf area index (LAI) at this stage. Plant characters like LAI and AGR contributed to higher TDM production. Results indicate that a high yielding soybean genotype should possess larger LAI, higher TDM production ability and higher AGR at all growth stages.

Key words: Soybean seed yield, total dry mass (TDM), leaf area index (LAI), absolute growth rate (AGR), relative growth rate (RGR).

INTRODUCTION

Soybean (*Glycine max* (L.) Merr.), one of nature's most versatile crops, is increasingly becoming an important food and cash crop in the tropics due to its high protein content (40%), high oil content (20%) and adaptability to various growing environments (Smith et al., 1995; Tukamuhabwa et al., 2001; FAO, 2004; McKevith, 2005). The crop has a variety of uses including for human food, livestock feed, vegetable oil, and many industrial products and is a major crop in several developing and developed countries (McKevith, 2005). It ranks 4th in acreage and production among the oilseed crops grown in Bangladesh (MOA, 2010). Oilseed crops cover an area of about 569,000 ha, where soybean occupies only 55,000 ha in Bangladesh (MOA, 2010). Oilseed crops cover an area of about 569,000 hectares, where soybean occupies only 55,000 hectares in Bangladesh (MOA, 2010). Despite suitable climatic and edaphic conditions, the yield of soybean is very low in Bangladesh. The average yield of soybean in the world is about 3.0 t ha^{-1}, while that in Bangladesh is only 1.64 t ha^{-1} (SAIC, 2007). There are many factors responsible for its lower acreage and yield but the most important one is the non-availability of high yielding varieties.

In spite of the best efforts to improve the soybean varieties, the yield of this crop remains low. Several studies have been made to understand their performances which mainly include the contribution of various yield components towards yield (Das et al., 1992; Mehta et al., 2000; Chettri, 2003; Jian et al., 2007). The yield components depend on some physiological traits. To understand the physiological basis of yield difference among the genotypes of soybean, it is essential to quantify the components of growth, and the relevant variables, which is useful in crop improvement. Variation in dry matter accumulation and pod production in different genotypes may be related to some factors such as leaf area (LA), crop growth rate (CGR), net assimilation rate (NAR) and relative growth rate (RGR). Pandey et al. (1978) analyzed growth parameters of five varieties of

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Abbreviations: TDM, Total dry mass; **AGR,** absolute growth rate; **LA,** leaf area; **LAI,** leaf area index.

Table 1. Average monthly rainfall, air temperature and relative humidity during the experimental period from January to April 2009 at the experimental area, Mymensingh, Bangladesh.

Month	Monthly average air temperature (°C)			Average rainfall (mm)	Average relative humidity (%)
	Maximum	Minimum	Average		
January	23.43	12.93	18.18	00.0	78.0
February	27.34	16.41	21.87	26.6	73.9
March	29.61	20.57	25.09	63.6	80.6
April	30.56	22.14	26.35	96.6	79.9

blackgram in order to study the physiological causes of yield differences and observed the differences in CGR, NAR, RGR and LA among the varieties. Egli and Zhen-wen, (1991) suggested that seeds per unit area were related to canopy photosynthesis during flowering and pod set and canopy photosynthesis rate is determined through LAI and CGR. A plant with optimum LAI and NAR may have higher biological yield as well as seed yield (Mondal et al., 2007). The dry matter accumulation may be the highest if LAI reaches its maximum value within the shortest possible time (Khan and Khalil, 2010). Not only TDM production, but also the capacity of efficient partitioning between the vegetative and reproductive parts may produce high economic yield (Shiraiwa et al., 2004; Oh et al., 2007). A better understanding of crop growth and yield parameters and the partitioning of assimilates into seed would help to expedite yield improvement of field crops. Very little work has been done in this regard in soybean in tropic areas. A detailed analysis of growth and yield parameters of five soybean genotypes was therefore undertaken.

MATERIALS AND METHODS

Experiment was carried out at the experimental field of Bangladesh Agricultural University (BAU), Mymensingh (24°8´ N 90°0´ E), Bangladesh in Rabi (January - April) season of 2009. Weather data (monthly average temperature, rainfall and relative humidity) during the experimental period was recorded (Table 1). With five soybean genotypes, three advanced lines (BAU-21, BAU-70 and BAU-80) and two widely cultivated varieties of Bangladesh (Shohag and BARIsoybean-5), were used as planting materials. The soil of the experimental field was silty loam having a total of 0.07% nitrogen, 1.13% organic matter, 18.60 mg kg^{-1} available phosphorus, 105.57 mg kg^{-1} exchangeable potassium, 18 ppm sulphur and 6.8 pH. Seeds were sown on 3 January 2009. A randomized complete block design with three replicates was followed. The plot size was 4 m × 3 m. Row to row and plant to plant distances were 30 and 10 cm, respectively. Seeds were sown in line and thinned to a density of 30 to 35 plants m^{-2} two weeks after germination. Urea, triple superphosphate, muriate of potash and gypsum were used as a source of nitrogen, phosphorus, potassium and sulphur at the rate of 40, 120, 80 and 30 kg ha^{-1}, respectively at the time of final land preparation. No biofertilizer was applied in the experiment because farmers do not use biofertilizer for soybean cultivation in Bangladesh. First weeding was done followed by thinning at about 21 days after sowing (DAS). A single irrigation was applied at 25 DAS. Insecticide (Ripcord 50 EC @ 0.025%) was sprayed at flowering and fruiting stages to control shoot and pod borer.

To study ontogenetic growth characteristics, a total of six harvests were made. Data were collected on some morpho-physiological parameters such as plant height, branch and nodule number $plant^{-1}$, LA and TDM $plant^{-1}$, LAI, AGR, RGR, harvest index (HI), chlorophyll content and photosynthesis (Pn) in leaves, yield attributes such as number of pods $plant^{-1}$, seeds pod^{-1}, 100-seed weight and seed yield. The first crop sampling was started at 35 DAS and continued at an interval of 15 days up to 110 DAS, that is till physiological maturity. From each sampling, five plants were selected randomly and uprooted from each plot for collecting necessary parameters. Selected plants were separated into leaves, stems, pods and roots, and the corresponding dry weight were recorded after oven drying at 80 ± 2°C for 72 h. Leaf area of each sample was measured by Li-COR automatic leaf area meter (Model: Li-COR 3000, USA). Leaf area index was measured by canopy analyzer (Model: LI 1400, USA). Calculations of AGR and RGR were carried using the formulae of Hunt (1978). Photosynthetic rate was measured at the flowering and pod development stages by automatic photosynthesis meter (Li-COR 200, USA). Chlorophyll was extracted in 80% acetone from the leaves of upper two nodes of a plant and the chlorophyll was determined following the method of Yoshida et al. (1976). Yield components were recorded at harvest from ten randomly selected plants of each plot. Seed yield was recorded from six inner rows of each plot to avoid border effects and converted into t ha^{-1}. All data were analyzed statistically following the analysis of variance (ANOVA) technique and the mean differences were adjusted with Duncan's multiple range test (DMRT) using the statistical computer package programme, MSTAT-C (Russell, 1986).

RESULTS AND DISCUSSION

Effect of genotypes on plant height, branch and nodule number $plant^{-1}$ and leaf area $plant^{-1}$ was significant at all growth stages (Figure 1). Results reveal that plant height increased with age till 95 DAS followed by plateau. Branch number increased with age till 80 DAS in four out of five genotypes. Branch number of BAU-70 increased till 90 DAS. Nodule number and leaf area (LA) $plant^{-1}$ increased with age till 65 and 80 DAS, respectively followed by a decline in all genotypes due to nodule degeneration and leaf shading. Genotype BAU-70 had higher plant height, branch and nodule number and LA $plant^{-1}$ and also had higher seed yield. These results indicate that plant height, LA, branch and nodule number are the most important morphological parameters for increasing seed yield in soybean. Shorter plant, lower number of nodules and lower LA was recorded in BAU-80 and BARIsoybean-5. These results are consistent with

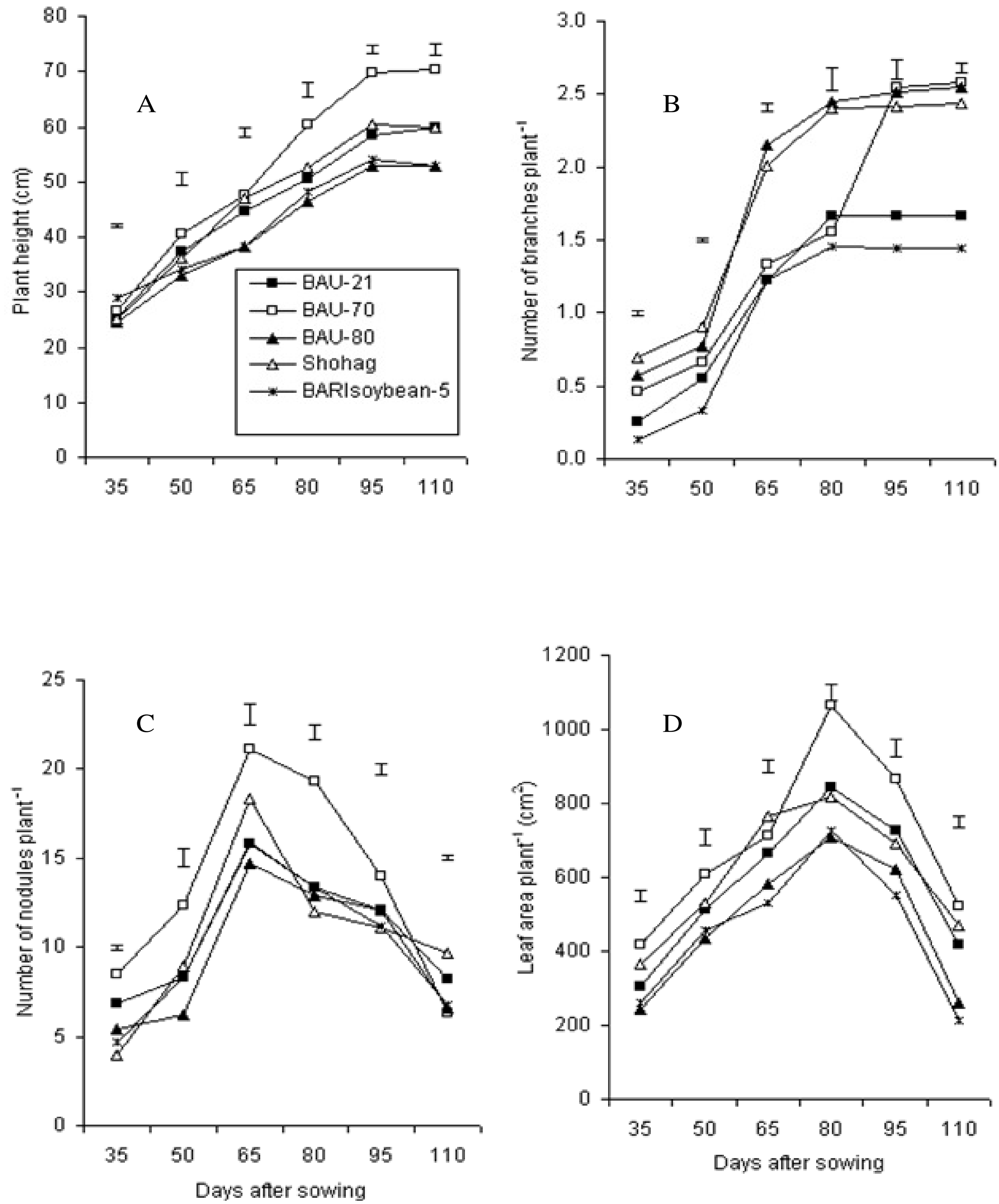

Figure 1. (A) Plant height, (B) branch production, (C) nodule production and (D) leaf area development at different days after sowing of soybean genotypes. Vertical bars represent LSD (0.05).

the study of Chettri (2003) who observed that seed yield depends on LA, branch and nodule number plant^{-1} in soybean.

Differences among the genotypes for total dry mass (TDM), leaf area index (LAI), absolute growth rate (AGR) and relative growth rate (RGR) were significant at all growth stages (Figure 2). Differential genotypic performance for LAI and their relation to the DM production, at each growth stage could be associated with the genetic make-up of the genotypes. A common feature of

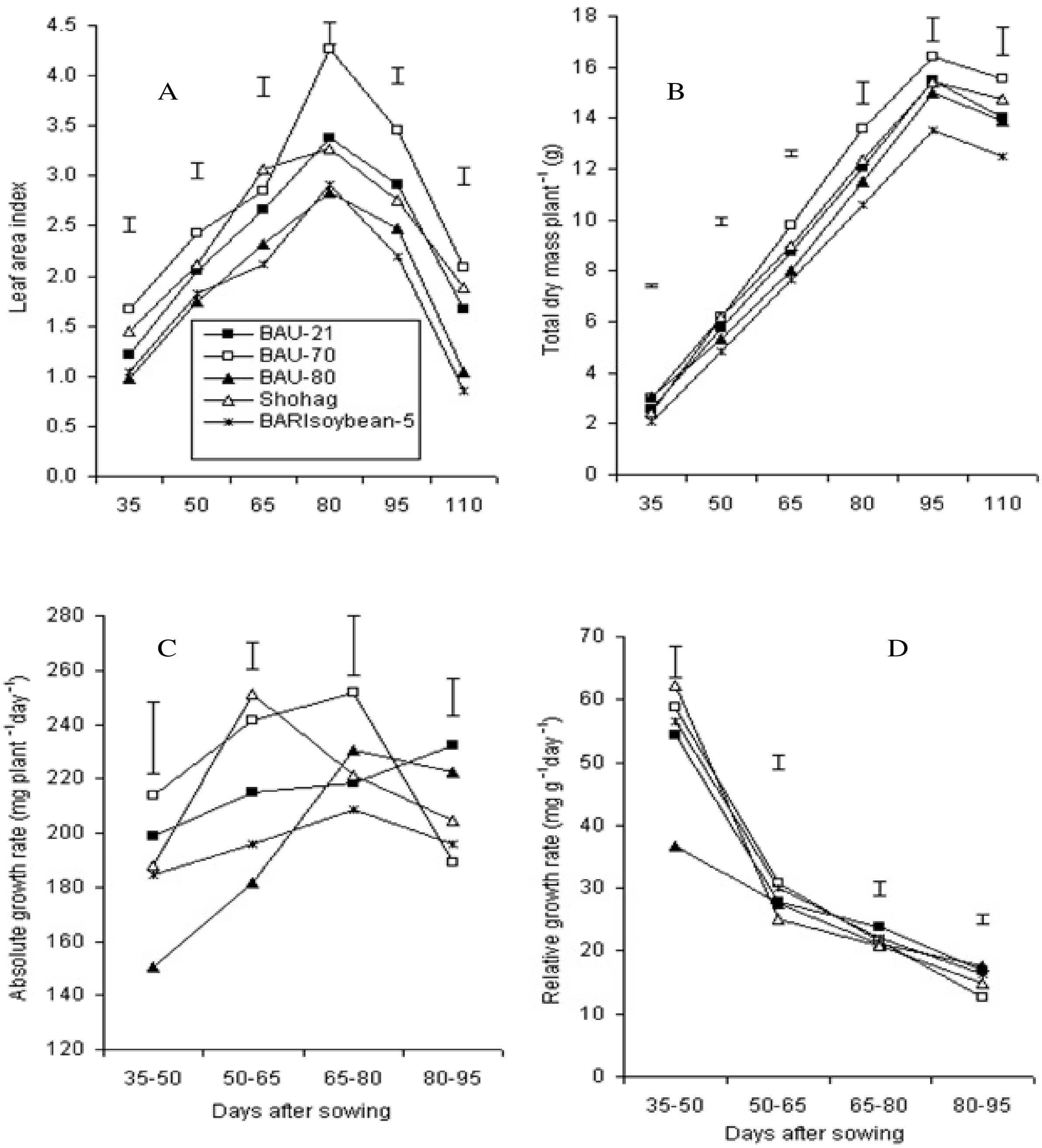

Figure 2. Pattern of (A) leaf area index, (B) total dry mass production, (C) absolute growth rate and (D) relative growth rate in five soybean genotypes during their growth period. Vertical bars represent LSD (0.05). AGR and RGR for 95-110 DAS were negative.

soybean genotypes was slow TDM accumulation and LAI during the first 35 DAS followed by a rapid increase after commencement of flowering. Flowering was started at 45 to 50 DAS, depending on genotypes. Faster TDM accumulation after the beginning of reproductive stage was the result of increased LAI (Khan and Khalil, 2010). Total dry matter production in all genotypes increased with age till the beginning of maturity (95 DAS) followed by a decline due to heavy leaf shading. Leaf area index followed a typical sigmoid pattern with respect to time and increased with age till 80 DAS in all genotypes followed by a decline because of abscission of old leaves. Results indicate that high yielding genotypes always showed superiority in TDM production and LAI as compared to low yielding ones at most of the growth stages. These results also indicate that LAI and TDM are the most important parameters for increasing seed yield in soybean. These results are consistent with that of

Table 2. Some physiological parameters yield components and yield in five soybean genotypes.

Genotype/ cultivar	Chlorophyll (mg g^{-1} fw)	Photosynthesis (µmol CO_2 s^{-1} dm^{-2})	Pods $plant^{-1}$ (no.)	Seeds pod^{-1} (no.)	100-seed weight (g)	Seed weight $plant^{-1}$ (g)	Seed yield (t ha^{-1})	Harvest index (%)
BAU-21	2.16	20.66^{b}	24.10^{b}	2.12	15.11^{ab}	7.71^{b}	2.57^{b}	33.22^{ab}
BAU-70	2.17	24.24^{a}	31.23^{a}	2.19	14.55^{b}	9.95^{a}	3.31^{a}	37.73^{a}
BAU-80	2.21	19.22^{b}	21.40^{bc}	2.17	16.08^{a}	7.47^{bc}	2.49^{b}	33.24^{ab}
Shohag	2.12	21.45^{b}	17.90^{d}	2.19	15.51^{ab}	6.08^{d}	2.02^{d}	28.28^{b}
BARIsoybean-5	2.09	19.89^{b}	20.8^{c}	2.13	15.88^{a}	7.03^{c}	2.34^{c}	34.16^{a}
F-test	NS	*	**	NS	*	**	**	*
CV (%)	3.06	6.90	6.57	2.59	3.44	4.43	5.55	8.11

Same letter (s) in a column does not differ significantly at $P \leq 0.05$ by DMRT; NS = Not significant; ** and * indicate significance at 1 and 5% level of probability, respectively.

Tandale and Ubale (2007) who observed that seed yield depends on LA and TDM production in soybean.

Absolute growth rate (AGR) tended to increase with the advancement of stage till 65 to 80 DAS in three genotypes of BAU-70, BAU-80 and BARIsoybean-5, whereas AGR increased with age till maturity in BAU-21 (Figure 2). It is evident that soybean had three distinct growth phases: early slow growth (up to 35 DAS, before flowering start), followed by a rapid growth (50 to 80 DAS, flowering and pod filling stage respectively) and then decline growth phase at pod maturity stage. Slow growth rate at early growth stage was associated with lower LA and TDM production. Initial slow growth favors weed growth and development; thus, crop ultimately suffers a loss. So, selection of genotypes with rapid growth rate in early part of a crop life is therefore warranted. In the present experiment, the high yielding genotype, BAU-70 had greater AGR than low yielding ones which is the desirable character. At the later stages of development (80-95 DAS), there was a decline in AGR, possibly owing to similar decline in LA during this stage (Figure 1).

Relative growth rate (RGR) declined with increasing age in all genotypes (Figure 2) and it decreased rapidly from 50 to 65 DAS till physiological maturity. At 35 to 50 DAS, RGR was higher in Shohag which was the low yielding genotype followed by BAU-70 and the lowest RGR was recorded in BAU-80 which was the third highest yielding genotype. Result indicates that there is no relation between RGR and seed yield. Kollar et al. (1970) observed a decrease in RGR as the season advanced. Sharp decline in RGR during reproductive stage was probably due to increased demand of assimilate by the growing seed fraction (Hamid et al., 1991). However, the RGR was maximum between 35 and 50 DAS. RGR declined at later growth stages (reproductive stage) which may be attributed to excessive mutual shading as the LA was maximum during this period and increased number of old leaves could have lowered the photosynthetic efficiency (Salam et al., 1987). In grain legume, excess LA was reported to have lower RGR and resulted in a decrease of dry matter accumulation, which probably resulted from excessive mutual shading (Pandey et al., 1978).

There were no significant differences in chlorophyll content in leaves but there were significant differences in photosynthesis in leaves among the genotypes (Table 2). BAU-70 had greater photosynthesis in leaves than the other genotypes. Pod number $plant^{-1}$ and 100-seed weight, seed yield (both $plant^{-1}$ and $hectare^{-1}$) and harvest index showed significant difference among the genotypes except number of seeds pod^{-1} (Table 2). Among the genotypes, BAU-70 produced the highest seed yield $plant^{-1}$ (9.95 g) and ha^{-1} (3.31 t) due to production of higher number of pods $plant^{-1}$ (31.23) and greater dry matter partitioning of seeds (harvest index, 37.73%) though it produced slightly smaller seed size than the others. Mehta et al. (2000) observed that seed yield of soybean had no positive relationship with pod and seed size. In the present experiment, similar result was also observed. Results further revealed that those genotypes had higher nodule number, LA, LAI, TDM and AGR also had higher seed yield. Further, TDM production and CGR depends on source strength by photosynthetic capacity (Egli and Crafts-Brandner, 1996). In the present experiment, the high yielding genotype, BAU-70 showed high TDM production for higher Pn rate and vice versa for BAU-80 and BARIsoybean-5. These results are consistent with that of Egli and

Zhen-wen (1991) and Tandale and Ubale (2007) who reported that high yielding genotypes of soybean had greater capacity of TDM for higher LAI and CGR. From the results of the present study, it can be concluded that in addition to superior *characters* of yield components, a high yielding soybean genotype possess a relatively larger leaf area with superior growth parameters, harvest index and leaf photosynthesis.

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