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Dry Matter Distribution and Growth Analysis in Soybeans under Natural Agricultural Conditions

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Abstract: This paper describes the dry matter investment in terms of "allocation" and "partitioning" beside, traditional analysis of growth in soybeans under natural agriculture practices in Egypt. The data indicates that the application of more than one method to analyze the allocation of plant dry matter is necessary. While the allocation was in the order: leaves > stems > fruits > roots when dry weights of different organs plotted versus time (traditional method), it was in the order: root > stem > leaves when the same values were plotted against total plant dry weight (slope allocation method). The biomass partitioning was expressed in the form of root/shoot and leaf/stem ratios. The first attained a maximum of 0.2188 g g^{-1} at the vegetative stage while the latter attained their highest values (about 3.3 and 4.2 g g^{-1}) during vegetative and fruiting stages with its minimal during flowering phase (2.1 g g^{-1}). The growth was examined in the form of change in biomass through time (traditional growth analysis). In this type of analysis, variation in a number of fundamental parameters, which provide one of the most ecologically significant growth parameters such as, RGR, TLA, LAI, LAD, SLA, LAR, LWR, NAR, and CGR over five different phenophases were studied, correlated and interpreted.

Key word: *Glycine max* L., soybeans, slope allocation, biomass partitioning, growth analysis

Introduction

Plant growth criteria reflect the net movement of many resources in and out of the plant and its various organs. Each resource may be invested differently and provide different insights into the plant's adaptive mechanisms and physiological balance (Abrahamson and Caswell, 1982).

A variety of approaches, commonly called growth analysis can be used to account for growth in terms that have functional or structural significance (Chiariello *et al.*, 1991). It provides considerable insight into the functioning of a plant as dependent on genotype or environment. Different growth analyses can be carried out, depending on what is considered a key factor for growth (Lambers *et al.*, 1989). The type of growth analysis that are concerned with the analysis of biomass growth requires some measurements of plant biomass and assimilatory area (leaf area) besides the methods of computing certain parameters that describe growth. These parameters can be calculated by three different approaches: interval, demographic and physiological growth analysis (Kvet *et al.*, 1971; Hunt, 1978).

Several studies have been carried out on growth analysis of some crops. For example, soybean, Harris *et al.* (1986); sugar cane, Singh and Rao (1987); tomatoes, Heuvelink (1989); cotton, Ibrahim and Buxton (1981). It is worth noting that the work of Harris *et al.* (1986) was concerned with the growth analysis of soybean at only the seedling stage. Other studies were also performed on some wild species (e.g. *Scirpus sylvaticus* & *Calotropis procera*, Crick and Grime, 1987; *Calotropis procera*: Ismail, 1992). Soybean growth and development are measured by the amount of dry matter accumulated and partitioned in different plant organs (Ritchie *et al.*, 1994). In this paper we focus on methods of traditional growth analysis of soybeans in a trial to understand the developmental trend and the physiological qualities of this plant. These and other information can be used in nutrient recommendation programs and yield-evaluation studies of soybean (Franzen, 1999).

Materials and Methods

Field and laboratory work: The present study was conducted during 2001 in a private farm at El-Behira province where soybeans were cultivated and irrigated biweekly with Nile water. One hundred plants were randomly selected and entirely harvested during five phenophases (S: seedling, V: vegetative, FL: flowering, EF: early fruiting, MF: maximum fruiting). The individuals were hand cleaned from soil particles and washed several times with tap water and then with distilled water, after that they were separated into leaves, stems, flowers, fruits and

roots. The area of leaves was determined by a digital planimeter (Bolab model 40) with sensitivity of 0.1 cm^2 . Different organs were bagged and oven-dried to constant weight at 65°C for biomass estimation.

Biomass allocation: Two variable methods of biomass calculations were introduced in this study. The first was to estimate the absolute values of plant organ and total biomass over five different phenophases. The second was the plotting of organ biomass versus the total plant biomass (slope allocation). This method applying regression analysis between total dry weight and each of (i) leaf dry weight, (ii) stem dry weight, and (iii) root dry weight then testing for significance using the correlation coefficient (*r*). These relationships can be represented by the equation:

$$Y = a + bx$$

Where Y = organ dry weight, x = total plant dry weight, b = slope and a = Y-axis intercept. Thus, the slope allocation "b" could be expressed as:

$$\text{Slope allocation "b"} = (Y-a) / x$$

Biomass partitioning: It was determined between aboveground (leaves, stems, flowers, fruits) and belowground (roots) (root: shoot ratio) and between leaf and stem (leaf: stem ratio).

Growth analysis

leaf area index (LAI)

LAI = leaf area per plant (m^2) X plant density [number of soybean plants per m^2 (25 plant m^{-2})]

Following growth parameters were calculated:

Specific leaf area (SLA) (cm^2/g)

$$\text{SLA} = A/W_L$$

Leaf area ratio (LAR) (cm^2/g)

$$\text{LAR} = A/W$$

Leaf area duration (LAD) ($\text{m}^2 \text{ month}$)

$$\text{LAD} = (A_2 + A_1)(t_2 - t_1)/2$$

Leaf weight ratio (LWR) (g/g)

$$\text{LWR} = W_L/W$$

$$\text{Therefore, LAR} = \text{LWR} \times \text{SLA}$$

Biomass duration (BMD) (g month)

$$\text{BMD} = (W_2 + W_1)(t_2 - t_1)/2$$

Net assimilation rate (NAR) or Unite leaf area (ULA) ($\text{g}/\text{m}^2/\text{month}$)
 $\text{NAR} = \frac{W_2 - W_1}{\text{LAD}}$

Relative growth rate (RGR) or specific growth rate (SGR) ($\text{g}/\text{g}/\text{month}$)
 $\text{RGR} = \text{LAR} \times \text{NAR}$

Crop growth rate (CGR) (g/m^2 ground area/ month)
 $\text{CGR} = \text{LAI} \times \text{NAR}$

Where

A = total leaf area of an individual (m^2);
 W = total dry weight of an individual (g);
 W_L = total dry weight of the leaves (g);
 W_R = total dry weight of the roots (g);
 $t_2 - t_1$ = time interval between two successive harvests;
 P = the ground area on which the dry weights have been estimated; then the

Treatment of data: Least-squares linear regression analysis was applied to evaluate the relationship between the variations in different growth parameters of soybean over different phenophases. Besides, simple linear correlation coefficient (r) was calculated to assess the relationship between these parameters.

Results

Biomass allocation and partitioning: Data of the absolute values of dry weight (Table 1) indicated that biomass (g plant^{-1}) began with a minimum value at seedling and smoothly increased till the beginning of the flowering phase. After that, a sharp increase was achieved till the early fruiting stage where the dry matter was allocated to different organs in the order: leaves > stems > fruits > roots. At mature fruiting the increase was minimized and the dry matter allocation was confined only for fruit development. The change in BMD was paralleled with those of organ biomass at the first period (from seedling to flowering), then exhibited a sharp increase till the end of the plant life cycle. On the other hand, the slope allocation method showed that, the dry weight of different plant organs increased linearly with the increasing level of the total plant weight (Fig. 1). There was highly significant correlation between root dry weight ($r = 0.988$), stem ($r = 0.966$), leaves ($r = 0.966$) and total biomass. The rank of order of increasing biomass on regression line basis was root > stem > leaves. The biomass partitioning was expressed in the form of root/shoot and leaf/stem ratios (Fig. 2). Root/shoot ratio attained a maximum value of about 0.2188 g g^{-1} at maximum vegetative stage. Thereafter, the ratio declined to a value of about 0.0385 over the two periods 'V-FL' and 'FL-EF', but later at MF phase the situation was more or less stabilized. Leaf/stem ratio attained their highest values (about 3.3 and 4.2 g g^{-1}) during 'S-V' and 'EF-MF' periods respectively with its minimal during 'FL' phase (2.1 g g^{-1}).

Growth parameters: RGR exhibited two peaks of maxima during 'S-V' and 'FL-EF' periods (about 0.066 and $0.059 \text{ g g}^{-1} \text{ month}^{-1}$ respectively) (Fig. 3). The values dropped to nearly its third during the transition from vigorous vegetative to the beginning of flowering stage ($0.02 \text{ g g}^{-1} \text{ month}^{-1}$). At mature fruiting it declined to a minimum value of about $0.0045 \text{ g g}^{-1} \text{ month}^{-1}$.

The variation in some other growth parameters over different phenophases is illustrated in Fig. 4. Expectedly, TLA and LAI followed the same pattern. They increased linearly following the initial seedling stage and reached maxima of about $0.63 \text{ m}^2 \text{ plant}^{-1}$ and $15.8 \text{ m}^2 \text{ m}^{-2}$ respectively just before mature fruiting stage. LAD ($\text{m}^2 \text{ month}$) curve showed three distinct phases. It started with a slight increase at seedling and early vegetative activity then achieved an exponential increase during maximum vegetative and flowering and later showed a sharp increase during the phases from flowering to the end of the plant life cycle.

Here again, RGR is factored into two components; LAR and NAR. LAR is the result of SLA times LWR. The values of the two parameters during seedling and vegetative stages were 212.6 and 123.88 for SLA and 155.2 and $77.98 \text{ cm}^2 \text{ g}^{-1}$ for LAR respectively.

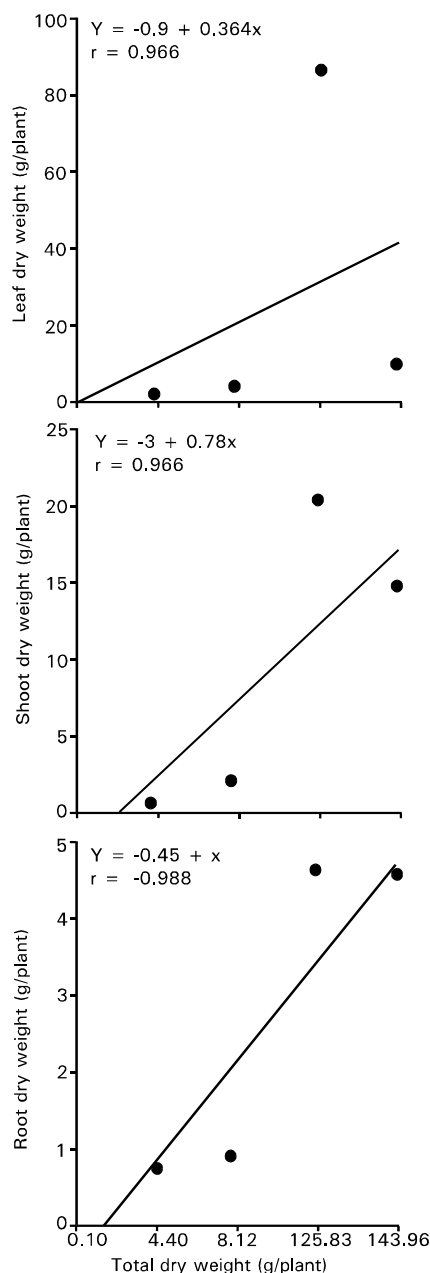


Fig. 1: The relationship between organ dry weight and total plant weight of soybeans over five different phenophases

The two growth parameters peaked at the flowering stage to reach a value of about 416.1 and $274.8 \text{ cm}^2 \text{ g}^{-1}$ respectively. After flowering the values showed a continuous decline. The curve of LWR showed a stepwise decrease in the amount of biomass devoted to leaf material till flowering stage. After that, the ratio fluctuated till the end of the plant life cycle.

NAR peaked two times during vegetative ($7.99 \text{ g m}^{-2} \text{ month}^{-1}$) and early fruiting ($9.43 \text{ g m}^{-2} \text{ month}^{-1}$) during which vegetative growth activities taking place. The minimum values occurred during seedling, flowering and mature fruiting stages.

CGR was minimal during the seedling stage. It began to rise slowly over the vegetative and flowering stages to reach a maximum value ($98 \text{ g m}^{-2} \text{ ground area month}^{-1}$) at early fruiting stage, then

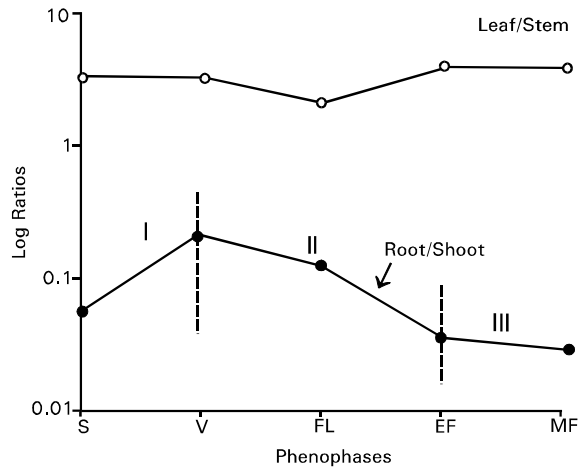


Fig. 2: Variation in root: shoot and leaf: stem ratio of soybeans over five different phenophases (S: seedling, V: vegetative, FL: flowering, EF: early fruiting, MF: mature fruiting)

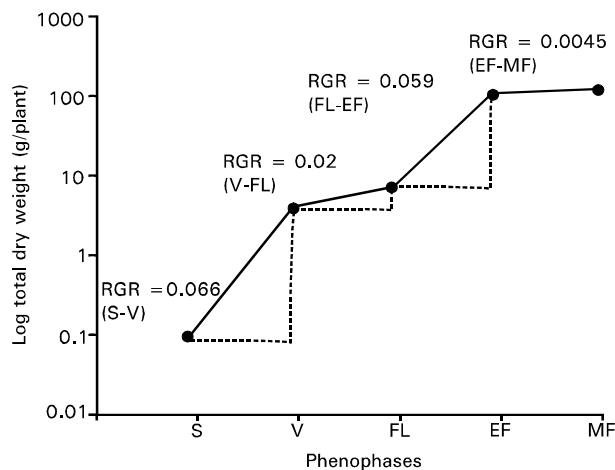


Fig. 3: Variation in relative growth rate (RGR) (g/g/month) of soybeans over five different phenophases (S: seedling, V: vegetative, FL: flowering, EF: early fruiting, MF: mature fruiting).

it declined to a value of $15.11 \text{ g m}^{-2} \text{ ground area month}^{-1}$ at mature fruiting.

Correlation matrix between different growth parameters is presented in Table 2. Significant positive correlation was noticed between CGR and each of TLA, LAI and NAR, between RGR and LWR, between SLA and LAR, between TLA and LAI, between LAD and BMD and both TLA and LAI. On the other hand, the correlation between RGR and both LAD and BMD, between BMD and both SLA and LAR were significantly negative.

Discussion

One of the main objectives of this paper was to describe the dry matter investment in terms of instantaneous increase in plant and organ biomass "allocation" and the all season dry matter distribution "partitioning" for soybeans under natural agriculture practices in Egypt. The two concepts of biomass estimation (i.e. allocation and partitioning) have previously introduced to study the interrelationship between the fitness or the ecological role and the allocation of some crucial substances such as dry matter and

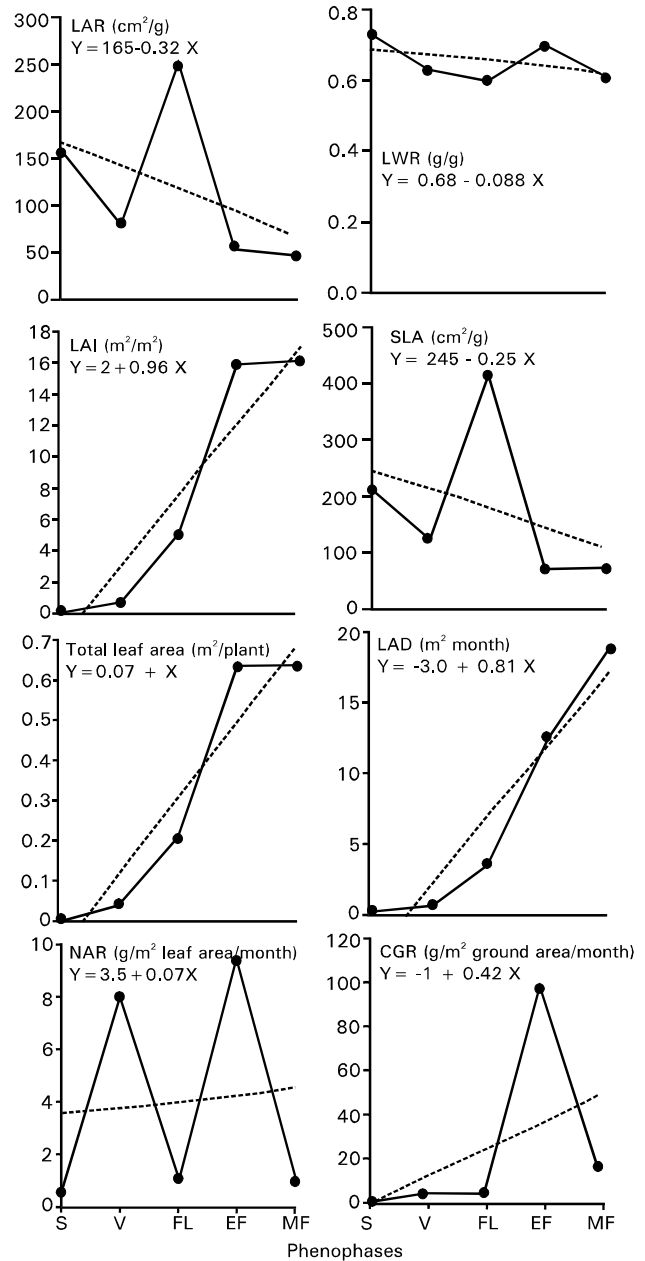


Fig. 4: Variation in LAR, LWR, LAI, LAD, SLA, NAR and CGR of soybeans over five different phenophases (S: seedling, V: vegetative, FL: flowering, EF: early fruiting, MF: mature fruiting)

LAR = leaf area ratio LWR = leaf weight ratio
 LAI = leaf area index TLA = Total leaf area
 LAD = leaf area duration SLA = specific leaf area
 NAR = net assimilation rate CGR = crop growth rate

nutrients (Harper and Ogden, 1970). It also provides an idea about the distribution and adaptation of different species to different niches (Bazzaz and Reekie, 1985).

On the basis of the absolute values of biomass versus time (traditional biomass estimation) the dry matter was allocated to different organs of soybeans in the order: leaves > stems > fruits > roots. At mature fruiting the dry matter allocation was

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Table 1: Variation in organ dry weights of soybeans as well as the total dry weight and biomass duration (BMD) \pm SE in relation to different phenophases. Number of replicates = 25

Phenophases	Organ dry weights (g plant ⁻¹)					Total dry weight (g plant ⁻¹)	Biomass duration (BMD) (g month)
	Leaves	Stems	Flowers	Fruits	Roots		
Seedling	0.073 \pm 0.01	0.022 \pm 0.002	-	-	0.005 \pm 0.0	0.1 \pm 0.01	1.5 \pm 0.12
Vegetative	2.77 \pm 0.3	0.84 \pm 0.1	-	-	0.79 \pm 0.06	4.4 \pm 0.3	67.5 \pm 4.5
Flowering	4.83 \pm 0.6	2.24 \pm 0.2	0.1 \pm 0.02	-	0.94 \pm 0.10	8.11 \pm 0.8	187.65 \pm 9.7
Early fruiting	87.66 \pm 6.4	20.73 \pm 2	-	12.76 \pm 1.2	4.67 \pm 0.6	125.82 \pm 10	2008.94 \pm 82
Maximum fruiting	88.56 \pm 7.2	21.04 \pm 2.2	-	29.73 \pm 2.4	4.63 \pm 0.7	143.96 \pm 9	4046.7 \pm 113

Table 2: Simple correlation coefficients between the different growth parameters of soybean plants.

	BMD	LAD	TLA	LAI	SLA	LAR	LWR	NAR	CGR	RGR
BMD	1.0	++	++	++	NS	-	NS	NS	NS	-
LAD		1.0	++	++	NS	NS	NS	NS	NS	-
TLA			1.0	++	NS	NS	NS	NS	+	NS
LAI				1.0	NS	NS	NS	NS	+	NS
SLA					1.0	++	NS	NS	NS	NS
LAR						1.0	NS	NS	NS	NS
LWR							1.0	NS	NS	+
NAR								1.0	+	NS
CGR									1.0	NS
RGR										1.0

+ : Significantly positive at $p < 0.05$

- : Significantly negative at $p < 0.05$

++ : Significantly positive at $p < 0.01$

NS: Not significant

BMD = Biomass duration

LAD = Leaf area duration

TLA = Total leaf area

LAI = Leaf area index

SLA = Specific leaf area

LAR = Leaf area ratio

LWR = Leaf weight ratio

NAR = Net assimilation rate

CGR = Crop growth rate

RGR = Relative growth rate

confined only for fruit development. Radin *et al.* (1990) reported that crop plants and annuals undergo a developmental phenomenon known as "cutout" which mean when fruiting begins vegetative growth slows and may finally cease. On the other hand, the slope allocation method showed that, there was highly significant correlation between root dry weight ($r = 0.988$), stem ($r = 0.966$), leaves ($r = 0.966$) and total biomass. The rank of order of increasing biomass on regression line basis was root > stem > leaves.

The discrepancy between the rank of order of biomass allocation to different organs in the two methods was clear. These may answer the question why the traditional method of calculating allocation by dry weights of plant organs versus time must also be accompanied by plotting the actual organ weights against total plant weight (slope allocation). Ismail (1992) in a study on *Calotropis procera* and El-Darier and Hussein (1999) on *Pancreaticum maritimum* provide argument about the necessity of the application of more than one method (e.g. slope allocation method and fractional allocation curves) to analyze the allocation pattern of plant dry weight.

The biomass partitioning generally expressed in root/shoot and leaf/stem ratios. The maximum value of the first ratio was attained when biomass proportion allocated to roots was higher than at any other phase (maximum vegetative phase). Explicitly, three distinct phases can be distinguished in root/shoot ratio curve. Firstly, biomass allocated to roots increased exponentially at the expense of that allocated to shoot. Secondly, some biomass was allocated to shoot growth with no further addition to root. Thirdly, the allocation was shared between root and shoot. Leaf/stem ratio attained its highest values (about 3.3 and 4.2 g g⁻¹) during 'S-V' and 'EF-MF' periods respectively with minimal during 'FL' phase (2.1 g g⁻¹).

The growth can be examined in the form of change in biomass through time (traditional growth analysis) or as the difference between the production of new biomass units or modules and the death or loss of old modules (demographic growth analysis) (Chiariello *et al.*, 1991). In both types of analysis, relative growth rate (RGR) is the fundamental parameter, which provides one of the most ecologically significant and useful indices of plant growth. Burdon and Harper (1980) confirmed the importance of RGR in the adaptation of the plant to its environment. In the present study the two peaks of maximum for 'RGR' during 'S-V' and 'FL-EF' periods and minimum during the mature fruiting may

explain the sharp increase and decrease in biomass during these periods respectively. Such a low RGR during the reproductive phase coincided with the diversion of photosynthates into the fruit maturation (Boot *et al.*, 1986; Ismail, 1992). Moreover, Franzen (1999) stated that early in the growing season, the source of carbohydrates in soybean is leaves and the main sink is the nodules, in addition to the growing points of the plant. After flowering, plants change the sink from nodules to the seed production.

The plant's leaf area is considered as the driving variable for RGR (Evans, 1972). Explicitly, and according to "Evans approach", RGR is factored into two components LAR and NAR. LAR is the result of SLA times LWR. It represents the ratio of photosynthesizing to respiring material within the plant (Lambers *et al.*, 1998). Both SLA and LAR are a ratio of leaf area to mass and both decreases in value, as leaves become thicker. SLA and LAR obviously exhibited a similar trend but in true the decrease occurred in SLA caused the following decline in LAR over different phenophases. Previously published work on *Calotropis procera* obtained the same results (Ismail, 1992). The curve of LWR showed a stepwise decrease in the amount of biomass devoted to leaf material till flowering stage. Seventy three % of plant biomass at seedling stage was in leaf fraction, then by the beginning of vegetative stage the value dropped to about 63% then to 59% at the flowering stage. After that, the value fluctuated till the end of the plant life cycle.

It was obvious that the increase in NAR was associated with the decrease in SLA. Moreover, at flowering NAR decreased in spite of increase in LAI which may be due to mutual shading between plants and self-shading between leaves resulting in attenuation of the intensity of light reaching the leaves and thus reducing photosynthesis (Bunce, 1986). The maximum CGR was coincided with the maximum in LAI (about 16) and with an increase in NAR (as CGR is a product of the two parameters). The remarkable decrease in NAR and CGR at the mature fruiting stage may be partially ascribed to yellowing and drying of a large number of lowermost leaves (Singh and Rao, 1987; Larcher, 1995). The higher values of NAR during vegetative and early fruiting, of LWR during seedling and early fruiting and of SLA during seedling and flowering phases may explain the increase in RGR. On the other hand, the drop occurred in NAR and LWR during flowering causes the two-third reduction in RGR in transition from vegetative to flowering stage.

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