Study of sugar beet growth pattern in Hamedan, Iran

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ABSTRACT

The current study was carried out to examine sugar beet growth pattern in climatic conditions of Hamedan, Iran and to recognize the factors affecting its quantity and quality as well as the physiological indices. Two sowing date experiments were conducted on the basis of a Randomized Complete Block Design with four replications and 11 harvests. The plots were destructively sampled and the growth was analyzed by regression method on the basis of the variations of leaf area index, leaf dry weight and total dry weight which are the basis of growth analysis. Results revealed that the maximum crop growth rate of the earlier sowing date reached to 20.2 and 23.3 g.m⁻².day⁻¹ 90 days after planting in 2002 and 2003, respectively. In the second sowing date, maximum crop growth rate reached to 29.5 and 25.0 g.m⁻².day⁻¹ 110 and 96 days after planting in 2002 and 2003, respectively. Maximum leaf area index of the earlier sowing date was obtained about three months after planting approximately concurrent with the realization of maximum crop growth rate and reached to 2.5 in 2002 and to 2.6 in 2003, but it started to slowly decrease at later growth period. Relative growth rate was the highest at the early growth period and linearly decreased during growth period. Net assimilation rate firstly increased slowly, but as the leaves grew and shaded each other, it started to decrease. The highest root growth rate in the earlier sowing date reached to 10.1 and 20.0 g.m⁻².day⁻¹ 94 and 92 days after planting in 2002 and 2003, respectively. The highest root growth rate in the second sowing date reached to 14.0 and 17.3 g.m⁻².day⁻¹ 108 and 95 days after planting in 2002 and 2003, respectively. In total, root potential yield was considerably higher in the earlier than in the delayed sowing date under climatic conditions of Hamedan in both years. The sugar beet growth pattern-related physiological indices were greatly consistent with crop yield potential during growing season. Therefore, given the climate changes and global warming, sugar beet sowing in the earliest possible date in Hamedan is recommended in terms of physiological indices and yield.

Keywords: GDD, Growth index, Growth pattern, Leaf area index, Root yield, Sowing date

INTRODUCTION

It is crucially important to study sugar beet growth pattern under cold climate of Hamedan, Iran, to recognize the factors impacting its quantity and quality during vegetative growth, and to determine the relation of these factors with environment and the patterns of their variations. Also, physiological indices can indicate the course and the extent of the impact of environment at various growth stages which allows collecting the data required for planning future researches like sugar beet growth modeling, yield prediction and sugar beet water demand estimation by such software as CROPWAT. Growth analysis allows estimating economical yield.

Early sowing dates usually result in longer growing period and consequently, allow optimal utilization of regional climate potential. Thus, a part of assimilates is accumulated in different organs of sugar beets as dry matter. Reaching to maximum leaf area index (LAI) is considered as one of the main parameters in determining the yield of sugar beet (Scott and Jaggard, 1993).

According to FAO classification (Doorenbos and Kassam, 1979), the growth of sugar beet is classified in four stages: (i) germination of 80-90% of seeds until plant establishment (four-leaf stage); (ii) vegetative growth stage starting from plant establishment until 70-80% of field green canopy cover (25-35 days to 16-leaf stage); (iii) yield formation starting from full cover until the onset of
green cover loss (75-125 days and almost constant leaf cover); and (iv) crop maturity which is the stage of reaching to maximum coefficient of sugar extraction and maximized sugar yield (40-50 days).

Leaf area index is one of the main parameters in measuring crop growth. Watson (1947) believed that leaf area was a major factor in estimating sugar beet yield and proved that root yield depended on quick development of leaf area. Also, he found that the maximum sugar beet growth rate was 32 g.m⁻². Maximum sugar beet growth rate reached to 31.8 g.m⁻² by early sowing (March 30) under Karaj climatic conditions in Iran (Abdollahian-Noghabi, 1992). Temperature, radiation intensity and day length are the main environmental factors limiting leaf growth (Milford and Lenton, 1976). Studies have shown that sugar beet leaf emergence rate has a linear relation with temperature rise over 1°C. Results of studies of the reaction of leaf expansion to temperatures over 3°C revealed that leaf area daily expansion rate was linearly related to the integral of daily temperature (Milford and Lenton, 1976).

Specific leaf area (SLA) is one of the important physiological parameters, which is an indicator of leaf growth. Specific leaf area can express the balance between leaf area expansion and biomass partitioning to leaves. Being influenced by some environmental parameters (Keating and Caberry, 1993), specific leaf area is a measure of leaf specific weight or its relative thinness since it measures the ratio of leaf area to its dry weight. The higher the SLA is, the thinner the leaves and the lower their photosynthesis efficiency will be (Karimi and Azizi, 1994). Some researchers reported that leaves grown under shadow are often thinner, have greater area and are more horizontal and so, their photosynthesis rate per unit area is lower under intense radiation (Keating and Caberry, 1993). Leaf area index can be estimated by SLA and leaf dry matter (Koocheki and Sarmadniya, 1994). Less radiation is absorbed in lower plant densities and hence, the photosynthesis efficiency of these densities is much lower. On the other hand, at higher densities with higher LAI, solar radiation is not adequately absorbed and photosynthesis efficiency is low because of mutual shading of the leaves. Therefore, the absorption of solar radiation in a longer period under maximal plant cover is very important (Sarmadniya and Koocheki, 1987). Specific leaf area exhibits a decreasing trend during sugar beet growth period and varies in the range of 8-10.5 m².kg⁻¹ (Khayamim et al., 2003). Shokohfar (2001) reported that sugar beet SLA showed a descending trend with time in the first year of the study, but in the second year of the study it showed an ascending trend up to 140-160 days and then, started to decline. In this study, the row spacings of 45 and 75 cm had the highest and lowest SLA, respectively. Furthermore, he reported the variations of SLA in the range of 0.013-0.019 m².g⁻¹ in the first year and in the range of 0.015-0.021 m².g⁻¹ in the second year. In another study on vetch, wider plant spacing (lower density) resulted in higher leaf thickness and single-plant seed yield. Also, it was shown that the increase in seed yield of one of the studied genotypes was mainly caused by the loss of SLA (the increase in leaf thickness) (Habibzade et al., 2006). Specific leaf area is an index of leaf thickness. The increase in SLA at early growing season is brought about by the quick increase in leaf area and the decrease in its thickness and the loss of this index at late growing season is resulted from the loss of leaf area due to the cessation of leaf formation (Farahmand-rad et al., 1999).

A study on sugar beet growth pattern in Kermanshah, Iran revealed that the trend of LAI variations as well as total dry weight in terms of days after sowing followed a quadratic equation. Relative growth rate (RGR) decreased with sugar beet aging and the highest net assimilation rate (NAR) was obtained at late-July. The maximum root growth rate was estimated to be 12 g.m⁻² (Kolvand, 1995). In autumn sowing of sugar beet in Khuzestan, Iran, the highest root growth rate (17.23 g.m⁻².d⁻¹) was obtained 142 days after emergence with a LAI of 4.2 (Hashemi Dezfooli et al., 1996). In Mugan, Iran, maximum LAI was reported to be 5.9 and maximum CGR and root growth rate were reported to be 36.8 and 14.7 g.m⁻².d⁻¹, respectively (Najafinejad, 1996). Studies showed that maximum root growth rate was 18.8 g.m⁻².d⁻¹ in Karaj, Iran (Abdollahian-Noghabi, 1992) and 22 g.m⁻².d⁻¹ in Isfahan (Ebrahimian and Jadhakbar, 1999). Therefore, given the special climatic conditions of Kermanshah, it is necessary to study the growth pattern of sugar beet and the variations of its growth indices in this region which is usually cold and has a relatively short growth period.

**Materials and Methods**

The current study was composed of two experiments including the earliest possible sowing date and sowing with one month delay. It was carried out in Ekbatan Agriculture Research Station of
Hamedan, Iran in two years. In the first experiment conducted in 2002, the first sowing date was May 7 and the second sowing date was June 5. In the second experiment conducted in 2003, the sowing dates were May 8 and June 7, respectively. The study was based on a Randomized Complete Block Design with four replications and 11 harvests starting after the establishment of the plants. Sugar beet monogerm cv. Rasool was used. The initial field preparation included plowing and disking in autumn and the secondary preparation was carried out in spring. The fertilizer level was determined on the basis of soil analysis (Table 1). The spacing between furrows was 60 cm and the spacing between the plants was 20 cm after on-row thinning and weeding. All field care operations were uniformly conducted in accordance with the field requirements and the recommendations of Sugar Beet Seed Institute including furrow irrigation, weeding, thinning and the management of pests, diseases and weeds.

After the establishment of the plants and their thinning, they were regularly harvested once every 14-15 days. During each harvest, four plots were randomly selected from each sowing date. Each plot included five 10-m-long rows. After discarding the border rows, an area of 14.4 m² was destructively harvested. Different traits of about 140 sugar beet roots were measured at each sampling. The fresh and dry weight of shoot and root including leaf blade, petiole, crown and root were measured. To determine dry weight, samples from different organs including leaf, petiole and a separate sample of root pulp was oven-dried at 85°C for 48 hours. To measure leaf area, the leaves of an area of 1 m² of each replication (all the plants located in 1.67 m of the rows) were completely harvested and their leaf area was measured by leaf area meter (Delta T, Cambridge).

The growth of the plants was analyzed by regression method. So, three traits of leaf area index, leaf blade dry weight and total plant dry weight were measured for each sowing date during the growth period. Then, the best quadratic equation was fitted on the natural logarithm of each trait by least significant squares method (Buttery, 1969; Abdollahian-Noghabi, 1992; Sadeghzade Hemayati, 2008). In these equations (Eq. 1, 2 and 3), the number of days after planting (DAP) was considered as independent variable. First, the natural logarithm (ln) of total dry weight (TDW), leaf dry weight (LDW) and leaf area index (LAI) was calculated and then, the best model with acceptable coefficient of determination (R²) was fitted with respect to time (t) using software SPSS (Table 2).

\[
TDW = e^{(a + b \times t + c \times t^2)}
\]  
(1)

\[
LAI = e^{(a + b \times t + c \times t^2)}
\]  
(2)

\[
LDW = e^{(a + b \times t + c \times t^2)}
\]  
(3)

The growth indices were measured by regres-

<table>
<thead>
<tr>
<th>Variable</th>
<th>Year</th>
<th>Experiment</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ln TDW</td>
<td>2002</td>
<td>Early-sowing</td>
<td>-0.8724</td>
<td>0.1139</td>
<td>-0.0004</td>
<td>0.93</td>
</tr>
<tr>
<td>Ln TDW</td>
<td>2002</td>
<td>Late-sowing</td>
<td>0.0461</td>
<td>0.0979</td>
<td>-0.0003</td>
<td>0.91</td>
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<tr>
<td>Ln LAI</td>
<td>2002</td>
<td>Early-sowing</td>
<td>-4.0722</td>
<td>0.0794</td>
<td>-0.0003</td>
<td>0.85</td>
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<tr>
<td>Ln LAI</td>
<td>2002</td>
<td>Late-sowing</td>
<td>-2.6824</td>
<td>0.0617</td>
<td>-0.0002</td>
<td>0.65</td>
</tr>
<tr>
<td>Ln LDW</td>
<td>2002</td>
<td>Early-sowing</td>
<td>-0.414</td>
<td>0.924</td>
<td>-0.0004</td>
<td>0.77</td>
</tr>
<tr>
<td>Ln LDW</td>
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<td>0.4855</td>
<td>0.0763</td>
<td>-0.0003</td>
<td>0.49</td>
</tr>
<tr>
<td>Ln TDW</td>
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<td>-0.331</td>
<td>0.1086</td>
<td>-0.0004</td>
<td>0.87</td>
</tr>
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<td>Late-sowing</td>
<td>-0.7049</td>
<td>0.1115</td>
<td>-0.0004</td>
<td>0.92</td>
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<td>Early-sowing</td>
<td>-2.6938</td>
<td>0.0619</td>
<td>-0.0003</td>
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<td>0.0406</td>
<td>-0.0002</td>
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<td>Ln LDW</td>
<td>2003</td>
<td>Early-sowing</td>
<td>0.5239</td>
<td>0.0761</td>
<td>-0.0003</td>
<td>0.60</td>
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<tr>
<td>Ln LDW</td>
<td>2003</td>
<td>Late-sowing</td>
<td>0.4682</td>
<td>0.0544</td>
<td>-0.0002</td>
<td>0.45</td>
</tr>
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sion method given the concept of each index and the fitted equations (Eq. 1, 2 and 3) and their coefficients (Wilson, 1981; Herbert and Litchfield, 1984; Bullock, 1988; Hashemi Dezfouli, 1990; Abdollahian-Noghabi, 1992).

To calculate relative growth rate (RGR), the equation of TDW (Eq. 1) was differentiated with respect to time (Buttery, 1969). Hence, RGR at a given time was directly calculated by the following equation:

\[
RGR = \frac{d(\ln TDW)}{dt} = b + 2ct
\]  

(4)

Given that leaf area ratio (LAR) displays the ratio of photosynthesizing area of the plant (LAI) to respiring area (TDW), it was obtained by dividing Eq. 2 by Eq. 1:

\[
LAR = \frac{LAI}{TDW} = e^{(a'-a)+(b'-b)+c'(c'-c)y^2}
\]  

(5)

Since RGR = NAR × LAR, net assimilation rate (NAR) was calculated by Eq. (6):

\[
NAR = \frac{RGR}{LAR} = (b + 2ct)e^{(a'-a)+(b'-b)+c'(c'-c)y^2}
\]  

(6)

Crop growth rate (CGR) was calculated by Watson’s equation (Watson, 1952):

\[
CGR = NAR \times LAI
\]  

(7)

To calculate root growth rate (CGR-r), the equation reported by Izumiyama (1984) and by including assimilate distribution rate (DR) in shoot and root of sugar beet was used:

\[
CGR-r = CGR \times DR = NAR \times LAI \times DR
\]  

(8)

Specific leaf area (SLA) is the ratio of leaf area to leaf dry weight. It, indeed, displays leaf weight unit area. Hence, SLA can be calculated by dividing Eq. 2 by Eq. 3:

\[
SLA = \frac{LAI}{LDW} = e^{(a'-a)+(b'-b)+c'(c'-c)y^2}
\]  

(9)

Specific leaf weight (SLW) which is inversely proportional to SLA is the ratio of leaf dry weight to leaf area and can be calculated by dividing Eq. 3 by Eq. 2:

\[
SLW = \frac{LDW}{LAI} = e^{(a'-a)+(b'-b)+c'(c'-c)y^2}
\]  

(10)

Leaf weight ratio (LWR) expresses the ratio of leaf dry weight to plant total dry weight and is like LAR. To calculate LWR, Eq. 3 should be divided by Eq. 1:

\[
LWR = \frac{LDW}{TDW} = e^{(a'-a)+(b'-b)+c'(c'-c)y^2}
\]  

(11)

Growth functions are the ratio of dry weight to thermal index variations (Karimi, 1993). Thermal index, i.e. growing degree days (GDD) is the sum of thermal units which affect the crop growth. It is calculated by the following equation:

\[
GDD = \sum \frac{T_{\max} + T_{\min}}{2} - T_B
\]  

(12)

where, \( T_{\max} \) and \( T_{\min} \) are the maximum and minimum daily temperature in the closest meteorological station to the study field, respectively, and \( T_B \) is the physiological base or zero temperature of sugar beet which is considered as 3°C (Milford et al., 1985; Gummerson, 1986; Durr and Boiffin, 1995; Jalilian et al., 2004). Although no specific reference maximum temperature for sugar beet was observed, it was considered as 30°C according to similar studies (Abdollahian-Noghabi, 1992; Sadeghzade Hemayati, 2008).

It should be mentioned that the highest values of the growth indices reported in this study were calculated by differentiating their corresponding equations and equating the equations to zero.

**RESULTS AND DISCUSSION**
Results of variations of LAI in 2002 showed that maximum LAI of early sowing date (early-May) was 2.5 obtained in early-September. But, it was about 4 and was obtained in early-October in late sowing date (early-June) (Fig. 1). Given that Hamedan has a cold climate and enjoys a plenty of precipitation in spring and since the first possible sowing date of sugar beet was early-May, so maximum LAI was obtained in September. The variations of LAI of both sowing dates in 2003 revealed that maximum LAI of early sowing date was about 1.8 which was obtained in mid-August. But one month delay in sowing postponed the occurrence of maximum LAI to late-September; however, its quantity did not considerably change (Fig. 1).

Higher LAI in 2002 than in 2003 can be related to the climatic conditions of late-March until mid-September, so that total sunny hours of April, June and July in 2002 was higher than that in 2003. Furthermore, the temperature was lower in July and August of 2002 than that of 2003. Therefore, these conditions in 2002 paved the way for greater expansion of leaf area in later sowing date than in earlier one (Fig. 1). Also, Sadeghzhade Hemayati (2008) reported a significant difference in LAI between 2005 and 2006 under climatic conditions of Karaj, Iran. Milford and Lenton (1976) named temperature, light intensity and day length as the possibly main environmental leaf growth limiting factors. Results of other studies showed that sowing date affects the expansion of canopy by affecting the growth, number, size and age of green leaves and whereby, influences the extent of radiation interception by plants during growth period (Rinaldi and Vonella, 2006). Also, Keating and Caberry (1993) indicated that the variations of these indices were affected by some environmental parameters.

Leaf area ratio is the ratio of leaf blade (photosynthesizing area) to plant TDW (respiring area) and displays how much leafy the plant is. In the both study years, LAR was higher in later than in earlier sowing date during the early growing season (Fig. 2). Given higher total dry matter of earlier sowing date than later one, more assimilates were partitioned to shoots during early growth period. But during later stages, the gradient of assimilate flow to root vs. shoot would increase (the denominator in early sowing date would be higher owing to higher dry matter and so, the result of the fraction would be smaller). Thus, at the beginning of sampling, higher total dry matter was found to be accumulated in leaf blades in later sowing date because the plants of this sowing date were still at the stage of leaf area expansion (greater nominator). Steeper slope of LAR de-
crease in 2003 than in 2002 might have been caused by higher temperature of July and August in 2003 than in 2002 because growth decreases under limiting environmental conditions due to the loss of leaf production per unit dry weight (Lambers et al., 1995). In addition, given that the variation of LWR (leaf weight per unit plant weight) was almost similar to that of LAR, just the results about LAR are presented in the current paper.

Specific leaf area is the ratio of leaf area to LDW. Indeed, it expresses unit area of leaf weight. In 2002, SLA of the first and second sowing date reached to its minimum level (85 and 183 cm$^2$.g$^{-1}$, respectively) after receiving 2000 and 1875 GDDs, respectively. In 2003, it reached to its minimum level (146 and 223 cm$^2$.g$^{-1}$, respectively) after receiving 2000 and 1875 GDDs, respectively. In both years, SLA was lower in earlier sowing date than in later one (Fig. 3); in other words, leaf blades of sugar beets were thicker in earlier than in later sowing dates. The higher the SLA was, the thinner the leaf blades and the less efficient the photosynthesis would be (Karimi and Azizi, 1993; Keating and Caberry, 1993). Therefore, lower efficiency of photosynthesis in later sowing than in earlier one could be explained by its lower NAR (Fig. 7) and consequently, the loss of root yield in later than in earlier sowing dates (Fig. 8).

Crop growth rate is in fact the increase in dry matter weight per unit area of a plant population per unit time. Crop growth rate of a plant population is lower at earlier growth stages because of incomplete plant cover and lower radiation absorption percentage. Over the time, leaf area expands, crop growth increases under which more assimilates are produced and as a result, CGR is improved. The highest CGR of the first sowing date in both years (20.19 and 23.32 g.m$^{-2}$, respectively) was obtained 90 DAP and then, it started to decrease (Fig. 4). The received GDDs for reaching to the maximum CGR were 1584 and 1578 in 2002 and 2003, respectively. The loss of CGR is usually brought about by senescence or loss of leaves. As can be seen, CGR reached to its maximum level earlier (by receiving less GDD) in earlier sowing dates in both years after similar DAP and receiving almost similar amount of GDD (Fig. 4). In the second sowing date in 2002 and 2003, CGR reached to its maximum level, i.e. 29.5 and 25 g.m$^{-2}$.d$^{-1}$, 110 and 96 DAP by receiving 2123 and 1964 GDDs, respectively. As can be seen, the plants of later sowing date reached to maximum CGR later than those of earlier sowing date after receiving more thermal units. This can be related to the fact that maximum canopy realized later in delayed sowing
which was followed by the decline of solar irradiance and the shortening of days and consequently, the loss of intercepted energy; whereas, maximum canopy of earlier sowing date was approximately concurrent with maximum day length and solar irradiance in July and August. This was the main cause of higher TDM in earlier than in later sowing date in both years. Since CGR is a direct function of LAI and NAR during growth period and varies with environmental conditions (Naderi et al., 2005), the loss of LAI as well as the decline of solar irradiance, the shortening of days and the resulting loss of intercepted energy results in the loss of CGR.

The highest root growth rate (CGR-r) in the first sowing date reached to 10.09 and 20.01 g.m\(^{-2}\).d\(^{-1}\) 94 and 92 DAP in 2002 and 2003, respectively and then, started to decrease. In the second sowing date, it rose up to 13.95 and 17.34 g.m\(^{-2}\).d\(^{-1}\) 108 and 95 DAP, respectively (Fig. 5). Kolivand (1995) reported the highest CGR-r to be 12 g.m\(^{-2}\).d\(^{-1}\) in Kermanshah, Iran, Hashemi Dezfouli et al. (1996) reported maximum CGR-r to be 17.23 g.m\(^{-2}\).d\(^{-1}\) obtained 142 DAP in Khuzestan, Iran and Abdollahian-Noghabi (1992) estimated it to be 18.8 g.m\(^{-2}\).d\(^{-1}\) in Karaj, Iran. The optimum temperature for sugar beet growth is 20-24°C, but sugar is mobilized from leaves into roots more effectively at lower temperatures (Scott and Jaggard, 1993). Appropriate mean temperature for maximum root growth is about 18°C. At higher temperatures, which are experienced in July and August, final root yield decreases and 22-26°C is suitable for maximum shoot growth. However, growth rate is independent of temperature during late growth period (Kenter et al., 2006). The maximum CGR and CGR-r were higher in Hamedan than in Karaj, Kermanshah and Khuzestan probably because mean temperature of Hamedan is lower in spring and summer than in those regions. So, Hamedan is more appropriate for sugar beet growth. Sugar beet needs a great deal of radiation for growth and sugar accumulation. The increase in day length from 8 to 10-14 hours approximately doubles its root weight and sucrose production, but it does not considerably increase its shoot weight. When it is mostly cloudy during the growth period of sugar beet, its sugar percentage decreases (Scott and Jaggard, 1993). Plentiful solar radiation within 65 DAP and in September-October improves sugar beet growth. In autumn, temperature does not play a decisive role in sugar beet growth anymore and meanwhile, solar irradiance declines (Kenter et al., 2006). Probably, this was the reason that maximum CGR and CGR-r was realized sooner in delayed than in earlier sowing.
date which finally, resulted in the loss of root yield in delayed sowing. The variation of RGR and its relation with time was linear. RGR was the highest at early growth period because of the lack of competition and the shading of leaves. But it started to decrease with the aging of the plants (Fig. 6). With the aging of the plants, the lower leaves are shaded or lose their photosynthesis capability due to senescence and so, RGR exhibits a descending trend during growing season (Karimi and Siddique, 1991).

Net assimilation rate is an indicator of photosynthesis efficiency of the leaves and is maximal when all the leaves are exposed to full radiation. Therefore, NAR naturally increased at early growth period owing to the lack of competition and shading of leaves; then, it started to decrease with the senescence of leaves, their shading and the resulting loss of photosynthesis efficiency. Maximum NAR reached to 10.47 and 16.04 g.m\(^{-2}\).d\(^{-1}\) in earlier sowing date in both years 80 and 88 DAP in late-July and early-August, respectively. In later sowing date, it reached to 8.28 and 14.85 g.m\(^{-2}\).d\(^{-1}\) 97 and 92 DAP in mid-September, respectively (Fig. 7). In earlier sowing date, the moderate conditions of early growing season provided the ground for maximum shoot growth. As a result, maximum leaf area coverage and solar irradiance concurred in June and July and so, the plants reached to their maximum NAR in shorter time than in delayed sowing. In addition, thicker leaves of sugar beets in earlier than in later sowing dates resulted in higher photosynthesis and NAR which is in agreement with the results of other studies (Keating and Caberry, 1993; Karimi and Azizi, 1994; Habibzade et al., 2006).

Root yield (RY) of sugar beet followed an ascending trend from the onset until the end of growing season and its variation was quick at first but it decelerated over the time (Fig. 8). Finally, RY potential was higher in earlier than in later sowing dates in both years probably because of higher CGR and NAR of earlier sowing date which proved its superior photosynthesis and assimilate storage over later sowing date (Sadeghzade Hemayati, 2008). This fact can, indeed, explain higher RY of earlier sowing date under normal conditions. However, it can be related to more similar rate of the variations of CGR with the variations of SLW, LWR and SLA. It can be concluded that lower SLA or thicker leaves in earlier sowing date resulted in its higher RY than later sowing date and played
the decisive role in CGR.

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