Journal of Environmental Biology **July 2007,** 28(3) 527-531 (2007)

Inter-relationship between growth analysis and carbohydrate contents of sweet sorghum cultivars and lines

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(Received: January 06, 2006; Revised received: October 18, 2006; Accepted: November 11, 2006)

Abstract: *The carbohydrate contents of sweet sorghum (Sorghum bicolor L. Moench) is an important industrial factor for crystal sugar or bioethanol production. In this study the relationship between growth analysis and carbohydrate contents were studied to recognize the best growth stages for sweet sorghum harvesting. Five sweet sorghum cultivars and four sweet sorghum lines were evaluated for leaf area index (LAI), net assimilation rate (NAR), relative growth rate (RGR) and stem crop growth rate (CGR) in relation to sucrose content, invert sugars and total sugar at booting, soft-dough, hard dough and post grain maturity. Except at post grain maturity stage, the correlations among LAI, NAR and RGR for sucrose content and total sugar were positive and for invert sugars were negative. The relationship between invert sugars including glucose, fructose, maltose and xylose at hard dough stage regarding LAI, NAR and GRG were negative. As plant grows LAI, NAR and RGR increases which consequently increases sucroses content and decrease invert sugar.*

Key words: *Sweet sorghum, LAI, NAR, RGR, CGR, Sucrose, Invert sugar*
PDF file of full length paper is available with author

Introduction

Sorghum (*Sorghum bicolor* L. Moench) is one of the 5 major cultivated species in the world. It can outproduce most other cereals under marginal environmental conditions, especially dry and hot climatic conditions which prevails the most parts of the country (Almodares and Darany, 2006). Sorghum tolerates drought relatively well, and it responds to adequate fertility and soil moisture with faster growth (Wayne and Frederiksen, 2005)**.** Many types of sorghum are suitable for grain and forage production (Showemimo *et al*., 2002) , as well as, alternative uses, such as energy, pulp for paper, food products and sugar or ethanol products (Gnansounoua *et al*., 2005 and Dolciotti *et al*., 1998). Three valuable growth analysis functions are relative growth rate (RGR), crop growth rate (CGR) and net assimilation rate (NAR) (Borras's *et al.,* 2007). Leaf area index (LAI) is a dimensionless variable and was first defined as the total one-sided area of photosynthetic tissue per unit ground surface area (Inge *et al.,* 2004). LAI is the component of crop growth analysis that accounts for the ability of the crop to capture light energy and is critical to understand the function of many crop management practices. Leaf area index can have importance in many areas of agronomy and crop production through its influence: light interception, crop growth, weed control, crop weed competition, crop water use, and soil erosion (Welles, 1990 and Sonnentag *et al.,* 2007). NAR measures the mean photosynthetic efficiency of leaves in a crop community. The integration of weight and leaf area measurement over time provides value that is highly useful for studying the growth of crops (Shipley, 2006). According to Patterson (1982), relative growth rate (RGR), net assimilation rate (NAR), and leaf area ratio (LAR) are good measures of solar radiation capture during growth with NAR and LAR for an individual plant and LAI for population helping to explain differences in RGR. Samba *et al*. (2003) found that interception of PAR is closely followed by LAI. Reduced NAR interception causes reduction of the RGR, NAR and LAR. Mansab *et al*. (2003) reported that for maximum crop growth, enough leaves must be present in the canopy to intercept most of the incident NAR. Therefore, growth is often expressed on a leaf-area basis. According to Tsuni and Fujise (1965), there is a linear relationship between leaf-area and net assimilation. Growth analysis of sweet sorghum in relation to sucrose has not been reported so the purpose of this experiment was to study the relationship between growth analysis and carbohydrate content of sweet sorghum cultivars and lines.

Materials and Methods

Field experiment was conducted at the University of Isfahan Experimental Station. Five sweet sorghum cultivars (Soave, Rio, Vespa, Turno and M81-E) and four sweet sorghum lines (IS-6962, IS-18154, IS-4546 and IS-16054) were assessed in a complete block design with four replications. Plots consisted of 8 rows, 5 m long and 0.80 cm apart. Plots received 300 kg/ha of diammonium phosphate and 100 kg/ha of urea disced into the soil before planting. Plots were side-dressed with 100 kg/ha of urea subsurface banded 30 days after planting. Three meters from two centre rows were harvested when the plants reached at booting, flowering, soft-dough, hard-dough and two weeks after seed maturity. The fresh stalk, after removing the panicles and leaves, were weighed and crushed in a sugarcane crusher to extract the juice. After filtration through a sieve to remove chaff, *etc.,* reducing sugars were measured according to Lane-Eynon (1970). The soluble solids (brix) and sucrose (pol%) were measured according to Varma (1988). HPLC

Table - 1: Coefficient of correlation (r) between LAI and sugar contents of sweet sorghum cultivars and lines at different growth stages

Carbohydrates	LAI			
	Booting	Soft dough	Hard dough	Post grain maturity
Sucrose	0.93	0.94*	0.98**	0.99**
Invert sugar	-0.84	-0.91*	-0.93*	0.95**
Total sugar	0.85	0.95**	0.98**	93.3*

* significant at 0.05, ** significant at 0.01

Table - 2: Coefficient of correlation (r) between RGR and sugar contents of sweet sorghum cultivars and lines at different growth stages

Carbohydrates	RGR			
	Booting	Soft dough	Hard dough	Post grain maturity
Sucrose	0.65	0.95**	0.83	0.41
Invert sugar	-0.65	-0.88	-0.74	0.21
Total sugar	0.59	0.84	0.81	0.69

* significant at 0.05, ** significant at 0.01

Table - 3: Coefficient of correlation (r) between NAR and sugar contents of sweet sorghum cultivars and lines at different growth stages

Carbohydrates	NAR			
	Booting	Soft dough	Hard dough	Post grain maturity
Sucrose	0.95	0.94*	0.96**	0.95**
Invert sugar	-0.64	-0.92*	-0.89	0.83
Total sugar	0.90	0.98**	0.97**	0.89

* significant at 0.05 ** significant at 0.01

Table - 4: Coefficient of correlation (r) between stem CGR and sugar contents of sweet sorghum cultivars and lines at booting and flowering- soft dough stages

Carbohydrates	Booting	Soft dough
Sucrose	0.98**	0.97**
Invert sugar	-0.85	-0.98**
Total sugar	0.93	0.97**

* significant at 0.05, ** significant at 0.01

Table - 5: Coefficient of correlation (r) between LAI, NAR, RGR and invert sugars of sweet sorghum cultivars and lines at soft dough- hard dough stage

Carbohydrates	LAI	NAR	RGR
Glucose	-0.99**	-0.97**	-0.85
Fructose	-0.95**	-0.96**	-0.75
Maltose	-0.87	-0.86	-0.65
Xylose	-0.98**	-0.93*	-0.82

* significant at 0.05, ** significant at 0.01

was used for determination of glucose, fructose, maltose, xylose, mannose, galactose and arabinose. The HPLC separation was accomplished by using an aminopropyl column (4.6 x 250 mm) with a mobile phase of 80% acetonitrile/ 20% water (Biermann and McGinnis, 1989). Quantitation was accomplished by using three point calibration curves. Growth analysis were performed by determining mean LAI, NAR (g/m^2 day) and RGR(g/g day) according to methods outlined by Hunt (1990) . Parameter results are presented graphically with best-fit polynomial equations plotted against growth degree days (GDD), calculated from emergence using a base temperature of 10 degree centigrade. Leaf area was determined using leaf area meter, then the samples were dried at 65 degree centigrade for 48 hr and then their dry weights were determined.

Results and Discussion

To study the correlations between growth and carbohydrates, growth indexes such as LAI, NAR, RGR and stem CGR at different growth stages were used. The relationships among LAI, for sucrose, invert sugar, and total sugar of sweet sorghum cultivars and lines at different growth stages are shown in Table 1. This correlation became significant after booting. As number of leaves increase, the amount of photosyntate such as sucrose increase. The leaves are the primary organ for light interception and photosynthesis in crop plants. According to Gardner *et al*. (1994), as the leaf area develops radiation interception by leaves increase. Sweet sorghum leaves are staying green after flowering which increase photosynthesis. Bulk of translocated substances, other than water, is the result of photosynthesis and 90% of the total solid in the phloem consists of carbohydrates, mostly. The predominant sugar, translocated in the phloem of most crop species is sucrose. The results show that at all growth stages, invert sugars are negatively correlated to LAI except at hard-dought post grain maturity stage (Table 4). As plants grow, there are more leaves which through photosynthesis, produce more sucrose and less invert sugar. The correlation among LAI, NAR and RGR with glucose, fructose, maltose and xylose at hard dough stage is shown in Table 5. The correlation among LAI and all the above mentioned sugars are negative which means that as a number of leaves increases, the amount of all the above mentioned sugars decreases. Table 2 shows significant ($p<0.01$) relationship between RGR and sugar content at soft dough. The relation between NAR and sugar content is presented in Table 3. Table 4 shows the relationships between stem CGR and the above sugars at booting and soft dough stage. In this study, CGR is presented on a 10 degree-day basis. At the end of the season, CGR will decrease. CGR in the beginning of the season increases because of the increase in leaf size and stem weight. According to Davidson and Campbell (1984) reduction of CGR at the end of the growing season is due to the reduction of photosynthesis rate and leaves abscission. In this study stem CGR at the end of growing season was not reduced due to the stay green conditioned leaves of sweet sorghum cultivars and lines. The relationships among LAI, NAR, RGR and stem CGR for sucrose and total sugar were positive and for invert sugar were negative

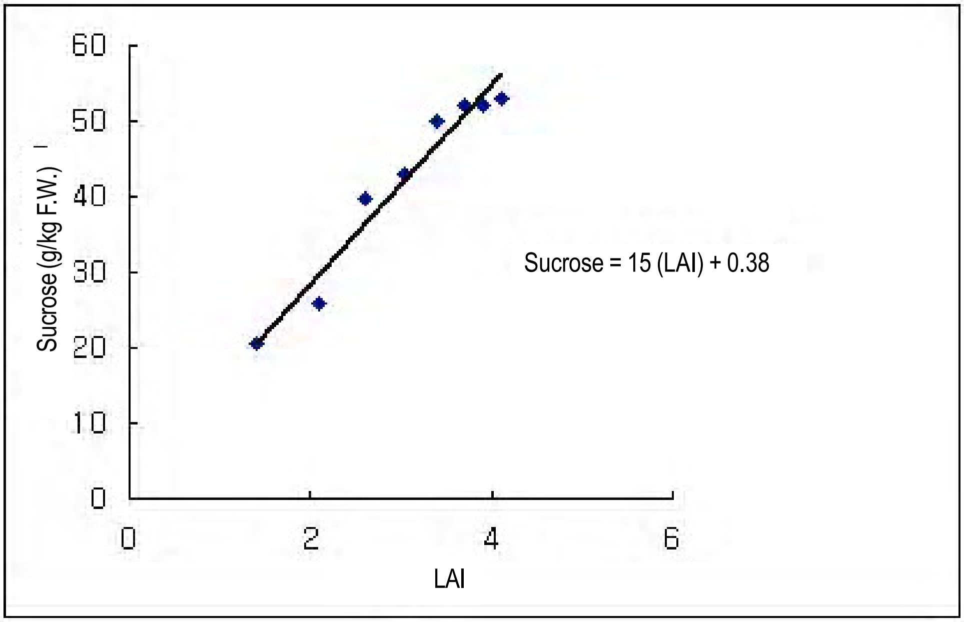

Fig 1: Correlation between LAI and sucrose content at physiological maturity

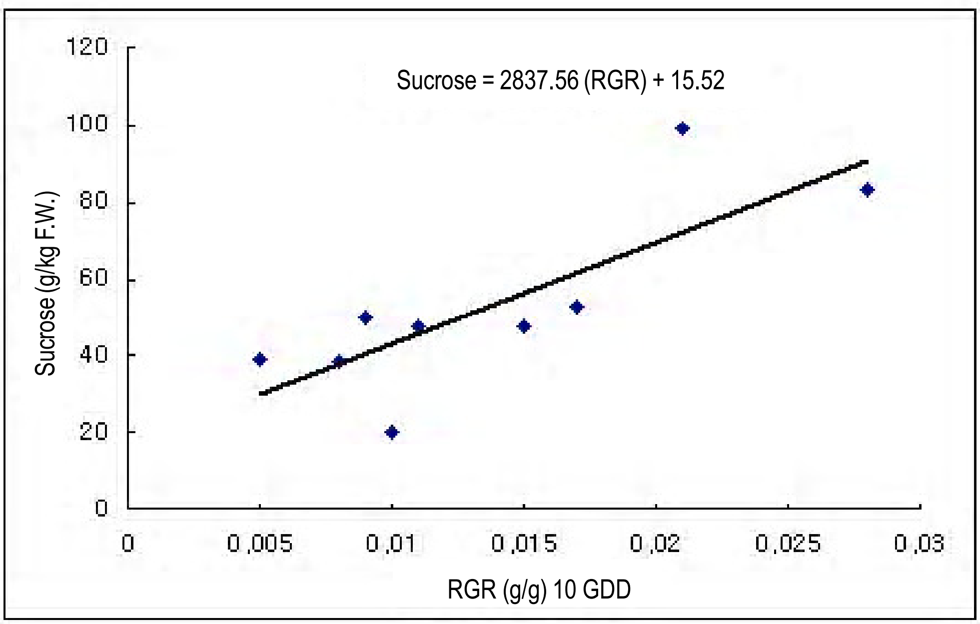

Fig 2: Correlation between RGR and sucrose content at physiological maturity

except during post grain maturity. During this stage, the amount of invert sugars was small. The relationships indicates that as the plant grows the amount of sucrose and total sugar increase while the amount of invert sugar decreases. Almodares *et al*. (1994) found that at all growth stages, total sugar and sucrose were higher than other carbohydrates. The relationships among LAI, NAR, RGR and invert sugars (glucose, fructose, maltose and xylose) are shown in Table 5. The coefficient of correlation for all these carbohydrates are negative which indicate that the plant grows LAI, NAR, and RGR also increase and the amount of these carbohydrates decreases. The correlations among LAI, RGR, NAR and CGR with sucrose for sweet sorghum cultivars and lines at hard dough stage are shown in Fig. 1-5 respectively. The relationships have linear and positive responses which indicate that as the plant grows, there are more leaves, more photosynthesis (NAR), and more growth (RGR and CGR) which increase sucrose content in the stem. The results showed as sweet sorghum cultivars and lines grow, LAI, NAR and RGR will be increased. As a result, the amount of sucrose increased while the amount of invert sugar (glucose, fructose, maltose and xylose) decreased. The results indicate that

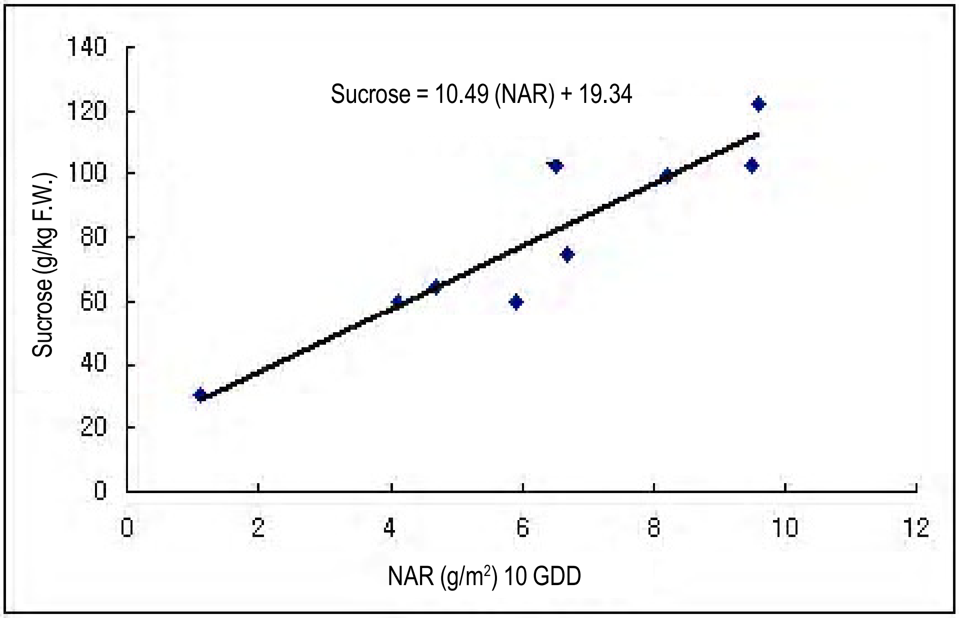

Fig 3: Correlation between NAR and sucrose content at physiological maturity

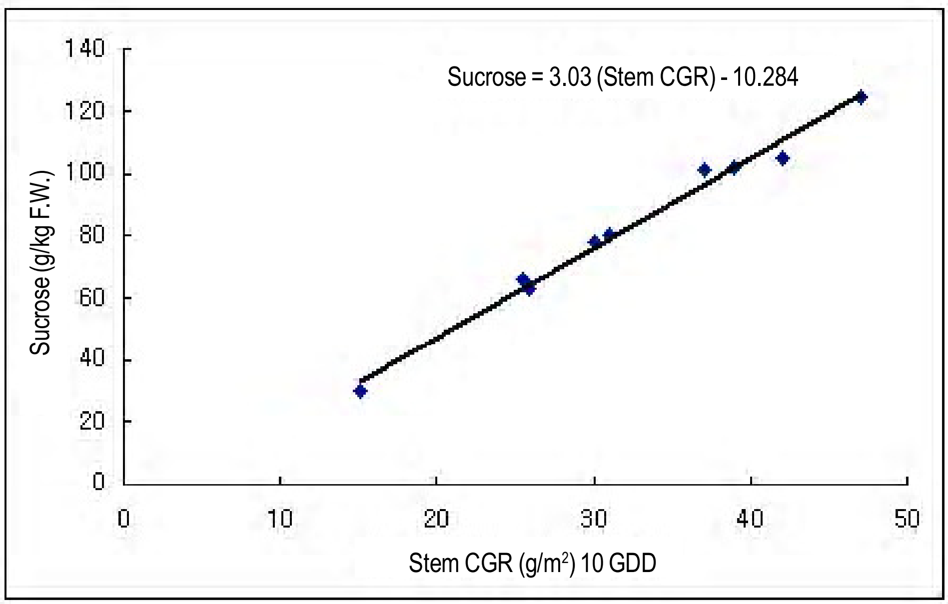

Fig 4: Correlation between stem CGR and sucrose content at physiological maturity

the time of harvesting sweet sorghum, cultivars and lines is dependent on the purpose of planting. If the purpose of planting is to produce crystal sugar, it is suggested to harvest sweet sorghum cultivars and lines at hard dough- post maturity stage when plants had the highest sucrose and lowest invert sugars, since invert sugars interfere crystallization. Harvesting sweet sorghum cultivars and lines at other growth stages are more suitable for liquid sugar production. It should be mentioned that as plants grow, biomass increases and plants at early growth stage had lower biomass than other growth stages.

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