Physiological Growth Responses of Sorghum Genotypes to Impairment of Plant Photosynthesis Using Potassium Iodide

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Abstract: Plant growth analysis is an explanatory, holistic and integrative approach to interpreting plant form and function. In this study, the effects of impaired photosynthesis on yield and growth analysis of sorghum maturity groups were examined. Treatments were arranged in a split-plot design as randomized complete block with 6 genotypes of grain sorghum (including short-, mid- and full-season genotypes) as main plot, and 2 treatments, non-interference with photosynthesis (control) and impaired photosynthesis through dehydration of the leaves using potassium iodide (KI) in three replications. The experiment was conducted at the Agriculture and Natural Resources Research Station of Toroq, Northern Iran in 2010. Grain and biological yields, LAI, CGR and RGR LAI in the different treatments were evaluated. Results showed that statistically significant differences have been found to exist between the genotypes on grain and biological yield. Genotype No. 15, which is a mid-season sorghum exhibited the greatest grain yield (6104 kg ha−1), while genotype No. 12 another mid-season genotype had the least grain yield (2261 kg ha−1). The CGR and LAI for plants were low during early vegetative growth and attained its peak at flowering then declined at maturity. The greatest and the least LAI and CGR at flowering were observed in genotypes No. 6 (mid-season) and genotype No. 9 (short-season).

Key words: Sorghum, physiological growth indices, genotypes, Senescing agent potassium iodide.

INTRODUCTION

The term plant growth analysis refers to a useful set of quantitative methods that describe and interpret the performance of whole plant systems grown under natural, semi natural, or controlled conditions. Plant growth analysis provides an explanatory, holistic and integrative approach to interpreting plant form and function. It uses simple primary data in the form of weights, areas, volumes and contents of plant components to investigate processes within and involving the whole plant or crops (Evans, 1972; Causton and Venus, 1981; Hunt, 1990). From its origins at the end of the nineteenth century, plant growth analysis first illuminated plant physiology, then agronomy and now physiological and evolutionary plant ecology.

Sorghum (Sorghum bicolor (L.) Moench) is a major crop ranked fifth in world production of cereals (Sato, et al., 2004). It is considered a primary staple food crop in the semi-arid tropics of Asia, Africa, and South America. The grain is normally used as food and animal fodder, but recently it has been used as raw material for the production of chemicals, such as levulinic acid (Ganjyal, et al., 2007). Sorghum is typically cultivated in the arid and semi-arid regions of Iran generally in areas with low precipitation that are not suitable for corn (Zea mays L.). Sorghum plants are considered to be relatively resistant to drought, although to achieve optimum growth or yield, sufficient water for irrigation is required.

Grain growth in cereal crops is largely dependent on the availability of current photosynthates. Remobilization and transfer of the stored photosynthates in vegetative tissues to the grain in monocarpic plants such as sorghum require the initiation of whole plant senescence (Gan and Amasino, 1997). Delayed senescence, which in practice is induced by either too much nitrogen fertilizer or an adoption of lodging-resistant cultivars that stay “green” for too long, results in much nonstructural carbohydrate left in the straw and leads to a low harvest index. Grain filling in sorghum depends on C from two resources: current assimilation and remobilization of reserves stored in the stem and other parts (mainly the sheath) either pre- or postanthesis (Kobata, et al., 1992). Normally, preanthesis assimilate reserves in the stem and leaves of sorghum contribute 25 to 33% of the final grain weight (Gong, et al., 2009). Remobilization of reserves to the grain is critical for grain yield if the plants are subjected to water stress during grain filling (Palta, et al., 1994; Ehdaie and Waines, 1996). It has been reported that postanthesis soil drying accelerates the grain filling and increases harvest index (Zhang, et al., 1998). Early senescence caused by impaired photosynthesis through dehydration of the leaves and green parts of plants using the senescing agent potassium iodide, however, reduces photosynthesis, shortens the grain-filling period, and results in reduction of grain weight (Meng, et al., 2011). Potassium iodide may destroy plant photosynthetic source in a controlled manner. It has been reported that the senescing agent KI reduced the chlorophyll content of the leaves, grain yield, grain number and grain size more severely than did water deficit treatments (Wang and Han, 2009).

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In this study, the effects of spraying the senescing agent potassium iodide (KI) after anthesis on grain yield and growth analysis using 6 sorghum genotypes grown under field conditions in 2010 were examined.

MATERIALS AND METHODS

Site Description:
Field experiment were conducted in 2010 at the Agriculture and Natural Resources Research Station of Toroq (36°15’ N, 59°28’ E, 985 m above sea level), in Northeast Iran. The experiment was established in a sandy loam soil (19% clay (<2 µm), 21% silt (2-20 µm), 41% fine sand (20-200 µm) and 19% coarse sand (200-2000 µm)), with a pH of 7.8, organic matter 0.11%, N-Nţ 2.9 ppm, P (Olsen) 2.2 ppm, and K 156 ppm (0-30 cm depth).

The experimental site is located in a cold and arid region with mean annual precipitation of 214 mm and annual mean long-term average temperature of 14.5°C. In the experimental year (2010) the annual precipitation and mean temperature were 258 mm and 13.2 °C, respectively. These values differed considerably from the long-term average. The preceding crop was winter wheat (Triticum aestivum).

Experimental layout:
Seedbed preparation included ploughing, disk harrowing and cultivating. All plots were given 250 kg P2O5 ha\(^{-1}\) as the triple super phosphate, 150 kg P2O5 ha\(^{-1}\) potassium sulfate (K2S04) together with half of the N fertilizer (750 kg ha\(^{-1}\)) pre-plant. Final N applications were applied with irrigation 30 days after planting. Foliar fertilizer was applied using a hand-operated knap-sack sprayer. The plots were sprayed during late-afternoon or evening hours when the wind speed was less than 10 km h\(^{-1}\) and the air temperature was lower than 25 °C. During the growing season, all plots were weeded manually. No serious incidence of insect or disease was observed and no pesticide or fungicide was applied. Flood irrigations were done using Hydro fixed tubes with control valves.

Main plot treatments were 6 genotypes of grain sorghum (including short-, mid- and full-season genotypes). Subplot treatments consisted of 2 treatments, no interference with the photosynthesis (control) and impaired photosynthesis through dehydration of the leaves and green parts of plants using potassium iodide (KI). The first potassium iodide spraying was carried out 8 to 10 days after anthesis using a dose of 0.4%.

The experimental design for this study was a split-plot randomized complete block design with three replicates. The treatments were laid out in 3×6 m plots and the crops were manually sown at a spacing of 0.75 m between the rows and 0.10 m within them, giving a plant density of 133,333 plants ha\(^{-1}\). Sowing date was May 5th, 2010. Adjacent subplots were separated by a 1.5-meter-wide ridge, and the main plots were separated by a 3-meter-wide ridge.

Plant Sampling and Growth Analysis:
Plants were sampled for growth analysis at approximately 7-day interval between 40 DAP and harvest. The plant samples were oven-dried at 76°C for 48 h to a constant weight and dry weight was recorded. The leaf area index (LAI) was measured using a leaf area meter (Model: LI-3100 Area Meter (USA)).

Crop growth rate (CGR), the increase in dry weight per unit ground area of crop in a unit time, was calculated as \(\frac{(W_2-W_1)}{(t_2-t_1)}\), where \(W_1\) and \(W_2\) are dry weight at times \(t_1\) and \(t_2\), respectively, and expressed as g m\(^{-2}\) per day.

At maturity, 5 plants were sampled and some vegetative growth parameters (including plant height, collar diameter and panicle length) as well as one hundred seed weight and grain number (panicle\(^{-1}\)) were separately recorded. Plants were harvested from each plot, sun dried for approximately 10 days to around 10% moisture content, threshed and weighed to determine grain yield. Total vegetative above-ground dry matter was determined by collecting all remaining above ground biomass from the same plots.

Statistics:
Data collected were subjected to the analysis of variance (ANOVA) with test of significance for treatment difference using a \(P=0.05\)%-test.

RESULTS AND DISCUSSION

Total Dry Matter:
Analysis of variance revealed that there is a significant difference in maximum of dry matter accumulation between genotypes (Table 1). Genotype No. 15(mid-season) exhibited the greatest total dry matter, which compared with the genotype No. 9 (short-season), produced 53.2% more total dry matter. (Asghari, et al., 2006) in explaining the higher dry matter production in full-season and mid-season sorghum varieties stated that the time intervals between inflorescence emergence and anthesis is longer and could account for these yield differences.
Total dry matter accumulation trends in all genotypes in the early stages of growth (six weeks after planting) were almost identical (Fig. 1). During physiological maturity dry matter accumulation was faster and increased differently for different varieties. Total dry matter declined during grain dough stage. At the beginning of the growing season dry matter accumulation in short-season genotypes was higher compared with the two other maturity groups; however, they quickly reached maximum dry matter accumulation levels at dough stage and then dry matter began to decrease. Similar results have also been reported by other researchers (Javadi, et al., 2003; Abdi, et al., 1992). Plant weight generally, depends on initial dry weight, growth duration and crop growth rate. Shedding of leaves at the end of the season reduced shoot dry weight and the short-season sorghums had the lowest dry matter weight.

Leaf Area Index (LAI):
Analysis of variance revealed that maximum LAI was affected by different sorghum maturity groups (Table 2). Genotypes No. 6 (mid-season) had the greatest maximum LAI, while genotypes No. 9 (short-season) had the least LAI (Fig. 2).

LAI is a function of leaf dry matter. In this experiment, leaf area index increased with increasing leaf dry matter. LAI changes over time and had a sigmoid trend. A number of researchers (for example, (Bueno, et al., 1982) reported that LAI increased with plant age. In this study, genotypes 6 and 15 (mid-season) had the highest LAI at flowering, followed by genotypes 7 and 8, which were full-season sorghums (Fig. 2).

Aging and leaf death in the late growing season resulted in LAI decreasing due to nutrients deficiency and low light penetration into the lower layers of the canopy. This decrease in the intermediate genotype was less than the other genotypes. The lower decrease in the mid-season genotypes could have resulted from better light penetration into the lower level of canopy due to less LAI in the flag leaf. Since LAI is associated with grain yields the maximum grain yield was obtained in genotypes No. 6 and 15.

Crop Growth Rate (CGR):
Analysis of variance revealed that maximum CGR was affected by different sorghum maturity groups (Table 2). The greatest CGR were observed in genotypes No. 7 and No. 6, while genotypes No. 8 had the lowest CGR (Table 3).

In the early stages of growth, CGR is less than late growth due to incomplete ground coverage and lower percentage of light absorption. But over time rapid increases in growth rate occurs due to the development of leaf area and less light penetration to the lower layers of the canopy. Maximum crop growth rate is generally consistent with the onset of flowering. In this experiment, early growth to 80 days after planting, CGR of short-season genotypes was higher than other maturity groups. However, after reaching maximum CGR a week before 50% flowering CGR began to decrease. Mid-season genotypes had lower CGR in comparison with the other maturity groups (Fig. 3). Similar findings by (Javadi, et al., 2003) confirmed these results. A number of researchers (for example, (Abdi, et al., 1992) believe those genotypes which have the highest CGR at 50% flowering had more yield than other genotypes.

Relative Growth Rate (RGR):
Statistically significant RGR differences were found to exist between the genotypes (Table 2). Genotypes No. 7 and 9 are full- and short-season genotypes and had the greatest RGR. Maximum RWR occurs in the early growing season and this parameter decreases with increasing plant age (Fig. 4). The results of this study are consistent with those of (Javadi, et al., 2003). Davidson and Campbell, 1984) have shown that the higher yield of wheat genotypes was due to their high RWR in the vegetative stage. This parameter represents the ratio of meristem tissue to differentiated issues, thus this ratio will decline during the growing period.

Grain Yield:
Analysis of variance revealed that grain yields were affected by genotypes, photosynthetic status and the interaction of genotypes by photosynthetic status (Table 1). The greatest grain yield was observed in full-season genotypes of No. 15 and 6, which had 149.75% more grain yield than the No. 9 short-season. Grain yield ranged between 2444 to 6104 kg ha⁻¹ across different maturity groups.

Overall results showed mid- and full-season genotypes exhibited the greatest and the least grain yield, respectively. The interaction between genotype and photosynthetic status revealed that under normal photosynthetic conditions mid-season genotypes No. 15 and 6 had the greatest grain yield, while in the impaired photosynthesis status short-season genotype No. 3 and the full-season genotype No. 8 produced less seed numbers per panicle and had the least grain yield. This showed that the number of seed per panicle was important in determining final grain yield (Table 3). Lower grain yield in full-season genotypes rather than the two other maturity groups may be due to impairment in some physiological characteristics such as photosynthesis and assimilate transfer to the seed. (Gambin and Borras, 2007) in their experiments showed that as assimilates increased, grain yield increase by 30 to 60%.
During the grain filling stage, photosynthesis was affected by either living or non-living stresses. Disruption of photosynthesis significantly reduces the grain yield by 377% in comparison with normal conditions. Reduction in photosynthetic capacity limited yield and yield components. Thus, the lower canopy photosynthetic capacity led to lower yields through reducing the grain filling period. The results found in this study are consistent with those of (Farhangi, 2007; Ghodsi, 2002; Royo, et al., 1999).

**Biological Yield:**

Biological yield was affected by genotypes, photosynthetic status and their interaction (Table 1). Trends in biological yield in different genotypes revealed that the greatest biological yield occurred in the mid-season genotype No. 15, while the least biological yield was observed in the short-season genotype No. 9. Biological yield in genotype No. 15 increased by 53% compared with genotype No. 9 (Table 3).

Under normal photosynthetic conditions biological yield was reduced 70% compared to those genotypes in which photosynthesis was impaired (Table 3). Interaction of genotype by photosynthetic status on biological yield showed that mid-season genotypes of No. 15 and short-season genotypes No. 9 had the greatest and the least biological yield whereas photosynthetically impaired short-season genotype No. 3 had the least biological yield (Table 3). Impaired genotypes had significantly lower yields (Table 3). This reduction shows the effect of current photosynthesis on the total plant dry weight. Impairment of plant photosynthesis reduced weight of all plant organs including the panicle, stem and leaves. These components make up the total biological yield.

**Conclusion:**

- Genotypes (including short-, mid- and full-season) showed different responses to photosynthetic conditions.
- Mid-season genotypes exhibited greater grain and biological yield rather than two other maturity groups.
- Analysis of growth revealed that leaf area as the most important factor of assimilate production differed across genotype maturity groups. These differences in leaf area caused differences in cumulative light absorption and radiation use efficiency.
- The results showed that fitted equations for leaf area index, relative growth rate and crop growth rate differed at different maturity groups.

**Table 1:** Analysis of variance table for the grain and biological yield of sorghum genotypes under different photosynthetic status.

<table>
<thead>
<tr>
<th>Sources of variation</th>
<th>Degrees of freedom</th>
<th>Total dry matter</th>
<th>Grain yield</th>
<th>Biological yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>2</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Genotype</td>
<td>5</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>The sub-experimental error</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Photosynthetic status</td>
<td>1</td>
<td>**</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>Genotype × Photosynthetic status</td>
<td>5</td>
<td>*</td>
<td>**</td>
<td>**</td>
</tr>
<tr>
<td>The main-experimental error</td>
<td>12</td>
<td>ns</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ns: not significant; (*) and (**) represent significant difference over control at P < 0.05 and P < 0.01, respectively.

**Fig. 1:** Trend of dry matter production in different sorghum maturity groups. (a) short-season, (b) mid-season, (c) full-season.
Fig. 2: The LAI Trend in different sorghum maturity groups. (a) short-season, (b) mid-season, (C) full-season.

Fig. 3: The CGR Trend in different sorghum maturity groups. (a) short-season, (b) mid-season, (C) full-season.
Fig. 4: The RGR Trend in different sorghum maturity groups. (a) short-season, (b) mid-season, (C) full-season.

Table 2: Effects of photosynthetic impairment in sorghum maturity groups on grain and biological yield.

<table>
<thead>
<tr>
<th>Genotypes</th>
<th>Grain yield (Kg ha⁻¹)</th>
<th>Biological yield (Kg ha⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal conditions</td>
<td>Photosynthetic impairment</td>
</tr>
<tr>
<td>3</td>
<td>5633f</td>
<td>761/11</td>
</tr>
<tr>
<td>6</td>
<td>9045ab</td>
<td>1837jk</td>
</tr>
<tr>
<td>7</td>
<td>6433c-g</td>
<td>972/2i</td>
</tr>
<tr>
<td>8</td>
<td>7272b-I</td>
<td>761/11</td>
</tr>
<tr>
<td>9</td>
<td>3599hiq</td>
<td>1300ki</td>
</tr>
<tr>
<td>15</td>
<td>9752a</td>
<td>2456jk</td>
</tr>
<tr>
<td>Photosynthetic status</td>
<td>6328a</td>
<td>1326b</td>
</tr>
</tbody>
</table>

* Values followed by the same letter within the same columns do not differ significantly at P = 5% according to DMRT.

REFERENCES


