



COMMUNICATIONS IN SOIL SCIENCE AND PLANT ANALYSIS
Vol. 34, Nos. 11 & 12, pp. 1611–1621, 2003

Effect of Flower Bud Removal on Carbon Dioxide Exchange Rates of Cotton

Disha Dumka,¹ Craig W. Bednarz,^{1,*} and Marc W. van Iersel²

¹Department of Crop and Soil Science, Coastal Plain Experiment Station,
University of Georgia, Tifton, Georgia, USA

²Department of Horticulture, University of Georgia,
Athens, Georgia, USA

ABSTRACT

Numerous fruit removal studies have demonstrated that reproductive sink removal enhances cotton (*Gossypium hirsutum* L.) vegetative growth and development. Few studies, however, have examined changes in CO₂ exchange rates accompanying fruit removal. The objective of this study was to establish the effect of early season flower bud removal on whole plant CO₂ exchange rates of cotton. The effect of flower bud removal on the CO₂ exchange rates of cotton was investigated in a 31-day study conducted in a controlled environment. Differences in net photosynthesis, dark respiration, daily carbon gain, and carbon use efficiency were not observed in this study with flower bud removal. However, the rate of increase (or decrease in dark respiration) for these parameters was greater with flower bud removal with their maxima occurring later in the study

*Correspondence: Craig W. Bednarz, Department of Crop and Soil Science, Coastal Plain Experiment Station, University of Georgia, P.O. Box 748, Tifton, GA 31793, USA; E-mail: cbednarz@tifton.uga.edu.

period. All selected photosynthetic parameters also increased steadily with time for both treatments.

Key Words: Cotton; Fruit removal; Photosynthesis.

INTRODUCTION

Growth, development, and reproduction in cotton are a function of the crop's photosynthetic activity and ability to partition carbon assimilated during photosynthesis to various sinks. During the early phase of cotton development (i.e., prior to flowering), a large portion of photosynthate produced by the leaves is used for vegetative growth. With the onset of reproductive growth, photosynthates produced by the leaves are directed increasingly into the production and development of fruit.^[1] The retention of these reproductive structures, however, is extremely dynamic and susceptible to environment stresses.

Compensation for flower bud and boll loss in cotton has been of interest to researchers, as it will help in establishing the recovery potential when fruit loss occurs in field situations (i.e., from water stress, insect pests, etc). Numerous fruit removal studies have demonstrated that reproductive sink removal enhanced cotton plant vegetative growth and development.^[2–8] These studies reported increased plant height, increased nodal development and branching, increased total vegetative dry weight, larger leaves, greater leaf area index (LAI), and a lengthening of anthesis. Removal of early season flower buds has also been shown to increase the growth of the taproot as well as the vegetative shoot component with respect to undamaged controls.^[9] While many studies have reported the effect of fruit loss on cotton plant vegetative growth, very few studies have reported the effect of fruit loss on whole plant CO₂ assimilation.

Holman and Oosterhuis^[10] reported a significant increase in cotton leaf as well as canopy photosynthesis with insect-induced early season flower bud loss. Jasoni et al.,^[11] however, discovered that complete boll removal transiently reduced canopy photosynthesis. The discrepancy between these studies may be explained by the stage of crop development in which fruit loss occurred (i.e., early-season vs. mid-to-late season) as well as maturity of the fruit removed (i.e., floral buds vs. bolls). Loss of early season floral buds may reduce intra-plant competition for nitrogen and carbon resulting in increased vegetative growth, including leaf area index, which may lead to increased canopy photosynthesis. Loss of mid-season cotton bolls may be sufficiently late such that this compensation cannot occur. The objective of this investigation was to further investigate the effect of early season flower bud removal on CO₂ exchange rates of whole cotton plants grown in a controlled environment.

MATERIALS AND METHODS

Cotton "Suregrow 501 BR" was planted in 20 L pots containing a soilless growing medium (Metromix, The Scotts Company, Marysville, OH) in a glasshouse at the University of Georgia Coastal Plain Experiment Station in Tifton on 8th March, 2001. The pots were fertilized with 672 kg ha⁻¹ of 10–10–10 NPK prior to planting. Each pot contained one cotton plant and all plants were irrigated as needed with normal tap water. From 50 to 56 DAP the plants were irrigated daily with full strength Hoagland's nutrient solution.^[12] At 52 days after planting (prior to flowering), the cotton plants were transferred to a calibrated, semi-continuous, multi-chamber CO₂ exchange system where continuous measurements of gas exchange were made according to the principles and setup described by van Iersel and Bugbee^[13] and van Iersel and Lindstrom.^[14] Whole canopy CO₂ exchange rates were measured on these plants for a 31-day period. During these measurements, flower buds were removed twice at 53 DAP and at 66 DAP respectively.

Four sealed transparent acrylic chambers (78.7 cm long by 61 cm wide by 72.4 cm high) containing two cotton plants each were used for the study. These CO₂ exchange chambers were constructed such that the 20-L pots were excluded from the chambers and gas exchange from root and growing medium respiration would not interfere with the canopy gas exchange measurements. Ambient air was blown into the acrylic gas exchange chambers and air-flow into the chambers was measured with mass flow meters (GFM 37-32 Aalborg Instruments and Controls, Monsey, NY). The CO₂ concentration of the incoming air was measured with an infrared gas analyzer (IRGA; SBA-1, PP-systems, Haverhill, MA). The difference in the CO₂ concentration of the air entering and exiting the chamber was measured with an IRGA in differential mode (LI-6262, LI-COR, Lincoln, NE). Air-flow to the differential IRGA was controlled by opening and closing of solenoid valves. The solenoid valves were controlled by an SDM-CD16-AC relay module and CR10T data logger (Campbell Scientific, Logan, UT). Whole chamber CO₂ exchange ($\mu\text{mol s}^{-1}$) was calculated as the product of mass flow (mol s^{-1}) and the difference in CO₂ concentration of the air entering and exiting the chamber ($\mu\text{mol mol}^{-1}$). Carbon dioxide exchange rates were subsequently expressed on a per plant basis ($\mu\text{mol plant}^{-1} \text{s}^{-1}$). Every chamber was measured for 30 s, once every 10 min. There was a 30 s delay in data collection after solenoids were switched to measure the next chamber to assure all air from the previous gas exchange chamber was purged from the tubing. The data from the 30 s measuring period was automatically collected, averaged, and stored by the data logger.

Errors in the CO₂ measurements due to water vapor in the air were minimized by cooling the air to 2°C and draining the water condensate from

the air stream. Fluorescent lighting was used in the growth chambers and photosynthetic photon flux density was $550 \mu\text{mol m}^{-2} \text{s}^{-1}$. The temperatures inside the growth chamber were maintained at $20/27^\circ\text{C}$ dark period/light period. The photoperiod was 14 hours, resulting in daily photosynthetic photon flux of $27.7 \text{ mol m}^2 \text{ d}^{-1}$.

Daily averages of net photosynthesis during the light (P_{net}) and respiration during the dark period (R_{dark}) were calculated from the CO_2 exchange data. Daily carbon gain (DCG; $\text{mmol plant}^{-1} \text{ d}^{-1}$), gross photosynthesis (P_{gross} ; $\mu\text{mol plant}^{-1} \text{ s}^{-1}$), and carbon use efficiency (CUE; mol mol^{-1}) were determined from the gas exchange data as follows^[13]:

$$\text{DCG} = (\text{LP} \times P_{\text{net}} - \text{DP} \times R_{\text{dark}}) \times 10^{-3} \quad (1)$$

$$P_{\text{gross}} = P_{\text{net}} + R_{\text{dark}} \quad (2)$$

$$\text{CUE} = \text{DCG}/\text{LP} \times P_{\text{gross}} \times 10^{-3} \quad (3)$$

where LP = light period (s) and DP = dark period (s).

In the calculations of carbon use efficiency and gross photosynthesis it is assumed that dark respiration and respiration during the light period were equivalent.^[15] Although this is not necessarily true, this assumption will affect all treatments similarly and, therefore, allows for meaningful comparisons among treatments.^[16,17]

Five sets of data were generated that included P_{gross} , P_{net} , CUE, DCG, R_{dark} . At the end of the experiment, leaf area was determined using a LI-3100 area meter (Li-Cor, Lincoln, NE). Shoot dry mass was determined after drying the plant material to constant weight at 60°C . The data were analyzed as a split plot in time where the main plots were the two reps and the two treatments (floral bud removal or no floral bud removal) and a subplot was a measurement taken over a period of time while the plants were in the growth chamber.^[18] Treatment comparisons were done using ANOVA, while changes of the various physiological variables (P_{net} , R_{dark} , CUE, DCG) over time were analyzed by quadratic regression:

$$Y = a_0 + a_1 \times \text{time} + a_2 \times \text{time}^2 \quad (4)$$

where time = days since the start of the experiment—15. The rate of change of these processes was calculated as the derivative of Eq. (4) ($a_1 + 2 \times a_2 \times \text{time}$), and the time at which these processes would be expected to reach their maximum was calculated as: $-a_1/(2 \times a_2)$.

RESULTS

Net photosynthesis increased during the 31 days of the experiment and did not change with flower bud removal (Fig. 1). Increased P_{net} with time has been observed in other studies and is attributed to increased leaf area with time.^[16,17] Twenty-five days after the beginning of the experiment (1 day after the 2nd flower bud removal treatment) the two treatments began to diverge with flower bud removal resulting in a higher P_{net} (Fig. 1). This is possibly due to a decline in respiration as a consequence of fruit loss (Fig. 2). Regression analyses indicated that intercepts for P_{net} (i.e., estimated P_{net} at day 15) were similar for both treatments (Table 1). The linear component (the rate of change at day 15) however was significantly greater for the flower bud removal treatment. This indicates that during the middle of the experiment, P_{net} increased at a greater rate with flower bud removal than without flower bud removal. Additionally, the quadratic component was significantly higher for the flower bud removal treatment, indicating that flower bud removal led to a maximum P_{net} at a later date (local peak at 50.0 days; Table 1). Leaf area at the completion of the study was also greater with

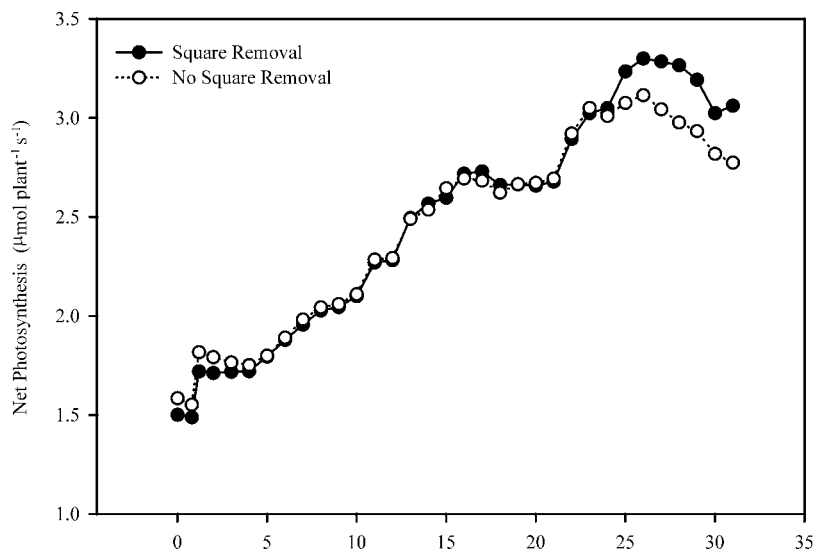


Figure 1. The effect of square removal on net photosynthesis in cotton. Data represent the mean of two gas-exchange chambers with two plants each. *Denotes significance for $P = 0.05$.

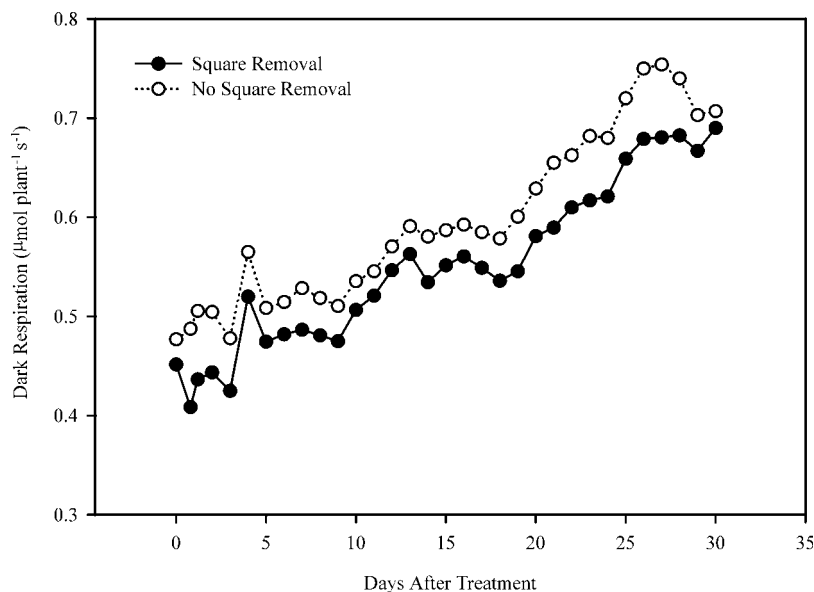


Figure 2. The effect of square removal on the dark respiration rate in cotton. Data represent the mean of two gas-exchange chambers with two plants in each chamber. *Denotes significance for $P = 0.05$.

flower bud removal (Table 2), which may have also contributed to the greater photosynthetic rates.

Dark respiration (R_{dark}) also increased steadily with time (Fig. 2), which is attributed to increased growth and maintenance respiration with increased plant mass and growth rate.^[16,17] Dark respiration was not influenced by flower bud removal (Fig. 2, Table 1). Flower bud removal did, however, result in less fruit at the conclusion of the study (Table 2).

Daily Carbon Gain (DCG) also increased steadily throughout the study (Fig. 3), an effect that is again considered normal during development.^[16,17] Differences between treatments were not observed. Intercepts for DCG were similar between treatments (Table 1). However, regression analyses indicated that the linear component was significantly greater for the flower bud removal treatment, indicating DCG increased at a greater rate with flower bud removal during the middle of the experiment. Additionally, the quadratic component was higher with flower bud removal, indicating flower bud removal led to a maximum DCG occurring later in the study period (local peak at 43.7 days; Table 1).

Flower Bud Removal and CO₂
1617

Table 1. Comparison of regression coefficients from the relationship between flower bud removal (S) and no flower bud removal (No S) on selected photosynthetic parameters of cotton plants grown in growth chambers.

Treatment	Statistic	Intercept	Linear	Quadratic	S vs. No S t-test	Local peak (days)
CUE (Carbon use efficiency)						
No flower bud removal	Mean	0.683	1.96×10^{-3}	-2.60×10^{-4}	1.795 ^a	18.8
	SE	0.0066	3.24×10^{-4}	3.90×10^{-5}		
Flower bud removal	Mean	0.700	2.64×10^{-3}	-1.90×10^{-4}		
	SE	0.0066	3.24×10^{-4}	3.90×10^{-5}		
P_{net} (Net photosynthesis)						
No flower bud removal	Mean	2.548	4.98×10^{-2}	-1.34×10^{-3}	1.813 ^a	33.6
	SE	0.0457	2.26×10^{-3}	2.73×10^{-4}		
Flower bud removal	Mean	2.539	5.90×10^{-2}	-0.85×10^{-3}		
	SE	0.0457	2.26×10^{-3}	2.73×10^{-4}		
R_{dark} (Dark respiration)						
No flower bud removal	Mean	0.587	0.87×10^{-2}	—	0.363	—
	SE	0.0082	0.62×10^{-3}	—		
Flower bud removal	Mean	0.541	0.85×10^{-2}	—		
	SE	0.0082	0.62×10^{-3}	—		
DCG (Daily carbon gain)						
No flower bud removal	Mean	107.6	2.202	-0.0732	1.907 ^a	30.1
	SE	2.314	0.1144	0.0139		
Flower bud removal	Mean	108.7	2.680	-0.0468		
	SE	2.314	0.1144	0.0139		

^a Represents the F-value for Quadratic test.

Although CO₂ exchange rates give an indication of the potential growth rate in plants, growth also depends on the efficiency with which plants convert carbohydrates into dry matter,^[14] which is described by carbon use efficiency (CUE). Carbon use efficiency did not change with fruit removal (Fig. 4). Carbon use efficiency was generally greater for the flower bud removal treatment than for the no flower bud removal treatment, but this difference was not statistically significant. Intercepts for CUE were similar for both treatments (Table 1). The linear component however was significantly greater with flower bud removal, indicating that CUE increased at a greater rate with flower bud removal at day 15. Additionally, the quadratic component was higher with flower bud removal, indicating that flower bud removal led to a maximum CUE occurring later in the study period (local peak at 22 days; Table 1).

Table 2. The effect of flower bud removal on cotton leaf area, leaf dry weight, stem dry weight, fruit number and fruit dry weight. Data represents the mean of 2 chambers per treatment with 2 plants in each treatment.

Treatment	Leaf area (cm ² plant ⁻¹)	Leaf wt. (g plant ⁻¹)	Stem wt. (g plant ⁻¹)	Fruit (plant ⁻¹)	Fruit wt. (g plant ⁻¹)
No flower bud removal	946 A ^a	36.5 A	33.6 A	40.0 A	16.7 A
Flower bud removal	1115 B	39.7 A	36.5 A	17.5 B	1.8 B
LSD (0.05)	49.0	42.0	25.2	21.5	13.9

^aWithin columns means followed by the same upper case letter are not significantly different.

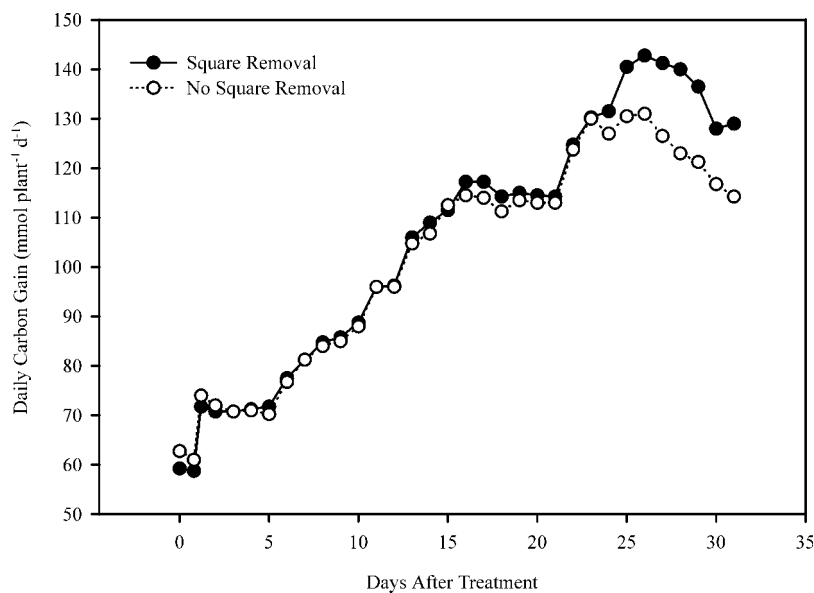


Figure 3. The effect of square removal on daily carbon gain in cotton. Data represent the mean of two gas-exchange chambers with two plants each. *Denotes significance for $P = 0.05$.

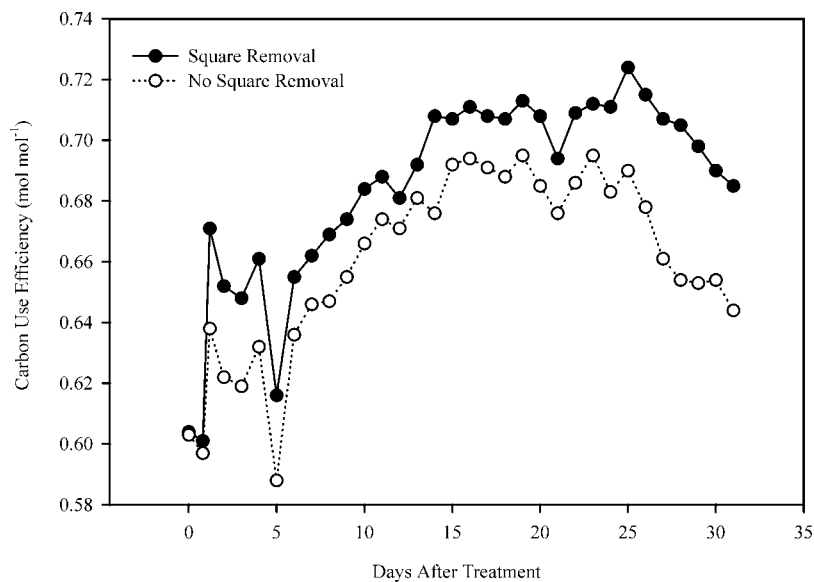


Figure 4. The effect of square removal on carbon use efficiency in cotton. Data represent the mean of two gas-exchange chambers with two plants each. denotes significance for $P = 0.05$.

DISCUSSION

The results of this study are comparable to those observed by Jasoni et al.,^[11] who showed that complete boll removal significantly alters CO₂ exchange rates of cotton plants. In the Jasoni et al.^[11] study, however, CO₂ exchange rates were more dramatically altered with fruit removal. One possible explanation could be flower buds were removed prior to flowering in our study while bolls were removed in the Jasoni et al.^[11] study at 95 DAP. Cotton bolls are large sinks and their removal may affect the nutritional status, hormonal balance, and sink strengths more severely than with flower bud removal.

In this study the selected photosynthetic parameters (P_{net} , R_{dark} , DCG) increased steadily over time for both the flower bud removal and the no flower bud removal treatments. Flower bud removal did not result in significant changes for these parameters. However, the rate of increase during the middle of the experiment was greater with flower bud removal for these parameters with their maxima occurring later in the season. This is probably because fruits



are respiring organs and their removal reduces respiratory rates and alters the partitioning of assimilates within the plant. Flower bud removal causes plants to redirect assimilates to alternate sinks and shift dry matter allocation from reproductive to vegetative organs.^[4,19]

ACKNOWLEDGMENTS

The authors of this paper wish to thank Benjamin G. Mullinix, Jr. for assistance with the statistical analyses and Walter Harvey, Dudley Cook, Lola Sexton, Keven Calhoun, and Larry Freeman for the technical support.

REFERENCES

1. Bednarz, C.W. *Characterization of the Fruiting Growth Curve Used in Crop Monitoring: Georgia*; Georgia Cotton Research and Extension Reports: Tifton, GA, 1998.
2. Bednarz, C.W.; Roberts, P.M. Spatial yield distribution following early-season floral bud removal. *Crop Sci.* **2001**, *41*, 1800–1808.
3. Guinn, G. Abscisic acid in cotton. *Plant Physiol.* **1985**, *77*, 16–20.
4. Jones, M.A.; Wells, R.; Guthrie, D.S. Cotton response to seasonal patterns of flower removal. II. Growth and dry matter allocation. *Crop Sci.* **1996**, *36*, 639–645.
5. Kennedy, C.W.; Smith, W.C., Jr.; Jones, J.E. Effect of early season flower bud removal on three leaf types of cotton. *Crop Sci.* **1986**, *26*, 139–145.
6. Mustaers, H.J.W. Leaf growth in cotton. I. Growth in area of main-stem and sympodial leaves. *Ann. Bot.* **1983**, *51*, 503–520.
7. Patterson, L.L.; Buxton, D.R.; Briggs, R.E. Fruiting in cotton as affected by controlled boll set. *Agron. J.* **1978**, *73*, 867–871.
8. Ungar, E.D.; Wallach, D.; Kletter, E. Cotton response to boll and bud removal. *Agron. J.* **1987**, *79*, 491–497.
9. Sadras, V.O. Cotton responses to simulated insect damage: radiation-use efficiency, canopy architecture and leaf nitrogen contents as affected by loss of reproductive organs. *Field Crops Res.* **1996**, *48*, 199–208.
10. Holman, E.M.; Oosterhuis, D.M. Cotton photosynthesis and carbon partitioning in response to floral bud loss due to insect damage. *Crop Sci.* **1999**, *39*, 1347–1351.
11. Jasoni, R.; Cothren, T.; Fernandez, C. Carbon dioxide exchange rate of cotton after complete boll removal. *J. Cot. Sci.* **2000**, *4*, 91–96.

**Flower Bud Removal and CO₂****1621**

12. Hoagland, D.R.; Arnon, D.I. *The Water-culture Method for Growing Plants Without Soil*; Calif. Agric. Exp. Stn. Circ. 347; University of California: Berkeley, CA, 1950.
13. van Iersel, M.W.; Bugbee, B. A multiple chamber, semicontinuous, crop carbon dioxide exchange system: design, calibration, and data interpretation. *J. Am. Soc. Hortic. Sci.* **2000**, *125*, 86–92.
14. van Iersel, M.W.; Lindstrom, O.M. Temperature response of whole plant CO₂ exchange rates of three magnolia (*Magnolia grandiflora* L.) cultivars. *J. Am. Soc. Hortic. Sci.* **1999**, *124*, 277–282.
15. Amthor, J.S. *Respiration and Crop Productivity*; Springer-Verlag: New York, 1989.
16. Bednarz, C.W.; van Iersel, M.W. Semi-continuous carbon dioxide exchange rates in cotton treated with commercially available plant growth regulators. *J. Cot. Sci.* **1998**, *2*, 136–142.
17. Bednarz, C.W.; van Iersel, M.W. Continuous whole plant carbon dioxide exchange rates in cotton treated with pyrithiobac. *J. Cot. Sci.* **1999**, *3*, 53–59.
18. SAS Institute. *SAS/C OnlineDoc™ (CD)*, Rel. 7.00; SAS Institute: Cary, NC, 2000.
19. Sadras, V.O. Compensatory growth in cotton after loss of reproductive organs. *Field Crops Res.* **1995**, *40*, 1–18.