

**THE BIRTH, LIFE, AND DEATH OF THE  
PHOTOSYNTHETIC FACTORY OR  
THE TOP TEN REASONS WHY: COTTON  
PHOTOSYNTHESIZES LIKE IT DOES  
AND WHY WE LOVE IT SO!**

**Randy Wells  
Department of Crop Science  
North Carolina State University  
Raleigh, NC**

**Abstract**

Photosynthesis is one of the most, if not THE most, important plant processes. The production of carbohydrates determines the ability of a plant to produce fruit and that is the ultimate goal of cotton production as a business. Many facets of crop management are, in reality, management of the photosynthetic factory. Interruption of the photosynthetic factory, due to some limiting factor (i.e. water, nutrients, light), can greatly alter the plant's ability to produce and retain fruiting forms during the reproductive cycle. It is imperative, therefore, that we attain and enlarge a sound understanding of photosynthesis. The knowledge that we have in our grasp is small compared with what is to be learned. A multitude of researchable questions exist and include, how and why carbohydrate is stored within the plant, why photosynthetic patterns differ amongst years or how hormonal fluxes within the plant impact photosynthesis during growth. Molecular techniques provide a new tool for studying these questions. To do so, however, societal and political attitudes toward basic research must be altered.

**Number 10: It's a C3 dog with that pesky photorespiratory shunt.**

The dual function of ribulose biphosphate carboxylase/oxygenase is well documented. The inefficiency of the oxygenase has long been a source of concern and has led to many suggestions that photosynthetic productivity would be increased if photorespiration was inhibited. Recently, some researchers have theorized that photorespiration and dynamic photoinhibition act as alternative electron sinks during periods of inhibited photosynthesis and high photosynthetically active radiation (Osmond and Grace, 1995). In other words, these non-assimilatory electron transport processes may utilize excess electrons, thus lessening chronic photoinhibition. Molecular or chemical inhibition of photorespiration, which has long been advocated by many researchers, may not increase productivity but could instead reduced the plant's ability to adjust to environmental conditions.

**Number 9: Canopy photosynthesis is positively associated with yield.**

Unlike single leaf photosynthesis, canopy photosynthesis is positively associated with fiber yield (Fig. 1) (Wells et al., 1986). Single leaf measurements measure the topmost, fully expanded leaves and probably are the leaves with the maximal photosynthetic potential on the plant. Integrated seasonal canopy photosynthesis, on the other hand, is an indicator of many factors which determine plant assimilatory capacity (i.e. canopy size, light interception, stress history, etc.). Therefore, realized yield has a closer association with seasonal canopy rates.

**Number 8: Greater leaf area is good early... but later on it's just too much.**

The amount of leaf area is a major factor limiting growth during early plant development, before significant plant-to-plant competition for space and essential environmental factors develops (Potter and Jones, 1977). Leaf area per plant is closely associated with photosynthesis per plant at approximately 40 days after planting (DAP) (Fig. 2). By the end of the vegetative period (71 DAP), there is no longer a positive association between leaf area and photosynthesis per plant (Fig. 3). Canopy closure is approaching at this time and mutual shading of leaves is occurring within the plant canopy. This change in stature causes the plants to cease acting as discreet individuals and the physical properties approximate a homogeneous community. At this juncture, leaf age and architectural factors other than leaf area *per se* prevail.

**Number 7: Theoretically okra leaves should be desirable**

**...but in reality are they?**

Okra leaf cotton genotypes have a number of desirable traits. These include greater light penetration and air movement within the plant canopy (Wells et al. 1986), greater leaf photosynthetic rates (Pettigrew et al. 1993), greater water use efficiency (Pettigrew et al., 1993), greater specific leaf weight (Pettigrew et al., 1993), and competitive or higher fiber yields than normal leaf genotypes (Meredith and Wells, 1986; Meredith, 1984). If okra leaf genotypes have so many positive characteristics, why aren't they grown in this country? Breeding efforts in Australia have resulted in a number of high yielding okra-leaf genotypes that are extremely competitive with normal-leaf types. Maybe okra-leaf morphology doesn't fit the American paradigm of a successful cotton cultivar. We must remember, however, that the Swiss invented the digital watch, but it was the Japanese that made it a success. The Swiss never believed that people would buy a watch with only numbers and no hands. Are we passing up a favorable plant trait?

**Number 6: It's a good "middle of the roader".  
Cotton photosynthesis doesn't like extremes.**

**Not too cold**

Moderately cold temperatures cause large reductions in photosynthesis, stomatal conductance, internal CO<sub>2</sub> concentration and the ratio of variable to maximal florescence (Perera et al., 1995; Warner and Burke, 1993). As seen in Figure 4, starch concentrations increase rather quickly in response to 15°C temperatures. Further, Koniger and Winter (1993) reported that even marginally low temperatures resulted in photoinhibition.

**Not too hot**

Feller et al. (1996) reported that at 32.5°C and above the light activation of ribulose biphosphate carboxylase/oxygenase (RuBisCO) is progressively reduced. The inactivation is reversible up to 45°C and irreversible thereafter. RuBisCO *activity per se* was not affected by any temperature treatment lower than 45°C. At 45°C, RuBisCO was denatured. The authors conclude that RuBisCO activase is very heat-sensitive *in vivo*. Despite its tropical origin cotton is quite sensitive to even moderately high temperatures.

**Number 5: It saves for a rainy day  
.....or a dry one.**

Cotton taproots contain nearly 20% (w/w) starch at 100 DAP, about mid-flowering (Fig. 5). Thereafter, the concentration of starch in the roots declines until defoliation when about 5% starch is present. Why does the cotton plant store carbohydrate in this manner? Is it efficient, with the cotton plant storing excess carbohydrate during vegetative growth and remobilizing it during reproductive growth? Or, is it a vestige from its ancestral past? De Souza and Vieira Da Silva (1987) reported that starch reserves in a modern day, annual genotype (annual in only in these sense that it yields abundantly in the first year of growth) were highest at 3 months of growth (Fig.6). The more perennial genotype, however, was still increasing in starch and may attribute to the ability of perennial genotypes to withstand drought. In this sense does starch storage in annual types result in the ability to withstand periods of stress which reduce photosynthetic capacity? These questions remain a mystery.

**Number 4: If cotton is a perennial, why doesn't it  
keep truckin' late in the season?**

The seasonal pattern of canopy photosynthesis is more similar to a group V maturity soybean than a group VI or group VII soybean in some years (Fig. 7). Due to its perennial growth habit, I would expect the pattern to more closely mimic a later maturity soybean. Why should cotton decline in photosynthesis during the month of August? It's certainly not because the environment is incapable of supporting high photosynthetic rates.

In another year, the photosynthetic rate appeared to be declining after 100 DAP but then the decrease in rate slowed and photosynthesis continued until nearly 140 DAP (Fig. 8). Why is there a difference between years? Is it related to the degree of boll loading and hence, the strength or timing of the cutout response? If this situation is the case, how does cutout influence the rate of photosynthesis? Is it merely the effect of leaf age or is it some other influencing factor? Again, no answers are forthcoming.

**Number 3: We have just scratched the surface in  
understanding  
hormonal change during the life of the photosynthetic  
factory.**

Some relationships between hormonal content and single leaf photosynthesis such as evident in Figure 9 have been described (Guinn and Brummett, 1993). The relationship observed between photosynthesis and free IAA concentration, while possessing a fairly high R-value, is not very compelling in a physiological sense. The fact is we do not understand the hormonal alterations which occur in the cotton plant, nor how they impact photosynthesis. What hormonal changes occur when cutout occurs, and further, what occurs during re-growth? During reproductive development does root activity decline, thereby affecting the production of cytokinins, thus impacting photosynthetic production? A research career could be built around such questions.

**Number 2: Carbon fixation by individual leaves on a  
sympodium is  
insufficient to support the branch's boll growth.**

Wullschleger and Oosterhuis (1990) reported that bolls on sympodia import as much as 50% of their required carbon. Carbon for the first position boll must be imported from elsewhere in the branch or from other sources in the plant. We know intuitively that this is such, because if it wasn't, a greater number of two and three boll sympodia would be the norm, not the exception. Again we see that the carbohydrate supply is the ultimate determinant of plant productivity.

**Number 1: Cotton photosynthesis is a natural  
for molecular manipulation.**

With all the interest in Bt and herbicide ready cotton, we tend to forget the power of molecular techniques in the elucidation basic physiological questions. Molecular tools can help elucidate many of the questions raised in the preceding points. Not all research should, or can, produce user ready solutions. Basic research will depend on a public attitude toward support of research on fundamental physiological problems. The present attitude of "what have you done for me lately" will eventually kill basic research and hamper the eventual attainment of applied solutions for present day management problems. Our approach to

research must reach further than last season's management problem and must encompass a vision of long-term production based on sound scientific knowledge.

### References

De Souza, J.G., and J. Vieira Da Silva. 1987. Partitioning of carbohydrates in annual and perennial cotton (*Gossypium hirsutum* L.). J. Exp. Bot. 38:1211-1218.

Feller, U., S. Crafts-Brandner and M. Salvucci. 1996. Heat stress inhibition of rubisco activation by rubisco activase. Agron. Abstr. P.96.

Guinn, G. And D.L. Brummett. 1993. Leaf age, decline in photosynthesis, and changes in abscisic acid, indole-3-acetic acid, and cytokinin in cotton leaves. Field Crops Res. 32:269-275.

Königer, M. And K. Winter. 1993. Growth and photosynthesis of *Gossypium hirsutum* L. At high photon flux densities: effects of soil temperatures and nocturnal air temperatures. Agronomie 13:423-431.

Meredith, W.R., Jr. 1984. Influence of leaf morphology on lint yield of cotton: Enhancement by the sub okra trait. Crop Sci. 24:855-857.

Meredith, W.R., Jr. and R. Wells. 1986. Normal vs okra leaf yield interactions in cotton. I. Performance of near-isogenic lines from bulk populations. Crop Sci. 26:219-222.

Osmond, C.B. and S.C. Grace. 1995. Perspectives on photoinhibition and photorespiration in the field: Quintessential inefficiencies of the light and dark reactions of photosynthesis? J. Exp. Bot. 46:1351-1362.

Perera, N.H., E. Hartmann and A.S. Holaday. 1995. Regulation of cotton photosynthesis during moderate chilling. Plant Sci. 11:133-134.

Pettigrew, W.T., J.J. Heitholt and K.C. Vaughn. 1993. Gas exchange differences and comparative anatomy among cotton leaf-type isolines. Crop Sci. 33:1295-1299.

Potter, J.R. and J.W. Jones. 1977. Leaf area partitioning as an important factor in growth. Plant Physiol. 59:10-14.

Warner, D.A. and J.J. Burke. 1993. Cool night temperatures alter leaf starch and photosystem II chlorophyll fluorescence in cotton. Agron J. 85:836-840.

Wells, R., W.R. Meredith, Jr. and J.R. Williford. 1986. Canopy photosynthesis and its relationship to plant productivity in near-isogenic cotton lines differing in leaf morphology. Plant Physiol. 82:635-640.

Wells, R., W.R. Meredith, Jr. and J.R. Williford. 19886. Heterosis in upland cotton. II. Relationship of leaf area to plant photosynthesis. Crop Sci. 28:522-525.

Wullschlegel, S.D. and D.M. Oosterhuis. 1990. Photosynthetic carbon production and use by developing cotton leaves and bolls. Crop Sci. 30:1259-1264.

### List of Figures

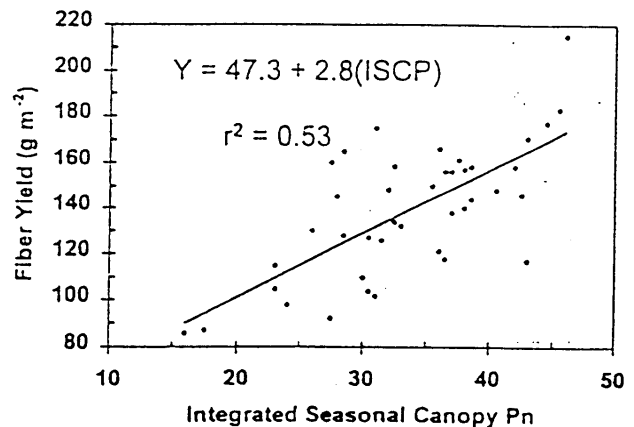


Figure 1. Relationship of fiber yield to integrated, seasonal canopy photosynthesis for cotton genotypes varying in leaf morphology (Wells et al., 1986). The predicted values were adjusted for year and replication effects (Wells et al., 1986).

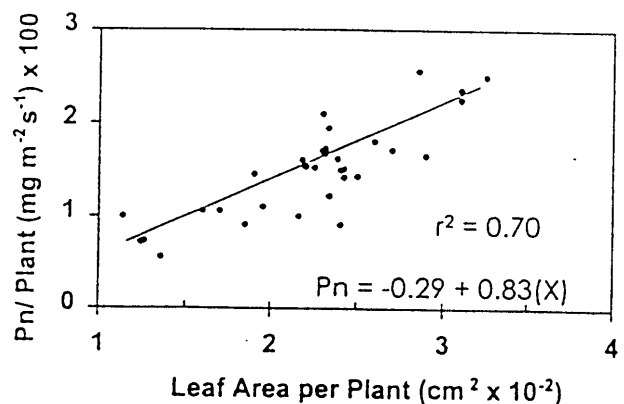


Figure 2. Relationship of photosynthesis per plant to leaf area per plant of F<sub>1</sub> hybrids and their parents at 41 days after planting (Wells et al., 1988).

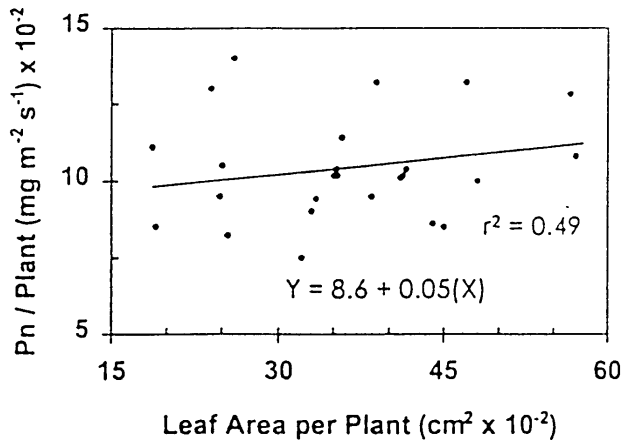


Figure 3. Relationship of photosynthesis per plant to leaf area per plant of F<sub>1</sub> hybrids and their parents at 71 days after planting (Wells et al., 1988).

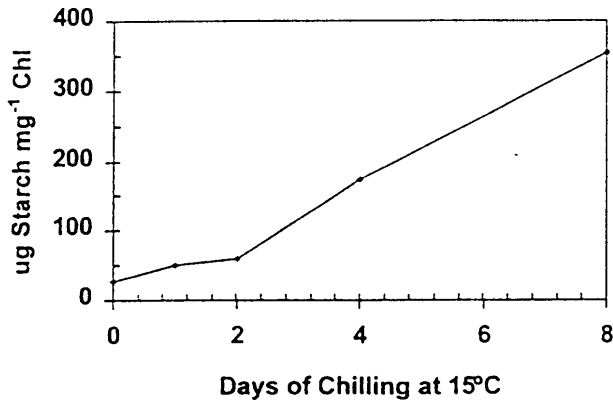


Figure 4. Starch content in cotton leaves at 7:45 AM in response to varying days of chilling at 15°C. Data adapted from Table 2 of Perera et al. (1995).

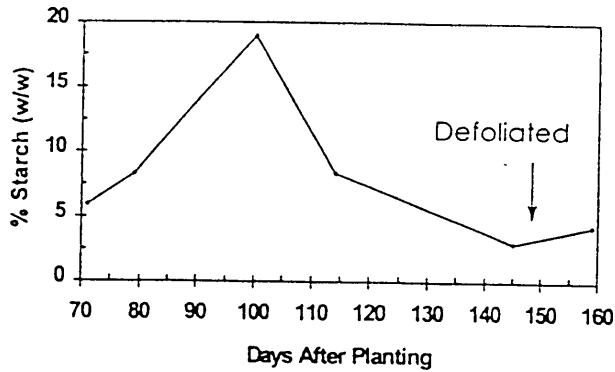


Figure 5. Percent starch content (w/w) found in taproots of cotton plants at varying days after planting. The values are means across two cultivars (DPL 14 and DPL 90) and four replications (Wells, unpublished data).

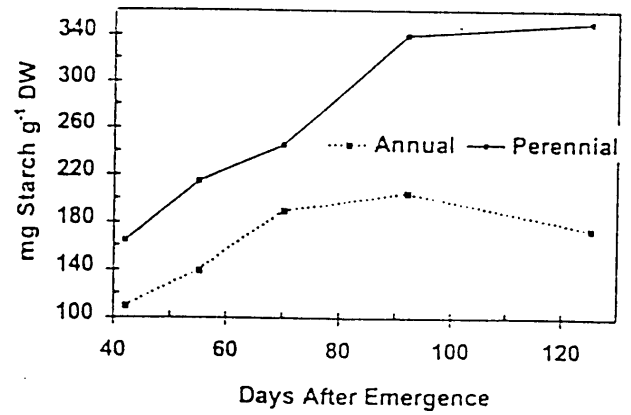


Figure 6. Starch content per unit weight of an annual and perennial cultivar within *Gossypium hirsutum* L. at varying days after emergence (De Souza and Vieira Da Silva, 1987).

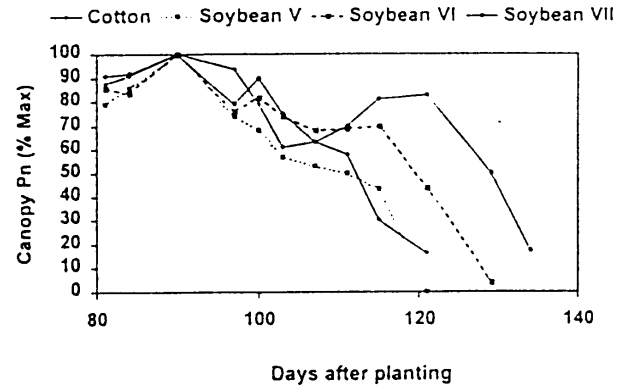


Figure 7. Seasonal canopy photosynthetic patterns of a cotton cultivar and three soybean cultivars differing in maturity (Wells, unpublished data).

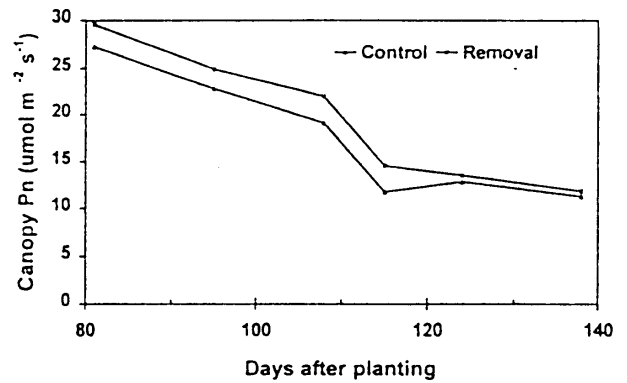


Figure 8. Seasonal canopy photosynthesis patterns of cotton with either the first two weeks of fruit removed or an untreated control (Wells, unpublished data).

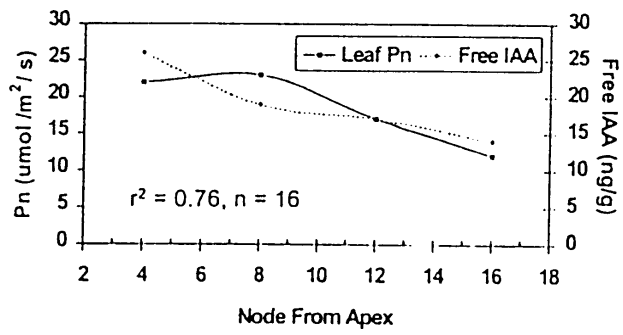


Figure 9. The relationship of leaf photosynthesis to free indole-3-acetic acid concentration for leaves residing a various cotton mainstem nodes (Guinn and Brummett, 1993).