ENVIRONMENTAL PRODUCTIVITY INDICES FOR COTTON GROWTH AND DEVELOPMENT

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Abstract

Most crops do not achieve their genetic potential, even under the best crop husbandry, because of environmental constraints. Improvements in crop adaptation to environmental stresses can be better assessed if the maximum potential is known and how each environmental factor limits that potential. Quantifying the effects of environmental factors on crop growth and development is a daunting problem, and limits our ability to develop mechanistic crop simulation models.

Several experiments were conducted by growing cotton plants in a suite of naturally-lit plant growth chambers known as Soil-Plant-Atmosphere-Research (SPAR) units in which temperature, atmospheric carbon dioxide concentration [CO_2], water, and nutrients were controlled and varied systematically. During the experimental period, canopy photosynthesis was measured continuously by a mass balance approach along with other related vegetative growth parameters and abiotic variables. From the photosynthetic light-response curves, canopy photosynthesis was estimated at a given radiation level and related to various environmental variables.

In experiments in which water deficits were imposed, complete nutrient solutions were provided, and plants were grown at near optimum temperature (30/22°C, day/night) and in ambient atmospheric CO_2 levels. Water was provided as a function of evaporative demand (120, 60, or 40% of the previous day's evaporation from the plants in the well-watered SPAR units). Excess water was allowed to drain from the fine sandy soil. Leaf water potentials were determined near solar noon from recently expanded, mature, sunlit leaves using the Scholander pressure chamber technique. In another experiment, canopy photosynthesis was measured continuously by growing plants under optimum temperature (30/22°C), water, and nutrient conditions throughout the measurement period. Daily canopy photosynthesis was related to total intercepted solar radiation for that day. A temperature experiment was conducted by growing plants at near optimum temperature (30/22°C) up to flowering, and then imposing various temperature treatments. Water and nutrients were provided abundantly. Canopy photosynthesis was measured several days during the temperature treatment and expressed as a function of temperature. The nitrogen and potassium deficit experiments were conducted by growing plants at near-optimum day/night temperatures (30/22°C) throughout the experimental period. A computer-controlled timing device applied a complete nutrient solution to each row of plants via a drip irrigation system in each SPAR unit. When nitrogen was varied in the experiment, selected treatments provided an altered solution in which calcium chloride was used to replace varying amounts of calcium nitrate. Cotton plants were grown until first square with all nutrients provided in sufficient quantities. Then the solutions were changed so that some plants received none and other plants received various percentages of sufficiency of N. Leaf N was determined weekly. Photosynthesis was expressed as a function of leaf N as determined by the microkjeldal technique, not as a function of the amounts of nitrogen fertilizer applied. Potassium deficit studies were conducted in a similar manner to that of the nitrogen deficit study. Leaf K was determined weekly. Photosynthesis and other growth processes were monitored throughout the period and related to leaf K. In the experiments where carbon was varied, plants were grown in optimum temperature (30/22°C) and nutrient conditions throughout the period, and carbon dioxide concentration were varied from 150 to 900 $\mu L\ L^{-1}$ when the canopies were growing actively and intercepting about 90 to 95% of the incoming radiation. Photosynthesis was monitored throughout the period and expressed as a function of [CO_2].

The environmental productivity index (EPI) concept was used to quantify the effects of environmental factors on photosynthesis and growth and development. The EPI is defined as:

EPI = Solar Radiation (Potential) * Water Index * Temperature Index * Nutrient Index (C, N, P, K) etc.,

Potential photosynthesis is defined as the amount of photosynthesis that occurs at a range of light levels under optimum environmental conditions (optimum water, nutrient levels, temperature (27°C in this case) and in an actively growing canopy. Individual environmental factors affect potential photosynthesis multiplicatively, not additively. For instance, if drought causes daily stomatal opening to cease, then photosynthesis will be reduced, regardless of the light level, or whether other factors are optimal for photosynthesis. All the indices range from 0 when it is totally limiting photosynthesis, to 1 when the environmental factors do not limit photosynthesis. Photosynthesis decreases as the effect of each particular stress becomes more severe.

The EPI concept quantifies the effects of environmental factors on photosynthesis and hence on productivity of any crop. The EPI facilitates the understanding and interpretation of stresses in field situations. If we know the most limiting factor at any point in time during the growing season, then we can make appropriate management decisions to correct that limitation. Similar concepts can be applied to various other facets of crop growth and development. The EPI concepts for growth, development, and photosynthesis were incorporated into a cotton crop simulation model and validated across a wide range of environmental and management practices. The predictive capability of the model was enhanced using the EPI concept, and the performance of the model was tested across the US Cottonbelt on 50 cropping systems with varying weather, soil and cultural practices. When the simulated plant height, mainstem nodes and yields were compared with observed data, the r^2 values were 0.97 for height, 0.99 for mainstem nodes, and 0.96 for yields. The respective slopes were 0.98 for height, 1.007 for mainstem nodes, and 1.006 for yields, indicating a close agreement with observed data.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 1:488-489 (2001)
National Cotton Council, Memphis TN