IDENTIFYING HIGH YIELD COTTON VARIETIES WITH CARBON ISOTOPE ANALYSIS

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Abstract

Genetic factors, such as improved dry matter partitioning to bolls, have been important in increasing yield of USA cotton varieties. Recent work suggests that improved stomatal conductance and leaf gas exchange is also important in increasing cotton yield. Also, carbon isotope discrimination is closely associated with stomatal conductance and leaf gas exchange. This study, conducted at three Texas locations (College Station, Lubbock, and Temple), two growing conditions (irrigated and dryland) and with twelve varieties, was conducted to determine if carbon isotope discrimination was associated with yield of upland cotton (*Gossypium hirsutum* L.). Data revealed a linear, positive relationship between carbon isotope discrimination and lint yield under all environments examined. When averaged over all environments, carbon isotope discrimination accounted for 55% of the variation observed in lint yield. However, the goodness of fit (r^2) ranged from 0.25 to 0.85 over the environments examined. We believe that the accuracy and reliability of this technique can be improved. Because carbon isotope discrimination is well correlated with stomatal conductance, we may be able to use this technique to screen germplasm for this trait in cotton improvement programs.

Introduction

Yield of cotton is highly conditioned by the environment, but genetic factors are also important. Meredith and Wells (1989) found that the yielding ability of current cultivars was about 30% higher than cultivars grown in the 1920's and 1940's. They attributed much of the increased yield to a shift in dry matter partitioning from vegetative structures to bolls, although the total dry matter accumulation of current cultivars was five percent higher than obsolete cultivars which suggest some genetic improvement in the plants' photosynthetic capacity.

Recent reports suggest that greater photosynthetic capacity through higher stomatal conductance is responsible for the higher yields of new cotton varieties (Cornish et al., 1991; Lu et al., 1994; Radin et al., 1994; Gerik et al., 1996; and Faver et al., 1996). Whether the higher yields, attributed to greater stomata conductance, resulted from maintenance of lower leaf temperatures (i.e., nearer the optimum for metabolic functions), or improved CO_2 gas exchange efficiency, or both has not been resolved. However, these data clearly support our fundamental understanding that stomatal conductance is important in maximizing the plants' photosynthetic capacity and suggest that breeders should pay attention to this trait in cotton improvement.

Yet, direct measurement of stomatal conductance is not suitable for modern breeding programs. Leaf porometers and other leaf gas exchange equipment developed for measuring stomatal conductance are laborious and subject to large errors. These errors are associated with the rapidly changing leaf environment, differences in operator technique, and instrument error and bias.

Carbon isotope discrimination is an indirect method for estimating stomatal conductance and CO_2 exchange rate of leaves (Farquhar, et al. 1989). The method is based on fundamental properties of CO_2 fixation enzyme systems in C_3 plants, like cotton. These enzymes prefer to use the widely available carbon isotope, $^{12}CO_2$, and discriminates against the naturally occurring heavy carbon isotope, $^{13}CO_2$. If the plants' stomata are widely open and the plants' photosynthetic enzymes are free choose the preferred isotope species (i.e., the enzymes are free to discriminate against the heavy isotope, ^{13}C, then the ratio of ^{13}C:^{12}C in the plant tissue will be low. But if the plants' stomata partially close and the CO_2 fixation enzyme system is not free to discriminate between the two isotopes, then the ratio of ^{13}C:^{12}C in the plant tissue will increase.

Therefore, the ^{13}C:^{12}C isotope ratio in plant tissue provides an integrated estimate of stomatal conductance at the time that carbon is being fixed by the plant. Leaves are typically used for carbon isotope analyses and require two to three weeks to achieve their maximum dry weight. Therefore, carbon isotope discrimination provides an integrated, very long-term estimate of stomatal conductance and leaf gas exchange properties compared to direct leaf gas exchange methods using leaf porometers and other instruments. This study was conducted to determine if carbon isotope discrimination can be used.

Materials and Methods

Irrigated and dryland field experiments were conducted at Temple, College Station, and Lubbock, TX over a three year period from 1992 to 1994. Twelve commercial varieities known to differ in yield were grown in a split plot design with 4 replicates. The main plots were water treatments (irrigated or dryland) and the subplots were varieties. Cultural practices, including planting and harvest date, weed and insect control, plant density, and row spacing, were typical of those used in the region.

Data collected were limited to measurements of lint yield and carbon isotope discrimination. The most recent, fully

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expanded leaves in the upper canopy were collected for carbon isotope analysis during the early square stage of development (approximately four to six weeks after planting). Leaves were oven dried, finely ground with a ball mill, and shipped to Isotope Services, Inc., Los Alamos, NM for mass spectrometer analysis of plant carbon. Carbon isotope ratios (^{13}C:^{12}C) were then calculated and normalized to air.

Results and Discussion

Of the 18 possible environments (i.e., location x year x irrigation) originally planted, data were only obtained from 14 environments over the three year period. Abnormal weather conditions prevented the data collection from four environments.

Lint yield for the twelve varieties differed widely among locations and years. Over the three years, irrigated yields of the varieties ranged from 400 to 1250 lbs/acre and dryland yields ranged from 100 to 800 lbs/acre. Similarly, carbon isotope discrimination also varied among varieties and years and ranged from about 16 to 19 ‰. Within any one year or location, however, the carbon isotope discrimination values fell within this range, but only varied about 1 ‰ among the varieties studied (Figure 1).

Significant and positive linear relationships were found between carbon isotope discrimination and lint yield under all environments tested (Table 1). For the individual environments, from 25 to 80% of the variation in irrigated cotton yield was accounted for by carbon isotope discrimination and the technique accounted for 30 to 85% of the variation in cotton yield under dryland conditions. When averaged over all environments, carbon isotope discrimination accounted for about 55% of the variation observed in lint yield.

These findings support the recent published evidence that high stomatal conductance and leaf gas exchange are very important in maximizing cotton lint yield (Cornish et al., 1991; Lu et al., 1994; Radin et al., 1994; Gerik et al., 1996; and Faver et al., 1996). Sufficient variation carbon isotope discrimination and yield existed among the varieties studied to conclude there is a positive association between carbon isotope discrimination and lint yield. Because carbon isotope discrimination is well correlated with stomatal conductance and leaf gas exchange, it may be suitable to screen cotton germplasm for these traits in crop improvement programs. However, the goodness of fit (i.e., r^2) between isotope discrimination and lint yield varied with environment. Future efforts should be made to better understand the basis of this variation and improve the accuracy and reliability of the technique.

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Table 1. Linear regression coefficients and the coefficient of determination of carbon isotope discrimination on cotton lint yield observed over a three years at College Station, Lubbock, and Temple, TX.

Location, environment, and year	Intercept	Slope	r^2
College Station, irrigated			
1992	-5781	354	0.80
1993	-7322	456	0.47
1994	-1932	141	0.25
College Station, dryland			
1992	-869	70	0.30
1993	-1989	139	0.44
1994	-2838	178	0.67
Lubbock, irrigated			
1993	-4387	318	0.65
1994	-4141	322	0.35
Lubbock, dryland			
1993	-3756	233	0.62
Temple, irrigated			
1992	-7298	462	0.85
1993	3064	233	0.57
1994	-2488	204	0.35
Temple, dryland			
1993	-2142	146	0.44
1994	-6671	417	0.66

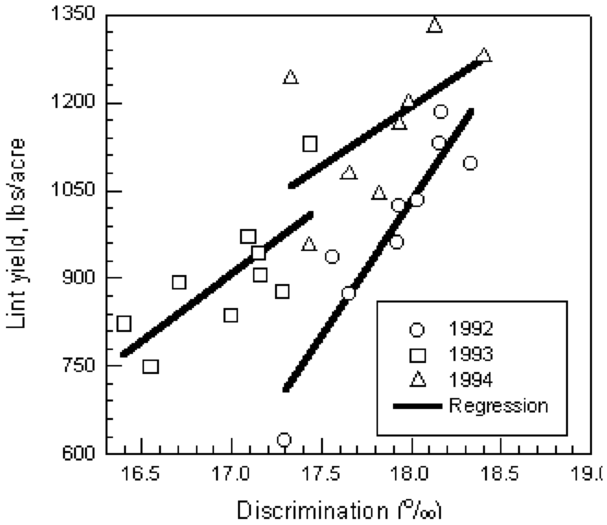

Figure 1. Relationship between carbon isotope discrimination and lint yield of irrigated cotton grown at Temple, TX.