Carbon Isotope Discrimination -- a selection criterion for improving cotton yield.

K.T. Hubick and G.D. Farquhar. Plant Environmental Biology Group. Australian National University. GPO Box 475 Canberra City, ACT 2601.

INTRODUCTION

Water is a growth-limiting resource in dryland farming areas; it may also be a limited resource in irrigated areas where water is expensive. Water shortages will occur but prediction of the shortages is difficult other than assigning a probability level to drought occurrence. Farm management in drought-prone areas must include development of drought-tolerant crops to stabilize crop production in rainfed areas (McWilliam, 1986). Breeding goals will include development of cultivars with higher rates of dry matter production per unit water transpired (transpiration efficiency) compared with present cultivars. Even when irrigation water is available, improved transpiration efficiency is needed.

During the assimilation of carbon, plants take up carbon dioxide containing the lighter isotope, ^{12}C, in preference to that containing ^{13}C. Farquhar *et al.* (1982) developed a mathematical model which predicted that this discrimination should depend on the ratio of photosynthetic rate to stomatal conductance. They also suggested that variation in transpiration efficiency, W (carbon accumulated divided by water transpired), would be revealed by altered isotopic composition if the variation were caused by changes in the above ratio.

The first demonstration of differences in transpiration efficiency and carbon isotope discrimination was with a range of wheat genotypes grown in pots (Farquhar and Richards, 1984). Considerable variation in W and in discrimination, Δ, was observed, and W and Δ were correlated in the expected manner. This raised the exciting prospect of assessing genetic variation in W of various crops and cultivars by means of differences in Δ. Subsequently, variation in Δ and W was observed to have a very significant correlation coefficient, in accordance with theory, in peanut cultivars (r=-0.81; Hubick *et al.*, 1986), barley cultivars (r=-0.82; Hubick and Farquhar, 1988), and cotton cultivars (r=-0.6; Hubick and Farquhar, 1987).

Using carbon isotope discrimination as a selection technique for increasing transpiration efficiency has several advantages. It requires very little dry matter -- as little as 5 mg of finely ground material is needed -- so it is relatively non-destructive. Once fixed into the dry matter of plants, the ratio of carbon isotopes remains invariant as long as the material is not degraded. Measurements of isotope ratios can be automated and can be made on any plant material providing plants being contrasted were grown in the same environment.

The Cotton Council has been funding our project, for which we intend to identify cotton varieties with efficiency of dry matter production when irrigation is expensive, or relatively inexpensive. The former will be achieved by identifying and testing varieties which show little discrimination against ^{13}C assimilation, since it has been shown that this correlates with water-use efficiency. The latter will have both large photosynthetic capacity and large stomatal conductance. We are also investigating the nature of inheritance of water-use efficiency.

RESULTS

We found, in young cotton plants, that transpiration efficiency and Δ were well correlated ($p<0.001$ for six genotypes) in a negative relationship (Figure 1).

We followed this experiment with another, in which we compared the genetic differences in transpiration efficiency in young plants with plants grown to maturity. There was significant genetic variation in W, but the variation among the four cultivars was small. There was no difference in the ranking of W of the cultivars when the plants were young or mature. A significant decrease in W occurred in the period from the first to the second harvest, which may have been due to changes in the environment or in the physiology of the plants. In this group of four cultivars, Namcala had a significantly greater transpiration efficiency than Sicot-2, PSP 251 671-6, and Coker 383. We note that, in this experiment, water stress reduced dry matter production significantly, but water use was proportionally reduced so that drought had little effect on transpiration efficiency. This is a particularly interesting result since drought tends to increase water-use efficiency in the other species we have tested.

In collaboration with Dr. Peter Lawrence of QDPI, Biloela, and Mr. Peter Reid of CSIRO, Narrabri, we have surveyed leaf material of cotton genotypes at the four to ten-leaf stage in eight of the ten regional variety trials and found significant genetic variation in discrimination at some of the sites, but not others. The broad sense heritability of isotope discrimination (and W by implication) when calculated for all sites, was low. This contrasts with peanut, where broad sense heritability is around 80% (Hubick, Shorter, and Farquhar, unpublished) and wheat, where it is 60%-90% (Condon *et al.* 1987). We will next examine leaf material from the same genotypes at maturity to see if the differences in W in young plants are too small to measure.

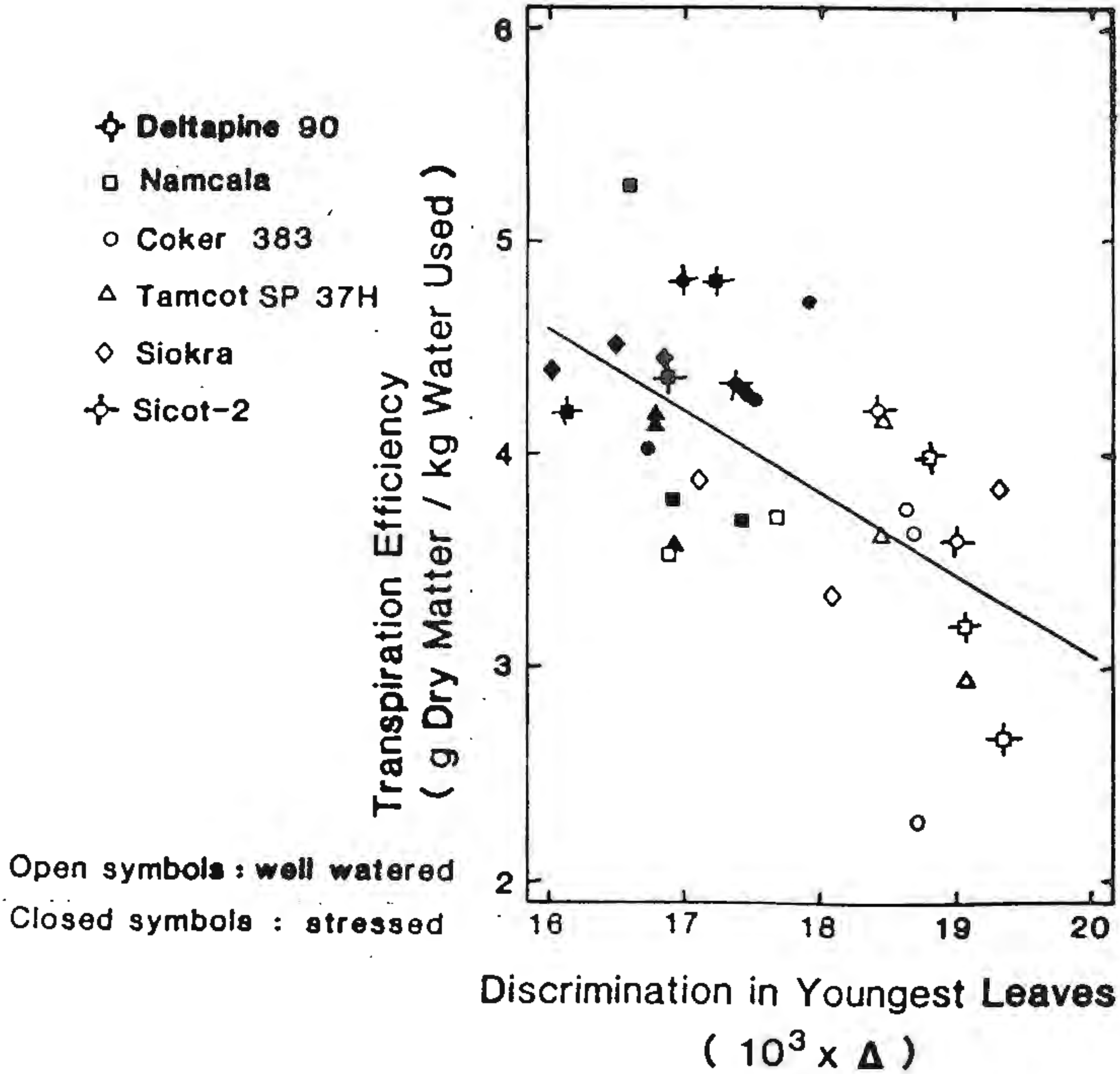
There are several possible reasons for the lack of genetic variation in leaf discrimination. It is quite likely that the germplasm used for selection in Australia is not broad enough in drought tolerance because selection has occurred in well-watered conditions where any stomatal limitation to water loss is also limitation to CO_2 uptake and potential yield. Perhaps a suitable strategy for improving yield in cotton is to introduce exotic germplasm which has less discrimination than present cultivars. We are doing this in collaboration with Dr. Lawrence.

From our results, the expectation is that along with less carbon isotope discrimination will come increased transpiration efficiency. With increased transpiration efficiency we consistently find an increase in dry matter production (Table I).

Table I. Dry matter and lint production, and transpiration efficiency of four genotypes of cotton at 12 weeks from sowing or at full maturity in 1987/88. Half the plants of each genotypes were allowed to deplete the soil water to near the wilting point (drought) and the others were watered well.

CULTIVAR	TREATMENT			
	Well-watered		Drought	
	Dry Matter accumulation (g per Plant)			
	Harvest 1	Harvest 2	Harvest 1	Harvest 2
PSP 251 671-6	21.2	142	6.9	28.3
Coker 383	18.8	142	7.4	31.8
Sicot-2	20.1	127	6.1	28.6
Namcala	20.5	150	7.8	32.5
	NS	NS	NS	NS
	Lint production (g per plant)			
		Harvest 2	Harvest 2	Mean
PSP 251 671-6		44.2	4.6	24.4
Coker 383		64.2	7.4	35.8
Sicot-2		53.9	8.5	31.2
Namcala		64.4	9.4	36.9
$LSD_{(0.05)}$		13.8	13.8	9.78
	Transpiration Efficiency (g DM/kg water used)			
	Harvest 1	Harvest 2	Mean	
PSP 251 671-6	2.84	2.31	2.58	
Coker 383	2.81	2.32	2.56	
Sicot-2	2.76	2.29	2.53	
Namcala	3.24	2.58	2.91	
$LSD_{(0.05)}$	NS	NS	0.30	

Figure 1. Transpiration efficiency of 65-day-old plants of six cotton genotypes *versus* carbon isotope discrimination (Δ) of the young leaves of the plants. Half of the plants of each genotype were not watered for about two weeks before the harvest.



CONCLUSIONS

Transpiration efficiency and carbon isotope discrimination are correlated in a negative manner for genotypes of cotton as they are for other C_3 species. Those genotypes which had a large transpiration efficiency in pot experiments also produced more dry matter, and more importantly more lint, than genotypes with smaller transpiration efficiency. Although we found that there is variation in W among cultivars of cotton, the variation was not as great as in other species. We also found variation in carbon isotope discrimination in field-grown plants but the range in discrimination was not large. The last two observations are consistent and suggest that it may be useful to look for increased W as a trait to introduce into local germplasm from exotic cultivars. We propose that using Δ would help to facilitate the introduction of greater transpiration efficiency into local cotton germplasm.

REFERENCES

Condon, A.G., Richards, R.A. and Farquhar, G.D. 1987. Carbon isotope discrimination is positively correlated with grain yield and dry matter production in field-grown wheat. *Crop Science* 27: 996-1001.

Farquhar, G.D., O'Leary, M.H., and Berry, J.A. (1982) On the relationship between carbon isotope discrimination and the intercellular carbon dioxide concentration in leaves. *Aust. J. Plant Physiol.* 9: 121-137.

Farquhar, G.D., and Richards, R.A. Isotopic composition of plant carbon correlates with water-use efficiency of wheat genotypes. *Aust. J. Plant Physiol.* (1984) 11: 539-52.

Hubick, K.T., Farquhar, G.D., and Shorter, R. Correlation between water-use efficiency and carbon isotope discrimination in diverse peanut (*Arachis*) germplasm. *Aust. J. Plant Physiol.* (1986) 13: 803-816.

Hubick, Kerry, and Farquhar, Graham. 1987. Carbon isotope discrimination -- selecting for water-use efficiency. *Australian Cotton Grower* 8(3): 66-68.

Hubick, K.T., and Farquhar, G.D. Genetic variation in carbon isotope discrimination and the ratio of carbon gained to water lost in barley. 1988 submitted to *Plant, Cell, and Environment*.

McWilliam, J.R. The national and international importance of drought and salinity effects on agricultural production. *Aust. J. Plant Physiol.* (1986) 13: 1-14 .