MODELLING AND MEASURING TRANSPIRATION EFFICIENCY IN COMMERCIAL AND EXOTIC SUNFLOWER

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Summary

Simulation studies for the sunflower-growing region of Australia showed that a 10% improvement in transpiration efficiency (TE – ratio of dry matter production to transpired water) should result in a grain yield increase of about 14%. The results of a glasshouse trial showed significant variation in TE among plants grown until ca. 50 days in 11kg soil. Single plants used an average of 3 *l* of water, at a TE of 5.55 g dry matter/kg water. Hybrids used 0.5 *l* more than parent lines and were more efficient. Delta (carbon ^{12}C/^{13}C discrimination) was determined from leaf samples at harvest. Excluding one accession, TE was significantly correlated with delta (r = 0.6) specific leaf weight (r = 0.65) and dry matter production (0.49), but not water use (r = 0.18). The strong correlation between TE and dry matter production was also reflected at the leaf level. Diurnal photosynthesis measurements of leaves on 6 genotypes resulted in an overall correlation of 0.8 between the rate of CO2 assimilation and TE.

The dominance of assimilation and dry matter production as components of transpiration efficiency at the plant and leaf level, respectively, suggested that photosynthetic capacity, rather than conductance is the main mechanism controlling transpiration efficiency in sunflower. Given their correlations with TE, high specific leaf weight and low delta may therefore be appropriate selection traits to improve TE in sunflower.

Introduction

In Australia, the majority of sunflower is grown in the summer in dry sub-tropical environments (<500 mm rainfall) on soils that vary in water holding capacity from 90 to 250 mm. Seasonal rainfall varies greatly with season largely due to the influence of the El Niño/Southern Oscillation (ENSO) climatic cycle in the Pacific Ocean. As daily solar radiation averages more than 25 MJ/m2/day and maximum temperatures frequently exceed 35°C, water is the major abiotic limitation to growth and yield. There are few agronomic options to improve water supply in these environments, and so genetic improvements in the ability of the crop to access water or to use it efficiently are appropriate.

Simulation modelling

Chapman *et al*. (1993) developed a simulation model for sunflower (QSUN) that was capable of simulating variety differences in phenology (i.e. flowering and maturity time) and the effects of water supply on the growth of sunflowers. Since that time, APSRU (Agricultural Production Systems Research Unit, QDPI/CSIRO Toowoomba) has developed the APSIM cropping systems model (McCown et al. 1995) which incorporates crop models like QSUN into a framework that can simulate many aspects of cropping systems, including soil water, N processes and different types of management. Once a crop simulation model has been validated, it can be used in several ways to assist breeding programs. Two of these are to describe the frequency of environmental challenges (e.g. drought) that exist across the entire cropping region (Chapman *et al*. 2000) and to evaluate the value of modifying attributes of cultivars that affect their adaptation to the environments, e.g. (Hammer *et al*. 1996). The latter approach is of particular value to determine whether potential traits are likely to be of value in all seasons and locations or only infrequently.

Increasing the efficiency of use of transpired water by crops

Transpiration efficiency (TE) has been shown to vary among genotypes of sunflower (Virgona and Farquhar 1996). However, the research of Virgona and Farquhar 1996 considered only a small number of genotypes that differed greatly in genetic background. In numerous crops, TE has been shown to be negatively correlated with delta, a measure of carbon isotope ($^{12}C/^{13}C$) discrimination. This theoretical relationship was outlined by Farquhar and Richards (1984). Delta is measured by isotope ration mass spectroscopy of oven-dried and ground samples. Samples can be collected rapidly in the field.

The efficiency with which water is transpired by growing plants is also affected by the daytime vapour pressure deficit (Tanner and Sinclair 1992). In order to make comparisons of results across different environments, it is useful to compute the transpiration efficiency coefficient (TEc):

TEc = biomass/water use / VPD

Following surveys of delta in commercial and exotic sunflower germplasm (Lambrides *et al*. 1999) we selected 25 genotypes to study in the glasshouse under non-water limiting conditions that allow genetic expression of TE and delta without interactions between plant and pot size. The genotypes included a range of commercial hybrids, together with public and private company parental lines and germplasm accessions.

To research alternatives for breeding for adaptation to these dryland environments, we first employed a simulation modelling approach to examine the likely value of transpiration efficiency as a trait. In a glasshouse trial, we have then evaluated TE in a range of commercial and exotic germplasm.

Materials and Methods

Simulation modelling

The sunflower crop model developed by Chapman *et al*. (1993) was improved and incorporated into the APSIM (McCown *et al*. 1995) cropping systems model. The model was then run parameters that describe a medium maturing sunflower crop. The inputs included 100 years of weather data (1897-1998) for the major locations in the sunflower growing region of north-eastern Australia (Table 1) and the most representative soil type for each location. The parameters used for simulating the growth of the crop included the following: sunflower crop/winter fallow; spring planting window in the south and summer in the north; soil one-third full; plant density of 50 000 per ha; minimum rainfall requirement of 30mm for planting within the window.

Table 1 Mean flowering dates and simulated effect of a 10% increase in transpiration efficiency on mean grain yield over 100 years at 9 locations

Location	Lat/long	Flowering date (DAS)	% increase in grain yield
Biloela	-24.4 150.52	61	14.6
Dalby	-27.17 151.27	70	14.9
Emerald	-23.57 148.18	61	15.6
Goondiwindi	-28.52 150.32	70	13.2
Gunnedah	-30.98 150.25	76	14.3
Miles	-26.67 150.18	69	12.9
Moree	-29.47 149.85	72	14.9
Roma	-26.55 148.77	69	13.8
Walgett	-30.02 148.12	72	12.9
Average		62	14.4

Glasshouse experiment

The experiment was conducted in a glasshouse in September/November 1999 in Brisbane. Day temperatures averaged 26.5°C (max of 34°) while night temperatures averaged 23°C (min of 18°). Daytime vapour pressure deficit averaged 1.55 Mpa.

On Sep 24 1999, four seeds of each genotype (Table 2) were planted in pots (0.15 m diameter, 0.6 m high) containing 11 kg of air dry soil with a field capacity of 18% and a lower limit (after free drainage) of 11%. Four replicate pots were planted per genotype and the pots were spaced 5 pots wide in the glasshouse in a randomised complete block design that also incorporated an alpha-lattice.

The soil mix included a complete nutrient fertiliser. The pots were watered to 14 kg with water added to keep them at that level until 21 days after planting. At that time, the plants were thinned to one per pot. Two of the thinned seedlings were weighed after oven-drying to determine initial dry weight. The pots were weighed and watered to field capacity and the surface covered to 0.02 m depth with plastic polyethylene beads that reduced evaporation from the soil surface to negligible amounts. By monitoring several pots of differing plant size, water was added every 2 to 3 days in 100 to 300 mm quantities. The pots were weighed each week and at the end of the experiment. Total water use was computed by the subtracting the final pot weight from the initial pot weight and adding the amount of water that had been put into the pots.

Over several days in the 2 weeks prior to final harvest, a Li-Cor 6400, was used to measure leaf transpiration and assimilation of CO_2. Sunlit leaves were equilibrated for up to 30 s in the leaf chamber before readings were made.

At harvest (5 Nov 1999), the plants were separated into stems and leaves and oven-dried after determination of leaf area. The soil was washed from the pots to recover roots, which were then also dried and weighed. Transpiration efficiency was calculated by dividing total dry matter growth (final – initial weight) by total water use. Specific leaf weight was calculated as leaf weight/leaf area (g/m^2 leaf).

Data from the lattice design were analysed using mixed models (SAS Institute), with fixed effects means estimated for genotypes, and contrasts were tested between hybrid and non-hybrid lines.

Genetic material

Several A, B and R lines were obtained from Drs Gerald Seiler and Jerry Miller USDA Fargo (Table 2), with the exception of SA52 (Pacific seeds). Commercial hybrids were supplied by Australian seed companies Pacific, Pioneer and Agseeds.

Results and discussion

For the standard genotype, mean simulated flowering dates ranged from 61 days after sowing in the northern region to 76 days in the south (Table 1). In about 60 of the 900 location/season combinations, the model planting rule was not satisfied. Average LAI at flowering was between 1.0 and 1.7, while yields rarely exceeded 2.5 t/ha (data not shown). The enhanced genotype with a 10% higher TE was able to yield an average of 14% more grain.

Over the growth period, plants used an average of 3.2 litres of water and produced 11.6 g dry matter (including root) (Table 2). When adjusted by the average daytime VPD of 1.55 MPa, this resulted in an average TEc of 5.55 g biomass per kg water transpired. This ranged from 4.7 to 6.2 across genotypes. While biomass was generally higher in hybrids than in lines, there were several lines with a biomass less than half of the largest lines (Table 2). TEc of hybrids was greater overall (5.99 ± 0.12) than that of A, B and R lines (5.44 ± 0.11) (Table 2).

Table 2. Dry matter production and transpiration efficiency coefficient (REML estimates and standard errors) for 19 genotypes tested in the glasshouse experiment. An additional 6 lines were tested, but are not described here for commercial reasons.

Pedigree	Source	Plant type (Hybrid , A, B or R line)	Dry matter production (g)		Transpiration efficiency coefficient (g DM per kg water transpired	
			mean	standard error	mean	standard error
DES-1474-2	USDA	R	12.91	0.77	5.34	0.20
BOL-774	USDA	R	9.56	0.89	5.90	0.23
TUB-346	USDA	R	10.24	0.77	5.54	0.20
ARG-3005	USDA	R	11.77	0.77	5.58	0.20
ANO1509-2	USDA	R	6.55	0.89	5.29	0.23
EXI-3003	USDA	R	8.66	0.77	5.84	0.20
SA52	Pacific	B	9.13	0.77	4.99	0.20
HA89 ANN1	USDA	B	13.17	0.77	5.55	0.20
cmsHA89 PET1	USDA	A	11.71	0.78	5.52	0.20
cmsHA89 MAX1	USDA	A	10.05	0.89	4.49	0.23
PAR-1673-2	USDA	R	10.02	0.77	5.07	0.20
PH3	USDA	B	13.98	0.77	5.60	0.20
HAR4	USDA	B	11.13	0.77	5.89	0.20
HA821	USDA	B	11.65	0.89	5.09	0.23
Hysun 46	Pacific	H	14.36	0.77	6.23	0.20
Hysun 36	Pacific	H	15.23	0.78	6.28	0.20
Monosun 140	Agseeds	H	15.82	0.78	5.84	0.20
Advantage	Pioneer	H	14.05	0.78	5.69	0.20
Suncross 53	Agseeds	H	14.06	0.78	5.91	0.20

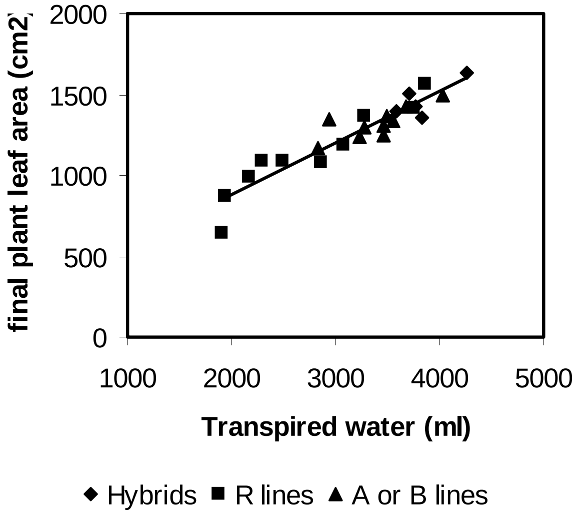

Fig. 1. Water use as affected by different leaf area of hybrid or lines ($y = 0.322\,x + 234.6$, $r^2 = 0.88$)

Dry matter production was associated with greater leaf area per plant (i.e. vigour; r = 0.93) and increased water use (r = 0.96). On average, hybrids used about 0.5 *l* more water than lines, related simply to their greater leaf area (Fig. 1).

Excluding one accession (ANO1509-2) which had the lowest vigour and the thickest leaves of any genotype, TEc was significantly correlated with specific leaf weight (r = 0.65) and dry matter production (0.49), but not water use (r = 0.18). Thicker leaves (i.e. higher specific leaf weight) were not associated with a smaller leaf area per plant. In fact, these two attributes were positively correlated (r = 0.76).

TEc was significantly and negatively correlated with delta (Fig. 2) over all lines, and when separating out either hybrid or A and B lines. While there was some overlap in delta values, TEc of hybrids was greater than that for lines. The specific parental lines had lower TEc and higher delta than their respective hybrids.

It seems then that higher TE was associated with factors contributing to a higher photosynthetic rate per unit area, rather than factors associated with reductions in water use. The strong correlation between dry matter production (CO_2 assimilation = A) and transpiration efficiency (A/g) was also reflected at the leaf level in measurements of CO_2 assimilation. Diurnal photosynthesis measurements of leaves on 6 lines ranging in TEc from 4.70 to 5.92 g/kg resulted in an overall correlation of 0.8 between the rate of CO_2 assimilation and A/g.

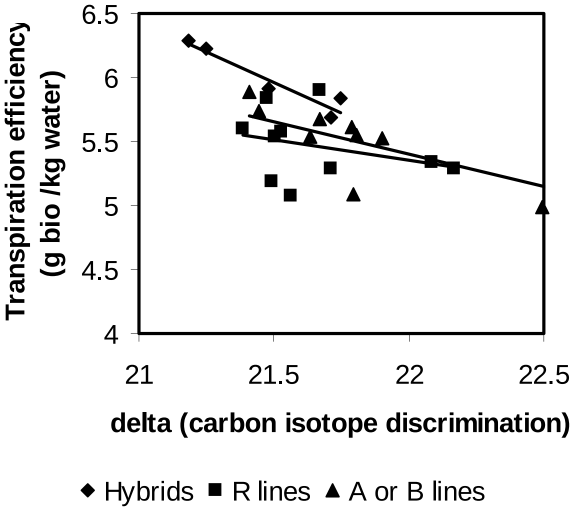

Fig. 2. Correlations between transpiration efficiency and carbon isotope discrimination for hybrids and lines. Simple correlations for hybrids, R lines and (A orB) lines were 0.95, 0.26 and 0.91. cmsHA89 MAX1 has been excluded from the A or B line correlation and had extreme values for delta (23.8) and TEc (4.70).

Conclusion

In selecting for genotypes with higher TE, both low delta and high SLW may be appropriate surrogates, as observed previously for peanut. While this type of strategy may have overlooked one of the accessions (BOL-774), simultaneous selection for vigour (leaf area or dry matter) would avoid the selection of poor genotypes with high SLW, such as ANO-1509-2.

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