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A FACTOR ANALYSIS OF PLANT VARIABLES RELATED TO YIELD IN SUNFLOWER UNDER WATER STRESS CONDITIONS

Jorge Elizondo Barron
Campo Experimental Las Adjuntas, INIFAP. MEXICO
P.O. Box 3, Santander Jimenez Tamaulipas, 87700

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ABSTRACT

A principal factor analysis was performed on 25 traits of eight varieties and strains of sunflower (*Helianthus annuus* L.) grown in replicated field plots at one location in the State of Tamaulipas, Mexico in 1990. Drought was created by terminating irrigation through vegetative to seed filling stage. Factors representing patterns of variables interpreted as yield, harvest index, escape and storage were extracted. These factors were identified with the source and sink constructs of crop physiologists. It is suggested that the development of higher yielding sunflowers under water stress must be based upon rapid phenological development combined with a long reproductive period, heavy stems at anthesis and the ability to translocate those assimilates to seed development; this could be achieved by producing a heavy biomass at maturity and a high plant and head growing rates.

INTRODUCTION

The only advance in basic yield potential of sunflower under water stress conditions has been through selection for adaptation and yield; improvement of seed yield has been slow, because it has been based largely upon combinations of characters designed by chance.

There has been little breeding or direct selection for specific drought resistant characters, because the traits especially beneficial in stress environments have not been identified in sunflower. However, both physiological and morphological traits are believed to play major and inter-independent roles in determining seed yield under conditions of water stress (Gimenez and Fereres, 1986).

Fischer (1981), has proposed an approach to breeding for drought resistance, based on identifying key morpho-physiological traits and incorporating them into drought resistance cultivars. Walton (1971, 1972) has used factor analysis in identify growth and plant morphological characters related to yield in spring wheats. The purpose of the present investigation was to search for and identify patterns of physiological and morphological characteristics in a set of sunflower varieties which we could then relate to seed yield under water stress.

MATERIALS AND METHODS

The trial was carried out at the Tablero Research Station, located in Padilla Tamaulipas, during the growing season of 1990. Eight strains of sunflower of diverse origin were grown (Table 1).

TABLE 1. NAMES AND ORIGIN OF 8 SUNFLOWER VARIETIES GROWN UNDER WATER STRESS AND IRRIGATION. TAMAULIPAS MEXICO, 1990.

ENTRY	LINE OR VARIETY	SOURCE*
1	(CMSDwarf x UP-02) x (UP-02)S1	UP
2	(CMSDwarf x UP-24) x (UP-24)S1	UP
3	(CMSDwarf x UP-42) x (UP-42)S1	UP
4	Cianoc-2	INIFAP
5	Victoria	INIFAP
6	Sereno	INIFAP
7	Rib-77	INIFAP
8	Inra	INIFAP

* UP = University of Pisa, Italy
INIFAP = Instituto Nacional de Investigaciones Forestales y Agropecuarias, Mexico.

The experimental units were arranged as a randomized block design combined over locations, with three replications. the experimental units consisted of four row plots, 6 m long with rows 80 cm apart. The experimental plots were planted in a deep soil. The center rows of each plot, eliminating plants at the row edge, were used for sample collection and final harvest.

Water stress was created by terminating irrigation through all the vegetative to seed filling stage. Irrigated treatments were well watered throughout the growing period. There was a lack of enough rain during the vegetative and most of the reproductive stages. At those stages of plant development, the irrigated treatments were well watered. Rainfall and irrigation were recorded during the course of the experiment (Figure 1).

At anthesis and physiological maturity five plants per plot were measured or scored for characteristics. Twenty five traits were taken or calculated for analysis (Table 2).

The main procedures used to analyze the data were Principal Factor Analysis (1, 6), in which patterns of traits were equated to one or more principal factors; and Stepwise Regression Analysis (2), which introduces characters into a multiple regression equation in the order of each trait's contribution to yield as determined by total variance.

RESULTS

STEPWISE MULTIPLE REGRESSION ANALYSIS, WATER STRESS.

According to the equation calculated by the multiple regression analysis for dependent variable grain yield, the best model selected included 13 variables and gave an R^2 value of 0.9959. Three variables accounted for 98% of variance. These

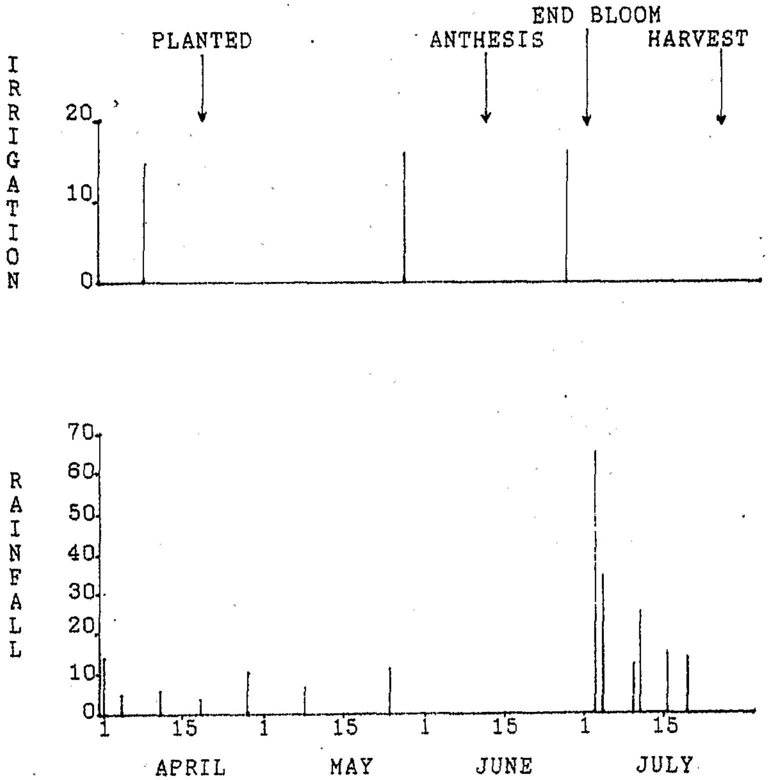

FIGURE 1. SUMMARY OF THE RAINFALL (mm) AND IRRIGATION (cm) FOR THE 1990 GROWING SEASON AT PADILLA TAMAULIPAS, MEXICO.

variables were: Head growing rate, harvest index and biomass at physiological maturity; in decreasing order of importance according to the magnitude of the R^2 value (Table 3).

TABLE 2. MEASURED AND CALCULATED CHARACTERISTICS. SUNFLOWER GROWN UNDER WATER STRESS AND IRRIGATION. TAMAULIPAS, MEXICO 1990.

1. Days to anthesis.
2. Days to end bloom.
3. Days to physiological maturity.
4. Efective reproductive period = # days to maturity - # days to anthesis.
5. Reproductive index = # days of reproductive period/# days to maturity.
6. Duration of flowering.
7. Plant height at maturity.
8. Dry weight of roots at anthesis.
9. Dry weight of stems at anthesis.
10. Dry weight of leaves at anthesis.
11. Biomass at anthesis.
12. Dry weight of roots at maturity.
13. Dry weight of stems at maturity.
14. Dry weight of leaves at maturity.
15. Dry weight of heads at maturity.
16. Grain yield.
17. Biomass at maturity.
18. Harvest index = Grain yield/Biomass at maturity.
19. Yield efficiency = Grain yield/#days to maturity.
20. Plant growing rate = Biomass at maturity/# days to seed filling - Biomass at anthesis/# days to anthesis.
21. Head growing rate = Head weight/# days from anthesis to seed filling.
22. Top/root ratio at maturity.
23. Top/root ratio at anthesis.
24. Leaf/stem ratio at maturity.
25. Leaf/stem ratio at anthesis.

TABLE 3. STEPWISE REGRESSION ANALYSIS OF DATA UNDER WATER STRESS WITH GRAIN YIELD AS DEPENDENT VARIABLE.

VARIABLE	PARTIAL REGR. COEF. (b)	F	PARTIAL R^2
Intercept	-41.462		
Head growing rate	1.224	36.48	0.6347
Harvest index	645.418	43.48	0.2502
Biomass at maturity	76.768	109.58	0.0981

SOURCE	D.F.	MEAN SQUARE	F
Regression	3	9309.350	366.08**
Error	19	25.429	

$R^2 = 0.9830$

FACTOR ANALYSIS, WATER STRESS.

There were five factors with roots greater than unity, and four factors with a contribution equal or greater than 10% to the total variance (Table 4). The first factor made the largest contribution to the variance and accounted for 31.81% of the total variation. The variables with the highest loadings in the first factor were biomass at maturity, head weight at maturity, head growing rate, stem weight at maturity, grain yield and plant growing rate. This is essentially a yield factor, because it identified itself with known yield characters.

TABLE 4. FACTOR ANALYSIS RESULTS. WATER STRESS CONDITION.

	FACTORS				
TRAITS	1	2	3	4	5
Days to anthesis	-.038	.003	-.984	-.118	-.017
Days to end bloom	-.028	.411	-.706	-.279	-.205
Days to maturity	-.054	.519	-.658	.066	-.182
Efect. reprod. period	-.010	.590	.587	.238	-.185
Reproductive index	.021	.295	.893	.201	-.098
Duration of flowering	.032	.328	.859	-.052	-.140
Root weight at anthesis	.543	.187	.063	-.747	.046
Stem weight at anthesis	.339	.548	-.158	-.064	.703
Stem weight at maturity	.833	.363	-.263	.126	-.217
Leaf weight at maturity	.640	.620	-.248	.283	-.105
Head weight at maturity	.889	-.073	.268	.244	.111
Grain yield	.814	-.499	.047	.039	.089
Biomass at maturity	.966	.123	.001	.209	-.025
Harvest index	.206	-.865	.010	-.212	.102
Plant growing rate	.809	-.182	-.140	.496	-.178
Head growing rate	.873	-.204	-.147	.264	.183
Top/root ratio maturity	.123	-.779	.042	.045	.242
Top/root ratio anthesis	-.361	.215	.026	.625	.315
Leaf/stem ratio anthesis	.200	-.097	.430	-.439	-.540
% VARIANCE	31.81	20.38	17.94	9.97	6.58
CUM. % VARIANCE	31.81	52.19	70.13	80.10	86.67

The second factor accounted for 20.38% of the total variation. This factor was represented on the negative axis by harvest index and top/root ratio at maturity, and on the positive axis by leaf weight at maturity; consequently, this factor was named harvest index.

The third factor accounted for 17.94% of the total variance. This factor was composed of escape characters, represented on the negative axis by days to anthesis, days to end bloom and days to maturity; and on the positive axis by efective reproductive period, reproductive index and duration of flowering.

Factors four and five accounted for 9.97% and 6.58% of the total variance, respectively. Factor four was highly associated with top/root ratio at anthesis, compensated by the negative loading of root weight at anthesis. Factor five was represented on the positive axis by stem weight at anthesis, and on the negative axis by leaf/stem ratio at anthesis. These factors were called storage.

ANALYSIS OF VARIANCE OF THE ECONOMIC YIELD.

The analysis of variance revealed a significant water effect (Table 5). Although, there was not a significant reduction between varieties, line # 3, Rib-77 and Cianoc-2 were the best under irrigation, whereas Rib-77, Cianoc-2 and Victoria the best under water stress conditions (Table 6). When compared the yield under both water conditions, Inra and Rib-77 showed the lower reductions (9% and 11%, respectively). Victoria increased grain yield 21% under condition of water stress.

TABLE 5. ANALYSIS OF VARIANCE FOR GRAIN YIELD OF 8 SUNFLOWER VARIETIES UNDER WATER STRESS AND IRRIGATION. TAMAULIPAS, MEXICO 1990.

SOURCE	D.F.	S.S.
Water treatment	1	7313.00 *
Rep.(Wat. tr.)	4	2647.56
Variety	7	12245.51
Wat. tr. * Var.	7	8965.63

* Significant at $P \leq 0.05$

C.V. = 24%

TABLE 6. EFFECT OF WATER STRESS ON THE GRAIN YIELD OF 8 SUNFLOWER VARIETIES. TAMAULIPAS, MEXICO 1990.

	GRAIN YIELD		
IDENTIFICATION	IRRIGATED	STRESS	% REDUCTION
Line #1	171.1	103.0	39.7
Line #2	140.3	105.3	24.9
Line #3	182.6	123.0	32.6
Cianoc-2	175.0	148.3	15.2
Victoria	122.0	148.0	-21.3
Sereno	148.6	107.6	27.5
Rib-77	181.6	161.6	11.0
Inra	132.3	119.3	9.8
MEAN	156.7	127.0	18.5
DMS 0.05 Wat.treat.	21		
DMS 0.05 Variety	67		

When selecting the three top yielding varieties by the criteria of drought susceptibility index, yield differential, arithmetic mean, and geometric mean; and comparing their yields under water stress and irrigated conditions, the mean yields of lines selected by the drought susceptibility index, and yield differential were lower than the mean yields of lines selected on the basis of the arithmetic and geometric means. This suggests the use of either the arithmetic mean or the geometric mean, in order to avoid selecting low yielding varieties under conditions of water stress (Table 7).

TABLE 7. DROUGHT SUSCEPTIBILITY INDEX, YIELD DIFFERENTIAL, ARITHMETIC MEAN AND GEOMETRIC MEAN OF 8 SUNFLOWER VARIETIES. TAMAULIPAS MEXICO, 1990.

IDENTIFICATION	S*	(Yc + Ys)/2	Yc - Ys	$\sqrt{Yc \times Ys}$
Line # 1	2.09	137.0	68.1	132.7
Line # 2	1.31	122.8	35.0	121.5
Line # 3	1.72	152.8	59.6	149.8
Cianoc 2	0.80	161.6	26.7	161.0
Victoria	-1.12	135.0	-26.0	134.3
Sereno	1.45	128.1	41.0	126.4
Rib 77	0.58	171.6	20.0	171.3
Inra	0.51	125.8	13.0	125.6

$$*S = \frac{1 - (Ys/Yc)}{1 - (\bar{X}s/\bar{X}c)}$$

DISCUSSION.

STEPWISE MULTIPLE REGRESSION ANALYSIS.

The positive loaded variables head growing rate, harvest index and biomass at maturity, which according to the R^2 value, explained 98% of the total variance was the most important variables. This is interpreted to mean that high yielding varieties are based on effective exploitation of photosynthesis to translocate a great part of their heavy biomass at maturity, to grain. Increasing head growing rate and biomass at maturity would be the recommended way to increase seed yield; the combination of the last two characters requires the maintenance of a high harvest index (H.I. = Economic yield/ Biological yield) if yield increase is to be achieved.

FACTOR ANALYSIS.

The first factor, yield, identified itself with yield characters such as biomass at maturity and its components, and head and plant growing rates. Any factor affecting photosynthetic activity is likely to affect its total dry matter content (biomass), and within broad limits, grain production.

The second factor, harvest index, indicates that there was an effect attributable to harvest index, but showing up in the form of the positive sign for leaf weight at maturity. Since leaf weight has long been established as important component of competitive ability (Hamblin and Donald, 1974), and since this characteristic will tend to increase the denominator (biological yield) of the harvest index, it follows that competitive ability and harvest index are likely to be negatively related.

The third factor, escape, indicates that it is important to select for early materials which possess a long reproductive period. This factor indicates that since there is not enough soil moisture available, there are water limitations to yield production, thus, the plant needs to shorten its growth cycle and to augment its reproductive cycle to avoid the stressed conditions.

The fourth and fifth factors, storage factors, appers important under water stress conditions, and it would be our hypothesis that this importance rests in part, upon the stem serving as a temporary storage site for assimilates which may be translocated to heads and seeds during the seed filling stage. During certain phases of development more assimilate is being produced than is being used in growth and development, and this excess, other than the portion lost in dark respiration or by root leakage, can be directed to storage sites. During later phases (fruting), when current photosynthesis is not able to furnish the assimilate requirements of yield sinks, storage compounds can be remobilized and moved to active sites, such as seed development.

CONCLUSIONS.

Better adapted sunflower varieties, under water stress imposed at the reproductive stage, can be developed by considering the following groups of plant characters: 1) High yield, accomplished by a heavy biomass at maturity (this combination results in a high harvest index) and a high plant and head growing rates. 2) Rapid phenological development combined with a long reproductive period. 3) Heavy stems at anthesis that ensures enough carbohydrates to be used in the critical period of seed filling.

This study has identified plant characters related with the production of sunflower under conditions of water stress, to make the desired combination of these characters, further research into the genetics of these identified traits would be appropriate in order to choose the best breeding method and design an efficient selection strategy to develop improved genotypes for water stress conditions.

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