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PHYSIOLOGICAL EXPLORATION OF CERTAIN MAIZE INBRED LINES AND HYBRIDS BY USING RAPID METHODS TECHNIQUE
3. PREDICTION OF GRAIN YIELD IN BREEDING PROGRAMS

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ABSTRACT

Eight maize hybrids, *i. e.* four single crosses and four three way crosses, were used to study the nature of associations among yield and some of the physiological indices at 30, 45 and 60 days after planting (DAP), *i. e.* LAI, photosynthetic (photo) efficiency, stomatal conductance (SC), chlorophyll (Chl) content and specific leaf area (SLA) under water deficit as well as to detect the relative importance of each index in determining plant yield variation through path analysis and coefficient of determination. Grain yield per plant of hybrids exhibited positive significant correlations with the different physiological indices overall the three irrigation treatments. Results elucidated clearly that maize breeder can select for high yielding plants at early periods of growth i. e. 30 DAP depending on LAI and photo. The suggested mathematical equations revealed that it is possible to detect the expected grain yield of maize hybrids at 30 DAP as well as 45 and 60 DAP depending on value of LAI, photo, Chl, SC, CTD and SLA.

Key words: Maize, Hybrids, Leaf area index (LAI), Photosynthetic efficiency, Canopy temperature depression (CTD), Stomatal conductance (SC), Chlorophyll (Chl) content, Path analysis, Heritability, Yield prediction

INTRODUCTION

Correlations between grain yield and physiological indices were investigated under water stress conditions to determine the most important characteristics related to yield which could be used as rapid and accurate selection criteria for selection under drought conditions. In this respect, **Kirkham *et al* (1984)** measured the canopy temperature of two drought resistant and another two drought sensitive maize inbred lines with their hybrids under well-watered conditions in the field over two seasons. From their results, plants with lower canopy tem-

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perature tended to give higher grain yield. They concluded that measurements of canopy temperature could be used to screen maize genotypes for drought resistance. Moreover, **Harold (1986)** found that water deficits imposed 41 days after planting reduced leaf area, stalk and ear yields while those imposed 55 days after planting reduced only stalk and ear yields. While, **Hernandez and Munoz (1988)** found that drought had the most sever effect on grain yield and this trait had better association with ear number per plants as compared to days to anthesis and silking, degree of wilting and number of green leaves per plant. Moreover, **Blum *et al* (1989b)** revealed that the mean difference between water stress and irrigated treatments in canopy temperature tended to increase with time (crop development) where it reached about 7°C on the last date of measurements. This was associated with non-tolerant varieties. However, **Nigem (1989)**, found a positive and significant correlation between maize grain yield and each of leaf area index, ear length and number of kernels/row under drought stress. Further, **Bolanos *et al* (1992)** practiced selection for grain yield under several drought stress conditions in maize and reported lack of direct and correlated changes in chlorophyll per unit leaf area and plant water status with grain yield. While, **Zaharieva *et al* (2001)** indicated that chlorophyll content was positively correlated with biomass and grain weight per plant. Plant temperature depression (the difference between air and plant temperature) was positively correlated with chlorophyll content when all the accessions were considered. Highly significant correlations were noted between leaf area and both biomass and grain weight per plant.

Therefore, this work was designed to study: 1) The interrelationships between grain yield and some of their contributors, 2) To identify the relative importance of each contributor in yield variation through path analysis and 3) To formulate suitable selection criteria for grain yield under water regime.

MATERIAL AND METHODS

The information of the experiment details is shown in the first paper of this series (**EL-Koomy *et al* 2005**). However, physiological parameters determined at 30, 45 and 60 days from planting overall irrigation regimes were used to predict maize yield. Correlation matrix was used to identify physiological parameters that have high correlation coefficients with yield. The regression analysis was followed to calculate the nature and magnitude of change in the associations between physiological parameters and maize grain yield, and hence, mathematical equations were deduced.

The expected mean squares (EMS) shown in Table (1) were used to estimate the genetic (σ^2_g) and genetic x year interaction (σ^2_{gy}) variance components as follows:

$$\sigma^2_g = \frac{M3 - M2}{ry} \qquad \sigma^2_{gy} = \frac{M2 - M1}{r}$$

Where, r = number of replications and y = number of years. The phenotypic variance (σ^2_{ph}) and broad sense heritability (h^2) estimated as follows:

Table 1. Expected mean squares (EMS) of the combined analysis of variance across two years.

S.O.V.	Df	Df Inbreds	Df Hybrids	MS	EMS
Years (Y)	(y-1)	= 1	= 1		
Y/rep's	y(r-1)	= 2	= 2		
Genotypes (G)	(g-1)	= 5	= 7	M_3	$\sigma^2_e+r\sigma^2_{gy}+ry\sigma^2_g$
Y x G	(y-1)(g-1)	= 5	= 7	M_2	$\sigma^2_e+r\sigma^2_{gy}$
Pooled error	y x Irrg (r-1)(g-1)	= 30	= 42	M_1	σ^2_e

$$\sigma^2_{ph} = \sigma^2_g + \frac{\sigma^2_{gy}}{r} + \frac{\sigma^2_e}{ry}$$

$$h^2_b = (\sigma^2 ph / \sigma^2 ph) \times 100 \quad \sigma^2 ph$$

RESULTS AND DISCUSSION

Correlation coefficients and heritability estimates for grain yield/plant and the physiological traits, i.e. chlorophyll (Chl) content, canopy temperature depression (CTD), leaf area index (LAI), specific leaf area (SLA), stomatal conductance (SC) and photosynthetic (Photo) efficiency are presented in Table (2). These estimates were done at 30, 45 and 60 DAP using the average data of 2001 and 2003 growing seasons. Data revealed significant, correlation. coefficients between grain yield of maize hybrids and Chl content, LAI, SLA, SC and photo, at 30,45,60 DAP (averages of 2001 and 2003 growing seasons).

Table 2. Correlation coefficients between grain yield/plant and some physiological indices (averages of 2001 and 2003 seasons)

Traits	Days after planting 30	45	60
Chl	0.830**	0.765**	0.784**
CTD	-0.295	-0.399	-0.311
LAI	0.967**	0.854**	0.907**
SLA	0.511*	0.795**	0.779**
SC	0.922**	0.945**	0.934**
Photo	0.932**	0.908**	0.930**

*,** significance at $P\leq 0.05$ and 0.01 levels, respectively.

Correlation between yield of maize grains and chlorophyll content being 0.830, 0.765 and 0.784 for plants at 30, 45 and 60 DAP, respectively. Moreover, the same relationship was realized between grain yield and LAI, SC, Photo and

SLA. On the other hand, insignificant negative correlation but was found between grain yield and canopy temperature depression at 30, 45 and 60 DAP. The obtained results are in agreement with those of **Blum *et al* (1989a)** who reported that canopy temperature under stress conditions was negatively correlated with grain yield and biomass. These results elucidate clearly that maize breeder can select for high yielding hybrids at early stages of growth, i.e. 30 DAPand some extent, depending on LAI, Photo, SC and Chl in descending order. In this respect, **Nigem (1989)** found positive and significant correlation between maize grain yield and leaf area index under drought stress. However, **Bolanos *et al* (1992)** practiced selection for grain yield under several drought stress conditions in maize and reported lack of direct and correlated changes in chlorophyll per unit leaf area and plant water status with grain yield. Moreover, **Zaharieva *et al* (2001)** indicated that chlorophyll content and LA were positively correlated with biomass and grains weight per plant.

Values of broad sense heritability estimated for different physiological traits at the three dates from planting over the three irrigation regimes are given in Table (3).

Partitioning phenotypic correlation coefficient between grain yield and physiological traits at the three dates during growth is presented in Tables 4 and 5. It is shown that chlorophyll content had positive effect on grain yield variation either directly or indirectly through Photo, LAI or CTD especially in the early stage of growth. Considering the relative importance of chlorophyll content, it is apparent that variable had 2.2% as direct contribution in addition to 5.42%, 8.97% through LAI and photosynthetic efficiency, respectively, with a total contribution of about 16.62% in the first date. In the second and third dates of planting, chlorophyll content had relatively low contribution.

Table 3. Broad sense heritability values (%) estimated for chlorophyll content (Chl) canopy temperature depression (CTD) leaf area index (LAI) specific leaf area (SLA) stomatal conductance (SC) and photosynthetic efficiency at 30,45 and 60 DAP (averages of 2001 and 2003 growing seasons).

Traits	Days after planting		
	30	45	60
Chl	76.6	74.0	74.0
CTD	12.5	6.6	3.5
LAI	97.7	84.2	92.9
SLA	88.1	70.3	78.6
SC	59.6	94.6	92.7
Photo	92.4	87.1	88.9

Regarding LAI, data in Tables (4) and (5) indicate that this variable has a major and notable effect on grain yield in the early date, larger than its effect in the 2nd and the 3rd dates. Leaf area index had a contribution of about 12.66% as direct effect in addition to 5.42%, 2.54% and 35.03% through chlorophyll content, canopy temperature depression and photosynthetic efficiency, respectively with a total of about 55.65%.

Photosynthetic efficiency also had considerable effect on grain yield variation especially in the early period of

Table 4. Path analysis of grain yield/plant versus chlorophyll content (chl), canopy temperature depression (CTD), leaf area index (LAI) and photosynthetic (Photo) efficiency at 30, 45 and 60 DAP.

Direct and indirect effects	Days after planting		
	30	45	60
1. Grain yield/plant *vs* Chl			
Direct effect	0.1494	0.0860	0.0694
Indirect effect *via* CTD	0.0293	-0.1445	-0.0520
Indirect effect *via* LAI	0.1815	0.3079	-0.0927
Indirect effect *via* Photo	0.3006	0.2206	0.5654
Total	0.6607	0.4699	0.4901
2. Grain yield/plant *vs* CTD			
Direct effect	-0.0714	0.1881	0.1239
Indirect effect *via* Chl	-0.0613	-0.0654	-0.0292
Indirect effect *via* LAI	-0.1779	-0.4288	0.1094
Indirect effect *via* Photo	-0.2694	-0.2959	-0.9143
Total	-0.5800	0.6000	-0.7101
3. Grain yield/plant *vs* LAI			
Direct effect	0.3558	0.5498	-0.1520
Indirect effect *via* Chl	0.0762	0.0482	0.0423
Indirect effect *via* CTD	0.0357	-0.1483	-0.0892
Indirect effect *via* Photo	0.4923	0.5003	1.1789
Total	0.9510	0.9500	0.9801
4. Grain yield/plant *vs* Photo			
Direct effect	0.5182	0.5380	1.2030
Indirect effect *via* Chl	0.0866	0.0352	0.0326
Indirect effect *via* CTD	0.0371	-0.1046	-0.0942
Indirect effect *via* LAI	0.3380	0.5430	-0.1489
Total	0.9710	0.9800	0.9925

Table 5. Components of direct and indirect effects and their relative importance as contribution percentage in the variation of grain yield per plant at three dates from planting.

Source of variation		Days after planting					
		30		45		60	
		CD*	RI%**	CD*	RI%**	CD*	RI%**
1. Chl	(X_1)	0.022	2.23	0.007	0.46	0.005	0.21
2. CTD	(X_2)	0.005	-0.51	0.036	2.26	0.015	0.69
3. LAI	(X_3)	0.127	12.66	0.302	18.88	0.023	1.05
4. Photo	(X_4)	0.269	26.85	0.289	18.08	1.447	65.48
5. X_1 x X_2		0.009	0.88	0.025	1.55	0.007	0.33
6. X_1 x X_3		0.054	5.42	0.053	3.31	0.013	0.58
7. X_1 x X_4		0.090	8.98	0.038	2.37	0.079	3.55
8. X_2 x X_3		0.025	2.54	0.163	10.19	0.027	1.23
9. X_2 x X_4		0.038	3.85	0.113	7.03	0.227	10.25
10. X_3 x X_4		0.350	35.03	0.551	34.37	0.358	16.22
Residual effect		0.011	1.05	0.024	1.50	0.009	0.41
Total		1.000	100	1.601	100	2.210	100

* CD = Coefficient of determination.
** RI% = contribution % (relative importance).

growth (Tables 4 and 5) with a relative contribution of 26.9% as direct effect and 8.98, 3.85 and 35.03% as indirect effect through chlorophyll content, canopy temperature and leaf area index, respectively with a total contribution of 74.71%. **Bolanos and Edmeads (1996)** showed that, across all traits, linear phenotypic correlations ($P<0.01$) between grain yield under drought and agronomic traits were existed. Genetic correlations were generally similar in size and sign.

From the obtained results path analysis revealed that photosynthetic efficiency and leaf area index appeared to be the major contributors to grain yield variations especially in the early stage of growth, suggesting that these two physiological indices could be used effectively in breeding programs as selected indices, since both indices were highly positively correlated with grain yield (Table 2), highly heritable (Table 3) and major contributors to grain yield variation especially in the first period of plant growth (Table 4). Thus, both indices could be considered as a helpful task in screening breeding materials at early stage of growth that save breeder's time and efforts.

Prediction of grain yield

Results revealed that it is possible to detect the expected grain yield of maize hybrids early at 30 days from planting as well as 45 and 60 days from planting depending on value of LAI, Photo, Chl, SC, and SLA. Regression equations to predict the expected grain yield via the morpho-physiological indices are shown in Table (6).

Table 6. Yield prediction equations using some physiological criteria at different dates from planting.

Physiological criteria	DAP	Mathematical relationship
Leaf area index (LAI)	30	Y = 220.359 LAI + 33.027
	45	Y = 65.588 LAI + 104.231
	60	Y = 41.874 LAI + 72.803
Photosynthetic efficiency (Photo)	30	Y = 8.464 Photo + 38.245
	45	Y = 9.348 Photo + 16.131
	60	Y = 9.884 Photo + 3.342
Stomatal conductance (SC)	30	Y = 775.887 SC + 72.321
	45	Y = 828.230 SC + 55.477
	60	Y = 865.147 SC + 47.458
Canopy temperature depression (CTD)	30	Y = -91.334 CTD +267.052
	45	Y = 55.784 CTD + 236.231
	60	Y = 76.145 CTD + 251.655
Chlorophyll content (Chl)	30	Y = 0.647 Chl - 93.881
	45	Y = 0.514 Chl - 49.801
	60	Y = 0.471 Chl - 40.658
Specific leaf area (SLA)	30	Y =16120.456 SLA + 44.039
	45	Y = 13613.177 SLA + 80.024
	60	Y = 16418.793 SLA + 11.718

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الاستدلال الفسيولوجى لسلالات وهجن معينة من الذرة الشامية باستخدام طرق القياس السريعة

٣. التنبؤ بمحصول الحبوب فى برامج التربية

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أظهرت دراسات الأرتباط بين المحصول والصفات الفسيولوجية المدروسة أن هنـاك ارتباطا موجبـاً ومعنويـاً بـين محصـول الحبوب وكلا من التوصيل الثغري ومعـدل التمثيل الضوئي ودليل مسـاحة الأوراق و تركيـز الكلوروفيل بـالأوراق والمسـاحة النوعية للورقة وذلك بعـد ٣٠ ، ٤٥ ، ٦٠ يوما من الزراعة ، وهذا الارتباط المظهري

يعكس العلاقة الموجبة علي المستوي الوراثي وأنه يمكن التوصيه بإستخدام صفة أو أكثر من هذه الصفات كمعايير إنتخابية سريعة ودقيقة فى برامج التربية لتحمل الجفاف عند إنتخاب التراكيب الوراثية من الذرة الشامية من حيث تحملها للجفاف.

كانت أقل قيمة لكفاءة التوريث بمعناها العام ١٢,٥% بالنسبة لصفة الفرق بين درجة حرارة الورقة ودرجة حرارة الجو وذلك عند ٣٠ يوما من الزراعة ، بينما نقصت هذه النسبة الى ٦,٦ ، ٣,٥% عند عمر ٤٥ ، ٦٠ يوما من الزراعة على الترتيب ، وكانت أعلى قيم لكفاءة التوريث العامة هى لصفتى معدل التمثيل الضوئى ودليل مساحة الأوراق حيث بلغت ٩٢,٤ ، ٩٧,٧ عند ٣٠ يوما من الزراعة على الترتيب ، بينما نقصت عند الأعمار الأخرى حيث وصلت الى ٨٨,٩ ، ٩٢,٩٥ وذلك بعد ٣٠ يوما من الزراعة (٤٥ ، ٦٠ يوما من الزراعة). والجدير بالذكر أن لكفاءة التوريث بمعناها العام للدلائل الفسيولوجية قد إتجهت الى النقص بتقدم النباتات فى العمر ، مما يدل على انه يمكن استخدام هذه الصفات كدلائل انتخابية تساعد مربى الذرة فى الإنتخاب المبكر للتراكيب الوراثية الأكثر تحملا للجفاف مما يوفر من وقت وجهد المربى.

أظهرت معادلة الإنحدار الخطي وجود علاقة مرتفعة المعنوية بين الدلائل الفسيولوجية وكمية المحصول فى المراحل المبكرة من نمو النبات (بعد ٣٠ ، ٤٥ ، ٦٠ يوماً من الزراعة) مما يؤكد على أنه يمكن التنبؤ بكمية المحصول بالإعتماد علي قيم دليل مساحة الأوراق ، معدل التمثيل الضوئي ، التوصيل الثغري ، تركيز الكلوروفيل ، كثافة مساحة سطح الأوراق كلاً علي حده وتم استنباط العلاقة الحسابية بين محصول حبوب نبات الذرة والخصائص المورفوفسيولوجية عند أعمار ٣٠ ، ٤٥ ، ٦٠ يوما من الزراعة.

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