EFFICIENCY OF LIGHT INTERCEPTION AND DRY MATTER PRODUCTION IN MAIZE[1]

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The traditional breeding methodology in maize and other cereal crops has based hybrid selection on yield and adaptation over a series of several locations. New genetic combinations in the form of hybrids and synthetic varieties have taken advantage of disease and insect resistance, and rather specific adaptation, to provide a tremendous genetic potential for yield, when this potential is combined with adequate fertility and moisture in the field. To further increase yields of maize, attention has recently focused on plant type and efficiency of grain production. When the farmer has controlled moisture, fertility, insects, pathogens, weeds, and other easily modified variables in the field, and his hybrid responds to this intensive cultural package, he is faced with the next limiting input -- incident light energy. The only feasible way to improve the genetic potential of maize with respect to use of energy is to change the form or type of the plant to utilize available light in the most efficient way possible. Recent work on leaf angle (Pendleton and others), on prolificacy by a number of workers, and on population, defoliation, and shading have focused on changing the plant type as the next important phase in our search for more potentially productive genotypes of maize.

In conjuction with growth analyses in New York (1968) and adaptation studies in Colombia (1969) at several altitudes, we have examined the efficiency of a number of maize lines and hybrids, and have summarized in a general way the relationships between some plant characteristics and yield. The results demonstrate clearly the importance of intercepting light and converting this light to dry matter in the grain.

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Experiment I -- New York

Four inbred lines and nine hybrids were planted at two populations in Aurora, New York in 1968 in a growth analysis study. In addition to plant height, ear height, flowering date, and final yield, other data collected included total plant leaf area, light interception by the canopy, and dry matter in the several plant fractions at harvest. Average leaf areas per plant varied from 33 dm2 for inbreds at 76000 plants/ha to 56 dm2 for hybrids at 38000 plants/ha. Average leaf area indices varied from 1.3 in inbreds at 38000/ha to 4.1 for hybrids at 76000/ha (Table 1).

Table 1. Average leaf area per plant and leaf area Indices in growth study, 1968.

	Population/Hectare			
	38000		76000	
	dm^2/plant	L.A.I.	dm^2/plant	L.A.I.
Inbreds (avg)	35.1	1.33	32.6	2.48
Hybrids (avg)	56.4	2.14	53.9	4.10

The total canopy light interception during the filling period by these same groups ranged from 66% for inbreds at the low population to 88% for hybrids at the high population. The average yields of total dry matter and dry matter in the ear were lowest in the inbreds at the low population: 7.8 and 4.0 T/ha, respectively, and highest in hybrids at the higher population: 21.4 and 12.5 T/ha (Table 2).

Table 2. Average total and ear dry matter yields (T/ha) in growth study, 1968.

	Population/Hectare			
	38000		76000	
	Total	Ears	Total	Ears
Inbreds (avg)	7.8	4.0	12.4	6.8
Hybrids (avg)	14.3	7.8	21.4	12.5

A number of efficiency parameters were calculated from the yield trial data. Ear and total dry matter production efficiency were calculated per unit of leaf area and per unit of light intercepted during the filling period. The energy intercepted per unit leaf area, and light use efficiency -- Kcal energy in grain/Kcal energy intercepted (%) -- also were determined for each genotype, and are summarized for groups of genotypes and populations in Table 3.

Table 3. Efficiency calculations from growth study, 1968.

Population	Ear D.M.		Total D.M.		
	mg/cm^2	mg/Kcal	mg/cm^2	Kcal/cm^2	Light Use Efficiency (%)
38000/ha					
Inbreds	30.3	2.8	58.4	10.8	1.12
Hybrids	36.7	4.6	67.0	8.0	1.83
76000/ha					
Inbreds	27.5	4.0	50.1	6.8	1.60
Hybrids	30.6	6.6	52.2	4.6	2.64

Hybrids were more productive per unit leaf area than inbreds, and the lower population was more efficient than the higher population. Even though more light was intercepted per unit leaf area in the inbreds, they were less efficient in using this light. The column on light use efficiency (Kcal grain produced per Kcal energy intercepted during the filling period, expressed as %) shows hybrids to be about 60% more efficient in use of light than inbreds. This efficiency of conversion was also significantly greater at the higher plant population.

Based on individual genotypes, correlations were calculated between grain yields per hectare and various efficiency parameters (Table 4).

Table 4. Correlation between grain yield and efficiency measures, growth study, 1968.

	Inbreds		Hybrids	
Variable	38000	76000	38000	76000
Total Yield	.23	.27	.84**	.85**
Harvest Index	.79	.59	.09	-.20
Leaf Area Index	.25	-.59	.05	.12
Total Energy Int.	-.61	-.77	-.63	-.60
mg Grain/cm2 LA	.71	.81	.68*	.49
Kcal Light/cm2 LA	-.73	.36	-.27	-.50
Kcal Grain/Kcal Light	.95*	.98*	.97**	.90**

Among these several parameters, the only consistent and significant correlation with grain yield is the "Light Use Efficiency", or grain yield produced per unit of light intercepted. Based on these limited genotypes and replications, there was no significant association with harvest index, leaf area index, or other parameter described above. There was also no consistent pattern with plant or ear height, relative maturity, leaf area distribution among layers in the canopy, or light intercepted by different strata. Also not correlated with yield were specific leaf area, linear regression coefficients for total dry matter produced during 3 periods of growth, ear dry weight production during 2 periods of growth, maximum rates of dry matter production, net assimilation rates, crop growth rates, nor relative growth rates. (NAR = dry wt increase/unit leaf area; CGR = dry wt increase/unit ground area; RGR = dry wt increase/unit time).

Experiment II -- Colombia

In 1969, an adaptation study was carried out in 3 locations at different altitudes and in 2 seasons in Colombia in collaboration with the Instituto Colombiano Agropecuario. Six lines and 19 hybrids were planted in 5 different trials, with plant populations of 55000 and 35000 per hectare. Average leaf areas per plant, light interception data, yields of grain, and plant heights are presented in Table 5.

Table 5. Data from five yield trials in Colombia, 1969.

Trial	Plant Ht. (cm)	LA/Plant (dm2)	Light Int. (%)	Yield (T/ha)
Turipaná 69A	272	65.7	64.6	3.33
Turipaná 69B	238	43.4	60.4	.78
Tulio Ospina 69A	179	50.4	56.4	2.99
Tulio Ospina 69B	232	52.6	59.1	2.09
La Selva 69	215	46.2	67.7	5.96

Rainfall was severely limiting in Turipaná 69B, and somewhat limiting in the Tulio Ospina 69B and Tulio Ospina 69A seasons. This limited moisture did occur later in the seasons, during pollination and filling, and thus affected the grain yield much more than it affected plant height and leaf area. The efficiency calculations are presented in Table 6.

Table 6. Efficiency calculations for five field trials in Colombia, 1969.

Trial	Kcal/cm2 LA	mg Grain/cm2	mg Grain/Kcal
Turipaná 69A	4.5	11.4	3.70
Turipaná 69B	4.7	4.4	.89
Tulio Ospina 69A	5.4	14.2	2.71
Tulio Ospina 69B	5.1	9.2	1.84
La Selva 69	8.6	28.6	3.54

The production of grain/cm2 of leaf area was comparable to the temperate data from New York in only one planting, La Selva 1969. It is interesting to note that the 3.3 Ton yield in Turipaná gave the same mg grain/Kcal energy intercepted during the filling period (3.70) as the 6 Ton yield in La Selva (3.54), where there is cooler weather and a much longer filling period.

Correlations of yield with several morphological and efficiency parameters were calculated for the five plantings. Representative data from the two populations in two plantings are shown in Table 7.

Table 7. Correlations between grain yield and efficiency measures -- Experiment II.

Variable	Turipaná 1969A 35000	Turipaná 1969A 55000	La Selva 1969 35000	La Selva 1969 55000
Leaf Area Index	.33	.32	.70**	.74**
% Light Int.	.16	.43*	.76**	.79**
mg grain/cm2 LA	.96**	.95**	.83**	.80**
mg grain/Kcal energy	.99**	.98**	.98**	.99**
Kcal/cm2 LA	-.34	-.17	-.28	-.49*
Adaptation Rating	.73**	.57**	.53**	.46*

Grain yield per hectare is positively and highly significantly correlated with production per unit leaf area and per unit energy intercepted, although values of r for the latter are consistently higher. These data confirm the earlier results from the New York trial, and it is apparent that energy conversion to grain -- energy utilization -- is more important than just leaf area or light interception alone.

The inclusion of four additional measurements into each yield trial would allow calculation of all efficiency parameters. Leaf area and LAI for each genotype may be estimated rapidly in several replications by measuring a single leaf per plant and applying the leaf area factor. Genotypic differences in light interception are relatively easy to evaluate with the modified Ozalid paper technique. Determination of physiological maturity is now possible by observing the formation of the black closing layer, and does not require periodic sampling and drying. And a sample of stover from the final harvest may be weighed, and a sub-sample dried, to allow the calculation of total biological yield and harvest index.

Final yields will show production per hectare in the traditional sense. Light and leaf area measurements allow calculation of production per unit of light energy and leaf area, respectively. These two measurements may be combined to show the light energy intercepted per unit of leaf area. Times of flowering, silking, physiological maturity, and harvest will demonstrate the variability which exists in maize and should suggest optimum lengths of vegetative, grain filling, and drying periods for maximum yield. The date of physiological maturity and percent moisture at harvest will permit calculation of the rate of moisture loss for each genotype. When data from these efficiency calculations are available from several locations, altitudes, seasons, and years, a more realistic concept of an ideal plant type should emerge.