Sowing Date Effects on Grain Yield Components for Different Maize Genotypes

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ABSTRACT

Shoot dry weight of maize (*Zea mays* L.) depends on the amount of photosynthetically active radiation intercepted by the crop (IPAR). The present work was conducted to analyze the variation in shoot dry weight production and its partitioning to reproductive sinks when seasonal changes of temperature and solar radiation occur during the growing cycle of the crop. Four commercial hybrids were grown at 8 plants m^{-2} on four sowing dates (20 Aug., 20 Sept., 20 Oct., and 20 Nov.) at Rojas ($34°08'$ S, $60°59'$ W), Argentina, on a silty clay loam soil (Typic Argiudoll) during 1990–1991 and 1991–1992, with no water or nutrient restrictions. Shoot dry weight at physiological maturity was associated with the amount of IPAR, with radiation use efficiency before silking (4.14 g MJ^{-1}) higher than after silking (2.45 g MJ^{-1}). Grain yield was correlated with shoot dry weight at physiological maturity, resulting in a stable (0.46 ± 0.02) harvest index. Shoot dry weight at silking showed a significant relationship with final grain number ($r^2 = 0.52$, $n = 32$) as well as with grain yield ($r^2 = 0.55$, $n = 32$). Ear dry weight at silking was associated with grain yield particularly for prolific hybrids ($r^2 = 0.64$, $n = 16$). Provided postsilking conditions do not limit assimilate supply to the grains, shoot dry weight at silking could be considered a good grain yield predictor. In temperate regions, maize potential productivity seems to be more limited by the amount of solar radiation available around silking (determinant of grain set) than during grain filling (determinant of grain weight). Early and intermediate sowings tend to best utilize solar radiation for grain production.

$\mathbf{S}$HOOT DRY WEIGHT PRODUCTION of any crop is strongly correlated to the amount of photosynthetically active radiation intercepted (IPAR) by its canopy (Kiniry et al., 1989; Sivakumar and Virmani, 1984). The slope of this relationship, called radiation use efficiency (RUE), is often assumed to be very constant within each cultivated species (Kiniry et al., 1989; Gosse et al., 1986), changing slightly with temperature (Andrade et al., 1993) and ontogeny (Bonhomme et al., 1982).

Temperature can change shoot dry weight by altering leaf area expansion and thus altering the fraction of PAR intercepted (Muchow and Carberry, 1989). Temperature also affects crop cycle duration (Allison and Daynard, 1979), and consequently the period of PAR interception and growth (Fischer and Palmer, 1984).

Finally, harvest index (HI), or grain weight divided by total shoot weight, is considered stable for maize grown in the absence of environmental constraints (Sinclair et al., 1990). Nevertheless, modifications introduced by genotype and environment could be expected, as those induced in dry matter partitioning by temperature during early stages of growth (Tollenaar, 1989).

In the present work, grain yield and yield components of four maize genotypes, well supplied with water and nutrients, is analyzed when solar radiation and temperature were changed using different sowing dates. The objectives were to (i) determine shoot dry weight production and its partitioning, at silking and physiological maturity; (ii) analyze how grain yield and yield components are modified by the above-mentioned practice; and (iii) evaluate grain yield prediction through biomass production.

MATERIALS AND METHODS

Experimental Design and Data Analysis

Field experiments were conducted at Rojas ($34°08'$ S, $60°59'$ W; 65 m elevation), Argentina, during 1990–1991 and 1991–1992 on a silty clay loam soil (Typic Argiudoll). Treatments were a factorial combination of (i) four sowing dates: 20 August (S1), 20 September (S2), 20 October (S3), and 20 November (S4) and (ii) four adapted commercial hybrids: DK 4F91 (FAO 430, flint, nonprolific, four-way), DK 636 (FAO 530, dent, nonprolific, single), DK 3S41 (FAO 630, semident, prolific, three-way) and DK 3F24 (FAO 630, flint, prolific, three-way). Treatments were arranged in a split-plot design with three replicates with sowing dates as the main factor. Each subplot was five rows, 0.7 m apart, and 10 m long. Planting density was always 80 000 plants ha^{-1}. Plots were hand-planted at three seeds per hill, and thinned to the desired density at the three-leaf stage.

On 19 Aug. 1990, the site was fertilized with 10 kg P ha^{-1} and 9 kg N ha^{-1}. On 18 Aug. 1991, 42 kg P ha^{-1} and 37 kg N ha^{-1} were added. Each subplot was fertilized at the eight-leaf stage with 96 kg N ha^{-1} in 1990–1991 and 202 kg N ha^{-1} in 1991–1992.

Weeds were controlled with 4 L ha^{-1} atrazine (half-strength) at sowing, and by hand weeding after the crop was established. Water stress was prevented using sprinkler irrigation, with soil water content near field capacity throughout the growing seasons.

Analysis of variance was used to evaluate the effects of treatments and their interactions on the response variables. Linear regression analysis was applied to the relationships among variables and differences between regression coefficients were tested (Steel and Torrie, 1988).

Crop Development

Phenological events were determined twice a week on each subplot. Dates of emergence (when coleoptiles were visible above soil surface), silking, and physiological maturity (black layer observed in grains of the midportion of the ear) were recorded when 50% of the plants reached the stage. Observations were taken on a whole row for emergence, on eight adjacent plants for silking and by collecting four ears per sampling for physiological maturity.

Biomass Production, Grain Yield and Yield Components

At silking and physiological maturity, eight adjacent plants were harvested from the central row of each subplot. Plant material was separated into green leaves, senesced leaves, stem plus sheaths, tassel, husks, and cob plus grains, and then was oven dried at 60°C for 7 d and weighed.

At physiological maturity, ears were hand-shelled. Grains were

weighed to determine subplot grain yield and counted. Mean grain weight was calculated as the ratio of grain yield and grain number.

IPAR and Weather Data

Percentage of PAR intercepted by the canopy was calculated from the PAR above the canopy and the PAR below the green leaves. Percentage intercepted was measured fortnightly between the four-leaf stage and physiological maturity with a line-quantum sensor (LI-191 SA, Li-Cor, Lincoln, NE). Five measurements were taken between 1100 and 1400 h on clear days (Gallo and Daughtry, 1986) within each subplot.

Daily values of global solar radiation and mean temperature were from a meteorological station 300 m from the plots. Global solar radiation was converted into PAR by multiplying by 0.45 (Monteith, 1965). Daily fraction intercepted was obtained by interpolation and applied to the corresponding values of PAR to estimate IPAR.

RESULTS AND DISCUSSION

Climatic conditions of both years are shown in Table 1. While mean temperatures before silking were similar between years for each sowing date, differences between years were noticeable after silking, being slightly greater in 1991–1992. The most noticeable difference between years was the incident solar radiation, resulting in smaller IPAR in the second season for all treatments.

Grain yield clearly differed between years, with means of 1326 g m^{-2} in 1990–1991 and 1153 g m^{-2} in 1991–1992 (Table 2). Grain yield was strongly associated with number of grains per square meter ($r = 0.81$; $n = 32$), and showed a poor correlation with grain weight ($r = 0.34$; $n = 32$). For prolific hybrids, the number of ears per plant (Table 2) explained 52% ($P < 0.05$) of the variation in grain number per square meter and 56% ($P < 0.05$) of the variation in grain yield. No such significant association was found for nonprolific materials.

As sowing date was delayed, growth occurred under greater temperatures, with concomitant reductions in duration of growing cycles and reductions in cumulative incident PAR at silking (Table 1). Nevertheless, six out of eight maximum IPAR values for the whole cycle corresponded to S2, indicating that higher levels of daily incident solar radiation and higher fraction intercepted compensated for reductions in crop cycle duration, as observed by Muchow (1990) for grain growth under high temperature conditions in Australia. The first sowing date had the greatest incident solar radiation and the lowest values of fraction intercepted, while S3 tended to show the greatest fraction intercepted. While S4 had the greatest daily solar radiation, the reduction in crop cycle was so large that seasonal IPAR was the lowest of any sowing. Even though fraction intercepted increased rapidly in S4 (data

Table 1. Developmental dates, mean temperature (T_m), seasonal accumulated incident radiation (R_i) and intercepted photosynthetically active radiation (IPAR), and mean fraction of PAR intercepted during the growing season (F) for four maize hybrids at four sowing dates during 2 yr.

Sowing date	Hybrid	Growth stages†		Presilking			Postsilking			F
		Silking	PM	T_m	R_i	IPAR	T_m	R_i	IPAR	
		—— DAE ——		°C	MJ m^{-2} ——		°C	—— MJ m^{-2} ——		
					1990–1991					
20 Aug.	4F91	82	143	16.4	720	279	21.7	658	593	0.63
	DK 636	84	143	16.6	745	354	21.7	658	592	0.67
	3S41	90	157	16.9	818	435	21.6	729	581	0.66
	3F24	90	157	16.9	818	399	21.6	729	592	0.64
20 Sept.	4F91	65	123	19.0	651	381	21.8	636	550	0.72
	DK 636	67	123	19.0	674	395	21.9	613	529	0.72
	3S41	73	141	19.2	729	494	21.6	747	542	0.70
	3F24	73	141	19.2	729	478	21.6	742	520	0.68
20 Oct.	4F91	57	118	20.6	603	356	21.7	677	612	0.76
	DK 636	59	118	20.6	622	433	21.7	658	543	0.76
	3S41	61	128	20.8	647	488	21.7	703	575	0.79
	3F24	61	128	20.8	647	463	21.7	703	560	0.76
20 Nov.	4F91	54	119	21.6	604	382	21.1	518	472	0.76
	DK 636	58	119	21.6	649	417	21.0	473	408	0.74
	3S41	63	129	21.6	717	414	20.1	470	448	0.73
	3F24	63	129	21.6	717	409	20.1	470	428	0.71
					1991–1992					
20 Aug.	4F91	82	142	16.0	589	303	22.2	608	401	0.59
	DK 636	89	149	16.5	668	308	22.3	583	452	0.59
	3S41	91	149	16.7	685	368	22.2	565	442	0.65
	3F24	91	149	16.7	685	348	22.2	565	436	0.63
20 Sept.	4F91	65	128	17.1	542	306	22.4	618	444	0.65
	DK 636	72	133	17.5	606	324	22.6	598	471	0.66
	3S41	76	141	17.7	640	375	22.7	655	524	0.69
	3F24	76	141	17.7	640	388	22.7	655	494	0.68
20 Oct.	4F91	56	122	20.0	532	270	22.8	667	489	0.63
	DK 636	63	122	19.9	592	304	22.9	587	442	0.63
	3S41	66	129	20.1	608	374	22.7	642	491	0.69
	3F24	66	129	20.1	608	368	22.7	642	378	0.60
20 Nov.	4F91	53	109	21.7	520	204	23.2	539	455	0.62
	DK 636	59	116	22.0	554	264	23.0	539	433	0.64
	3S41	62	127	22.1	592	330	24.4	570	472	0.69
	3F24	62	127	22.1	592	326	24.4	570	457	0.67

† PM, physiological maturity; DAE, days after emergence.

Table 2. Grain yield (GY), prolificacy (P), grain number per square meter (GN), and grain weight (GW) for four maize hybrids at four sowing dates during 2 yr.

Sowing date	Hybrid	1990–1991				1991–1992			
		GY	P	GN	GW	GY	P	GN	GW
		g m⁻²	ears plant⁻¹	grain m⁻²	mg grain⁻¹	g m⁻²	ears plant⁻¹	grain m⁻²	mg grain⁻¹
20 Aug.	4F91	1037	1.05	3257	318	882	1.13	3178	279
	DK 636	1494	1.05	4109	363	1101	1.04	3508	317
	3S41	1488	1.50	4943	301	1264	1.42	4661	278
	3F24	1539	1.58	5067	304	1154	1.54	4871	247
20 Sept.	4F91	1283	1.03	3694	347	1014	1.00	3588	282
	DK 636	1538	1.00	4211	365	1292	1.00	3950	327
	3S41	1571	1.43	5521	285	1298	1.33	4604	290
	3F24	1769	1.77	6026	294	1257	1.33	4826	277
20 Oct.	4F91	1337	1.00	4187	319	1011	1.04	3648	280
	DK 636	1431	1.00	4359	328	1301	1.02	4084	318
	3S41	1250	1.30	4680	267	1276	1.13	4861	264
	3F24	1436	1.50	5330	269	1289	1.25	5027	267
20 Nov.	4F91	899	1.00	3253	276	924	1.00	3580	258
	DK 636	944	0.90	2944	321	1146	1.00	3819	301
	3S41	1014	1.07	3613	281	1157	1.17	4092	285
	3F24	1193	1.30	3723	320	1090	1.38	4155	272
LSD (0.05)†		108	0.01	354	23	127	0.11	411	24
LSD (0.05)‡		180	0.25	650	71	186	0.41	555	26

† Least significant difference for hybrids within dates.
‡ Least significant difference for hybrids among dates.

not shown), the shorter duration caused smaller seasonal IPAR than for S2 and S3.

Shoot dry weight at physiological maturity was significantly associated with the IPAR for the entire growth cycle (Fig. 1). The slope (or RUE) was similar to values in literature (Bonhomme et al., 1982; Andrade et al., 1992). Nevertheless, the model obtained for the postsilking period (shoot dry weight = 202.3 + 2.45 IPAR; r = 0.545; n = 32) was significantly different (a***, b**) from that calculated for presilking (Fig. 2), indicating a reduction in RUE during grain filling. As suggested by Kiniry et al. (1989), this would be expected in temperate regions if increasing biomass and increasing temperatures promote higher maintenance respiration levels. Leaf condition should also be taken into account, as by the end of grain filling, a fraction of the incoming PAR is intercepted by partially senesced upper leaves with reduced photosynthetic capac-

ity, which would also explain the higher dispersion around the fitted line for this period.

Shoot dry weight at maturity was an excellent estimator of grain yield, suggesting no temperature effect on HI for the environmental conditions tested in the present study and supporting the stability of this parameter for maize grown under nonlimiting conditions (Sinclair et al., 1990) (Fig. 3). Shoot dry weight at silking accounted for >50% of the variance of both grain number per square meter (r^2 = 0.52; n = 32) and grain yield (Fig. 4). This suggests that postsilking conditions did not limit dry weight accumulation for the number of kernels defined at each sowing date. In our experiments, postsilking crop growth generally exceeded grain yield (Fig. 5), indicating no limitations by source during this period, unlike those pointed out by Ruget (1993) and Tollenaar and Daynard (1978) for maize grown at high latitudes. This could explain the above-mentioned reductions in RUE after silking, as the only aerial organ with a high growth rate during this period
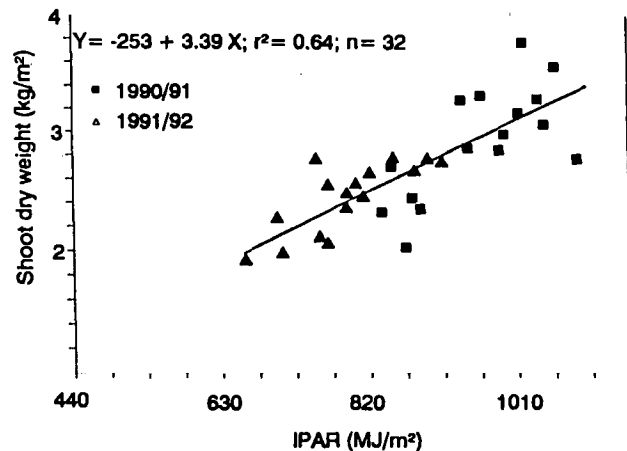

Fig. 1. Relationship between shoot dry weight at physiological maturity and intercepted PAR from seedling emergence to physiological maturity.
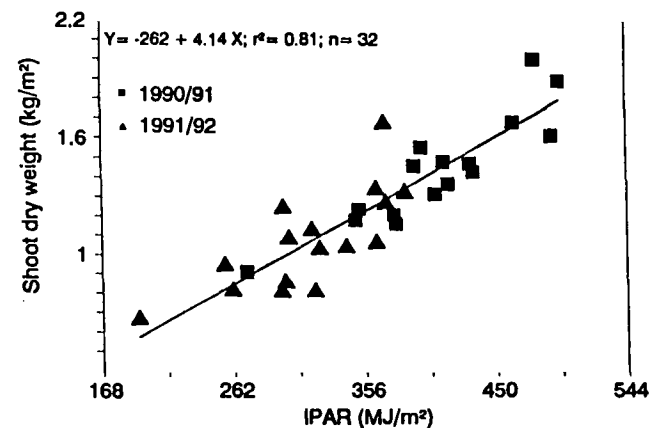

Fig. 2. Relationship between shoot dry weight at silking and intercepted PAR from seedling emergence to silking.
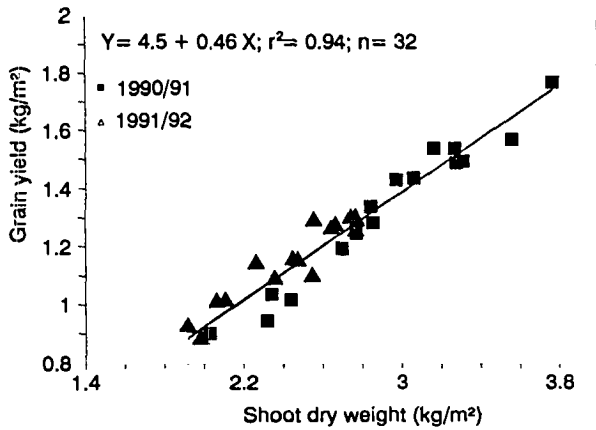
Fig. 3. Relationship between grain yield and shoot dry weight at physiological maturity.
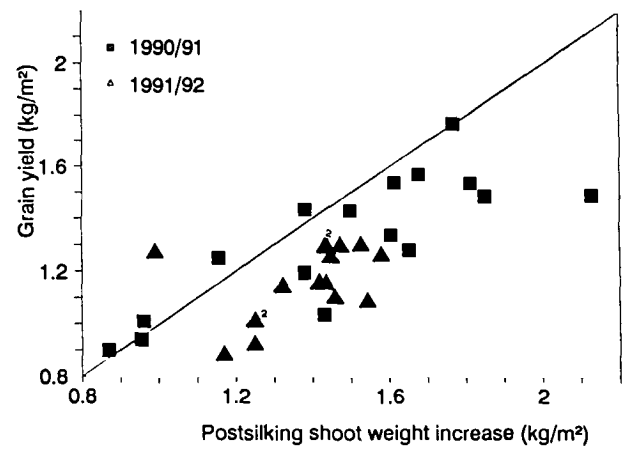
is the ear. If its demand of photoassimilates is satisfied, photosynthesis rate could be reduced (Hansen, 1977), decreasing RUE.

Among the lowest in postsilking crop growth and grain yield were DK 4F91, DK 636, and DK 3S41 in S4 of 1990–1991, which agrees with their low levels of incident solar radiation after silking. When these points were eliminated, the relationship between shoot dry weight at silking and grain yield improved ($r^2 = 0.74$, $n = 28$), supporting the idea that shoot dry weight at silking is a good grain yield predictor (Otegui and Ruiz, 1993), provided that postsilking radiation does not limit grain filling.

At silking, the amount of dry weight partitioned to the ear (apical plus subapical) was exponentially associated with the summed IPAR prior to silking (Fig. 6). This relationship supports the idea that, during this period, the ear is a dominated organ (Tollenaar, 1977), competing for photoassimilates with the leaves, the tassel, and the stem (dominating organs). As the demand from dominating organs is satisfied, more resources are allocated to the ear, increasing ear dry weight proportionally more than shoot dry weight.

Ear dry weight was significantly associated with grain yield ($r^2 = 0.41$, $n = 32$). If genotype characteristics are considered, however, the relationship holds only for prolific hybrids ($r^2 = 0.64$, $n = 16$); no correlation is observed
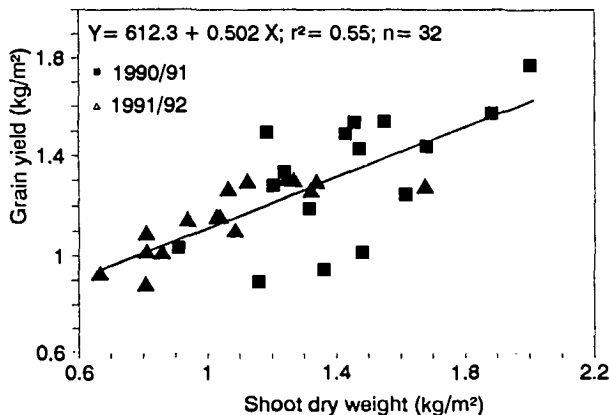

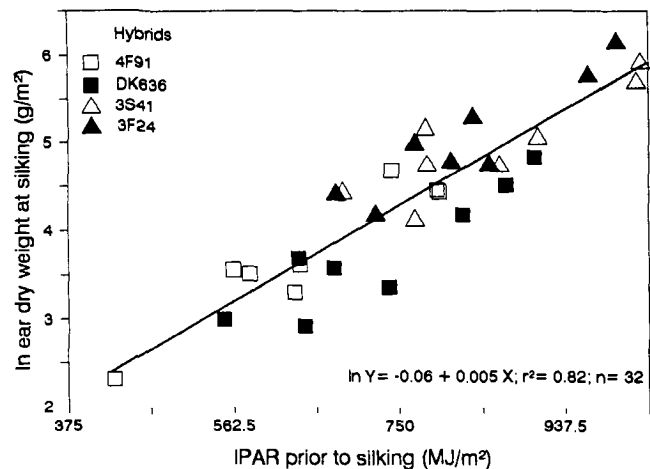Fig. 4. Relationship between grain yield and shoot dry weight at silking.

Fig. 5. Relationship between grain yield and shoot dry weight increase from silking to physiological maturity. The line represents the 1:1 ratio.

for nonprolific ones. Differences among prolific types also hold when ear dry weight is divided by shoot dry weight to correct for different plant size. This pattern is consistent with the association found between grain yield and its components (Table 3). Despite the fact that grain yield was strongly associated with grain number per square meter, and varied weakly with changes in grain weight, different genotype responses were evident when hybrids were considered individually. While grain yield of prolific hybrids was responsive only to grain number per square meter, that of nonprolific ones also changed with grain weight. Grain yield of prolific hybrids appeared highly dependent on environmental conditions during the period between ear differentiation and the beginning of the grain filling lag phase, when the number of ears per plant and grain number per plant are defined (Kiniry and Ritchie, 1985; Fischer and Palmer, 1984; Hallauer and Troyer, 1972). In wheat, Fischer (1984) observed a strong association between grain number per square meter and spike dry weight at anthesis. In maize, shoot dry weight partitioning to the ear seems to be an important factor controlling grain yield of prolific hybrids, and could explain the difficul-

Fig. 6. Relationship between ear dry weight at silking and accumulated IPAR from seedling emergence to silking.

Table 3. Values for r^2 for regression of grain yield (GY) on grain number (GN) and grain weight (GW) for each maize hybrid.

Hybrid	Type	r^2	
		GY = f(GN)	GY = f(GW)
4F91	FAO 430, nonprolific, flint, four-way	0.655*	0.702**
DK 636	FAO 530, nonprolific, dent, single	0.831***	0.575*
3S41	FAO 630, prolific, semident, three-way	0.889***	0.140ns
3F24	FAO 630, prolific, flint, three-way	0.685**	0.120ns

*,**,*** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

ties observed when predicting grain yield of these materials using the CERES–Maize model (Jones and Kiniry, 1986). For nonprolific hybrids, whose grain yield is under control of both grain number per square meter and grain weight, and which do not respond to ear dry weight at silking, postsilking environment determines grain yield, in agreement with the results obtained by Kiniry and Ritchie (1985) and applied by the above-mentioned mechanistic model.

In summary, it can be stated that shoot dry weight at silking is a good grain yield predictor in maize if the postsilking environment does not limit photoassimilate supply to the grains. This condition is particularly important for hybrids whose grain yield is significantly related to grain weight. Nevertheless, maize production in temperate regions seems to be more limited by source (incident solar radiation) around flowering (determinant of grain set) than during grain filling (determinant of grain weight).

ACKNOWLEDGMENTS

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