Kernel Number Determination in Argentinean Maize Hybrids
Released between 1965 and 1993

L. Echarte,* F. H. Andrade, C. R. C. Vega, and M. Tollenaar

ABSTRACT

Grain yield and the stability of harvest index are greater in newer than in older Argentinean maize (Zea mays L.) hybrids. The objective of this study was to elucidate mechanisms underlying the superior yield and harvest index stability of newer Argentinean maize hybrids using the relationship between kernel number per plant (KNp) and plant growth rate during the period bracketing silking (PGR). Three experiments were performed at Balcarce, Argentina, during two growing seasons (1998–2000). Maize was grown under a wide range of plant densities (from 2 up to 30 plants m$^{-2}$ ) to generate contrasting availability of resources per plant. Growth of individual plants during the period bracketing silking was estimated through a nondestructive method on the basis of relationships between actual shoot dry matter and morphometric variables, including stem and ear diameters and ear length. Detasseling and silk pollination synchronization treatments were imposed in one experiment to also modify available resources per kernel and kernel sink strength. Newer hybrids set more kernels per unit PGR than older hybrids as is indicated by (i) the lower threshold PGR, for kernel set and (ii) greater potential kernel number at high availability of resources per plant, for newer than for older hybrids. At low and intermediate PGRs, the greater kernel set per unit PGR in newer vs. older hybrids was attributable to a greater partitioning of dry matter to the ear during the period bracketing silking, whereas number of kernels set per unit of ear growth rate did not differ. In contrast, kernel set per unit of ear growth rate was greater in newer than in older hybrids when PGR was high. Results of this study indicate that genetic yield improvement in maize is attributable, in part, to increased partitioning of dry matter to the ear during the critical period bracketing silking.

YIELD OF NEWER ARGENTINEAN MAIZE HYBRIDS is greater than that of older ones (Echarte et al., 2000). Genetic yield improvement in North American maize hybrids has been associated with increased dry matter accumulation and not with the proportion of above-ground dry matter that is partitioned to the grain (i.e., harvest index), which has remained relatively stable (Tollenaar and Lee, 2003). Contrarily, harvest index has increased from older to newer Argentinean hybrids (Echarte and Andrade, 2003). More recently released hybrids are more tolerant to high plant-density stress than older hybrids (Russell, 1984; Castlesberry et al., 1984; Tollenaar et al., 1992; Duveck, 1997; Tollenaar and Wu, 1999; Echarte et al., 2000; Tollenaar and Lee, 2002). This is associated with higher stability in harvest index of newer hybrids (Echarte and Andrade, 2003), which may result from their ability to maintain a high kernel number per plant (KNp) as resource availability per plant decreases (Echarte and Andrade, 2003).

Grain yield improvement is highly associated with kernel number (e.g., Andrade et al., 1996; Echarte et al., 2000; Tollenaar et al., 2000). Kernel number per plant is associated with plant growth rate during the critical period bracketing silking (PGR) (Aluko and Fischer, 1988; Tollenaar et al., 1992; Andrade et al., 1999; Vega et al., 2001a). In maize, the KNp–PGR relationship has been described by two successive curves to account for the first and second ear in prolific, or a single curve in nonprolific plants (Tollenaar et al., 1992; Andrade et al., 1999; Vega et al., 2001b). A particular feature of the KNp–PGR relationship is the significant PGR threshold for kernel set which probably reflects the abrupt decreases in dry matter partitioning to the ear when resources per plant are low (Edmeades and Daynard, 1979; Tollenaar et al., 1992; Andrade et al., 1999; Vega et al., 2001a). The lower threshold of biomass per plant measured at physiological maturity for yield observed in newer hybrids (Echarte and Andrade, 2003) could be associated with a lower PGR threshold for grain set in comparison with older hybrids. On the other hand, the greater KNp response to increases in resource availability per plant of newer hybrids (Echarte and Andrade, 2003) could be the result of a greater potential kernel number in the topmost ear. Greater kernel number per plant in newer hybrids was related to a greater kernel set in the topmost ear and not to a greater prolificacy (Echarte and Andrade, 2003).

Differences among hybrids in the number of kernels set per unit of PGR, (i.e., KNp/PGR) may be attributable to either or both dry matter partitioning to the ear and number of kernels set per unit of ear growth rate during the period bracketing silking (Andrade et al., 1999; Vega et al., 2001b). First, increased partitioning to the ear could increase KNp/PGR. Genetic reduction in tassel size or tassel removal have generally favored dry matter partitioning to the ear and increased kernel set (Fischer and Palmer, 1984; Bolaños and Edmeades, 1993; Edmeades et al., 1993). Tassel size has declined linearly in U.S. hybrids from the 1930s to the 1990s (Tollenaar et al., 2000). A lower response of kernel number to tassel removal would be anticipated in newer than in older hybrids if the reduction in tassel size has been associated with a concomitant reduction in tassel dominance over the ear. Second, an increase in the number of kernels set per unit of ear growth rate during the critical period bracketing silking (EGR) could in...
increase KN$_p$/PGR$_s$. Differences in the assimilate requirement per kernel (Edmeades and Daynard, 1979; Edmeades et al., 1993; Vega et al., 2001a) may account for differences in number of kernels set per unit of EGR, among hybrids. In addition, differences in kernel number per unit EGR, may be associated with differences in synchronization of fertilization of florets within the ear (Cárcova et al., 2000; Cárcova and Otegui, 2001). Therefore, if kernel number set per unit of ear growth is a mechanism underlying a greater KN$_p$/PGR$_s$ of newer hybrids, (i) a lower minimum assimilate requirement per kernel and/or (ii) a lower kernel set response to improved synchronism in silk pollination would be expected in newer than in older hybrids.

In this work, we examine the mechanisms that underlie the differences in kernel number per unit of PGR$_s$ between newer and older Argentinean maize hybrids. The PGR threshold for kernel set and the response of KN$_p$ to PGR$_s$ increments could be involved in the high kernel number and HI stability of new Argentinean maize hybrids. We tested the hypothesis that the PGR$_s$ threshold for grain set is lower and the kernel response to PGR$_s$ increments is greater in newer than in older hybrids by examining the response of KN$_p$ to resource availability of individual plants rather than that of plot means. In addition, we examined whether dry matter partitioning to the ear and kernel number set per unit of ear growth rate during the critical period bracketing silking is associated with the greater kernel number per unit of PGR$_s$, of a newer versus an older maize hybrid.

**MATERIALS AND METHODS**

**Site and Crop Management**

Maize was grown at Balcarce, Argentina (37°45’ S, 58°18’ W; elevation 130 m), during the 1998–1999 (Exp. 1) and the 1999–2000 growing seasons (Exp. 2 and 3). Crops were fertilized with 35 kg P ha$^{-1}$ before sowing, and with 150 kg N ha$^{-1}$ at V6 (Ritchie and Hanway, 1982). Soil water to 1-m depth was kept over 50% of maximum available water by sprinkler irrigation. Weeds and insects were effectively controlled.

**Plant Material and Experimental Design**

The maize hybrids Morgan 400, DeKalb 4F36, DeKalb 664, and DeKalb 752 (Exp. 1) and DeKalb F880 and DeKalb 752 (Exp. 2 and 3) were sown on 6 Oct. 1998 (Exp. 1) and 8 Oct. 1999 (Exp. 2 and 3). Each of these hybrids was among the three topmost cultivated hybrids in the Argentinean Pampas for at least 5 yr after their release (Table 1). In all three experiments, plant density was used as the source of experimental variation for KN$_p$ and PGR$_s$. Plots were oversown and thinned to the desired plant densities at V3. The experimental design was a split-plot randomized complete-block design with three replications, with plant densities as main plots and hybrids as subplot. Plant densities at harvest were 2, 4, 8, 16, and 30 plants m$^{-2}$ in Exp. 1 and 2, and 8 and 16 plants m$^{-2}$ in Exp. 3. Subplots comprised five 7-m-long rows at low plant densities and six to seven 7-m rows at intermediate (8 plants m$^{-2}$) and higher plant densities (16–30 plants m$^{-2}$). The distance between rows was 0.7 m in all cases. In Exp. 3, treatments of detasseling and artificial synchronous pollination were applied at random within each experimental unit. Detasseling was performed by hand (n = 80 plants per hybrid) when the tassel was still surrounded by four leaves (i.e., 6.5 ± 0.14 d before silking, average for both hybrids and plant densities). In plants chosen for artificial synchronous pollination (n = 80 plants per hybrid), both the uppermost and the second ears were bagged before silk emergence. Both ears were pollinated 5 d after first silks emerged from the husks of the uppermost ear. In border rows, additional plants were sown 2 wk after 8 Oct. 2000 to assure adequate pollen availability during the whole period.

**Table 1. Year of hybrid release, hybrid type and endosperm type, and relative maturity.**

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Year of release</th>
<th>Hybrid type and endosperm type</th>
<th>Relative maturity†</th>
</tr>
</thead>
<tbody>
<tr>
<td>DKF880</td>
<td>1965</td>
<td>Double cross, flint</td>
<td>120</td>
</tr>
<tr>
<td>M400</td>
<td>1978</td>
<td>Double cross, flint</td>
<td>128</td>
</tr>
<tr>
<td>DK4F36</td>
<td>1982</td>
<td>Double cross, flint</td>
<td>127</td>
</tr>
<tr>
<td>DK664</td>
<td>1993</td>
<td>Single cross, semi-dent</td>
<td>116</td>
</tr>
<tr>
<td>DK752</td>
<td>1993</td>
<td>Single cross, semi-dent</td>
<td>125</td>
</tr>
</tbody>
</table>

† Relative maturity 120 = FAO 600; Relative maturity 130 = FAO 700.

**Measurements**

Shoot biomass of tagged plants was quantified at approximately 10 d before and 15 d after silking (henceforth this period is referred to as the critical period bracketing silking) through a combination of destructive and nondestructive sampling following methodologies described by Vega et al. (2001a, 2001b) (see below). At maturity, KN$_p$ was determined in the topmost (KN$_t$) and second ear. In Exp. 1 and 2, anthesis and silking dates were recorded for each experimental unit as the dates when 50% of the plants presented visible anthers on the main branch and at least one emerged silk from the husks, respectively. In Exp. 3, silking and anthesis dates were recorded for each individual plant (n = 240 plants per hybrid).

**Destructive Sampling**

Morphometric variables, i.e., basal stem diameter and diameter and length of the topmost ear, were measured on a density-dependent number of plants (three plants per replicate at low plant density and six to eight plants per replicate at high plant densities). Diameter of the stem and the ear were measured on the widest section. Immediately after measurements, plants were harvested, leaving borders of at least 1 m between successive harvests. Plants were separated into leaf blade, stem plus sheath, and ears and oven dried at 65°C until constant weight. Allometric relationships were established between morphometric variables and dry weights of shoot and female reproductive structures. Reproductive structures included kernels and rachis of the topmost ear. Models fitted to shoot dry weight are summarized in Table 2 and models fitted to dry weight of the topmost ear are summarized in Table 3.

**Nondestructive Sampling**

Before silking, a density-dependent number of consecutive plants were tagged within each subplot, i.e., six plants at the lowest plant density and up to 30 plants at the highest plant density. Shoot and reproductive biomass were assessed for each tagged plant using the allometric relationships shown in Tables 2 and 3. In all cases, sample areas were bordered by at least three (low plant densities) or four (intermediate and higher plant densities) guard rows; and by at least 1 m within the row. The radiation profile along the stem was measured 2 wk after flowering for control and detasseled plants in Exp.
Data Analysis

Growth rate during the critical period for kernel set was estimated as the ratio between accumulated biomass in shoots or topmost ear and the duration of the period. We assumed a linear relationship between biomass accumulation per plant and days during the period bracketing silking, and female reproductive biomass to be negligible at 10 d before silking (beginning of the critical period bracketing silking).

The relationship between KN1 and PGRs was investigated using a nonlinear model (Model 1; Jandel Scientific, 1991). This model was chosen because it includes parameters with biologically meaningful parameters (Echarte and Andrade, 2003).

\[
\text{KN}_1 = a_1 [1 - \exp(- (PGR - x_0)/b_1)]
\]

if \(PGR \geq x_0\) \hspace{1cm} \text{[Model 1]}

\[
\text{KN}_1 = 0 \quad \text{if} \quad PGR < x_0
\]

Parameter \(a_1\) quantifies the potential number of kernels set in the topmost ear, and \(b_1\) is a measure of the curvilinearity of the KN1–PGRs relationship. A large \(b_1\) value indicates that the curve approaches a straight line. The parameter \(x_0\) (g plant\(^{-1}\) d\(^{-1}\)) represents the PGRs threshold for kernel set in the uppermost ear. Free iteration of parameters yielded large errors in the estimation of the PGRs threshold for kernel set (parameter \(x_0\)). Particularly, the model did not adequately estimate KN1 for plants with KN1 < 200 kernels. Most of the residuals of the model were negative for these plants, especially for older hybrids. This was mainly explained by a large variability in KN1 close to the threshold and to the high initial slope of the KN1–PGRs relationship. Therefore, parameter \(x_0\) was set in the model as an input based on PGRs data from nonbarren plants bearing nubbins. The threshold of PGRs for kernel set was estimated as the average PGRs of plants that set 1 to 100 kernels. Selection of a narrow range of KN1, i.e., 1 > KN1 > 50 did not provide enough number of plants to perform valid statistic comparisons among hybrids. Barren plants were not included in the calculation of the PGRs threshold because they underestimate its value.

Additionally, we fitted the relationship between KN1 and the ear growth rate at the period bracketing silking (EGRs) using Model 2 (Vega et al., 2001a); which presented a greater \(R^2\) than Model 1.

\[
\text{KN}_1 = [a_2 \times (\text{EGR} - x_1)]/[1 + b_2 \times (\text{EGR} - x_1)]
\]

if \(\text{EGR} \geq x_1\) \hspace{1cm} \text{[Model 2]}

\[
\text{KN}_1 = 0 \quad \text{if} \quad \text{EGR} < x_1
\]

Parameters \(a_2\) and \(b_2\) represent the initial slope and the curvilinearity of the KN1–EGRs relationship, respectively. Low \(b_2\) indicates that the curve approaches to a straight line. Parameter \(x_1\) quantifies the EGRs threshold to set kernels.

The minimum assimilate requirement per kernel (mg kernel\(^{-1}\) d\(^{-1}\)) was estimated as the mean EGRs, KN1 for the interval of EGRs, at maximum kernel set per unit of EGRs ± 10%. The maximum kernel set per unit of EGRs was obtained from the hyperbolic KN1–EGRs relationship (Vega et al., 2001a).

Data were processed by \(t\) test of parameters and \(t\) tests were used to assess differences between hybrids in KN1 and EGRs for intervals of EGR or PGRs.

RESULTS AND DISCUSSION

Relationship between KN1 and PGRs

The relationship between KN1 and PGRs was curvilinear (Fig. 1) with a PGRs threshold for kernel set \((x_0)\). A trend toward a plateau for kernel number of the topmost ear (KN1) at high values of PGRs indicates morphogenetic limitations in reproductive plasticity. There was not a clear trend in mean PGRs at each plant density with year of hybrid release (data not shown).

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Hybrids</th>
<th>Shoot biomass</th>
<th>(R^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M400</td>
<td>(S_1 = -58.1 + 53.6 \times x)</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>DK4F86</td>
<td>(S_1 = -5.0 + 16.4 \times x^{2} + 2.4 \times (ed \times el)^{0.6})</td>
<td>0.93</td>
</tr>
<tr>
<td></td>
<td>DK664</td>
<td>(S_1 = -45.7 + 45.2 \times x)</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>DK752</td>
<td>(S_1 = -0.4 + 21.4 \times x^{1} + 0.1 \times (ed \times el)^{1.3})</td>
<td>0.94</td>
</tr>
<tr>
<td></td>
<td>S1 M400</td>
<td>(S_1 = 0.3 + 9.0 \times x^{1})</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>DK752</td>
<td>(S_1 = 8.7 + 8.0 \times x^{1} + 0.7 \times (ed \times el)^{0.9})</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Parameters \(a_0\) and \(b_1\) were fixed for the calculation of the PGRs threshold because they underestimate its value.

Additionally, we fitted the relationship between KN1 and the ear growth rate at the period bracketing silking (EGRs) using Model 2 (Vega et al., 2001a); which presented a greater \(R^2\) than Model 1.

\[
\text{KN}_1 = [a_2 \times (\text{EGR} - x_1)]/[1 + b_2 \times (\text{EGR} - x_1)]
\]

if \(\text{EGR} \geq x_1\) \hspace{1cm} \text{[Model 2]}

\[
\text{KN}_1 = 0 \quad \text{if} \quad \text{EGR} < x_1
\]

Parameters \(a_2\) and \(b_2\) represent the initial slope and the curvilinearity of the KN1–EGRs relationship, respectively. Low \(b_2\) indicates that the curve approaches to a straight line. Parameter \(x_1\) quantifies the EGRs threshold to set kernels.

The minimum assimilate requirement per kernel (mg kernel\(^{-1}\) d\(^{-1}\)) was estimated as the mean EGRs, KN1 for the interval of EGRs, at maximum kernel set per unit of EGRs ± 10%. The maximum kernel set per unit of EGRs was obtained from the hyperbolic KN1–EGRs relationship (Vega et al., 2001a).

Data were processed by \(t\) test of parameters and \(t\) tests were used to assess differences between hybrids in KN1 and EGRs for intervals of EGR or PGRs.

RESULTS AND DISCUSSION

Relationship between KN1 and PGRs

The relationship between KN1 and PGRs was curvilinear (Fig. 1) with a PGRs threshold for kernel set \((x_0)\). A trend toward a plateau for kernel number of the topmost ear (KN1) at high values of PGRs indicates morphogenetic limitations in reproductive plasticity. There was not a clear trend in mean PGRs at each plant density with year of hybrid release (data not shown).
At fixed ranges of PGRs, KN1 was greater in newer than in older hybrids (P < 0.05). For example, the newer hybrid DK752 set 26 and 51% more kernels than the older hybrid M400 at low (i.e., 0.5 < PGRs < 1.5 g d⁻¹) and at high (i.e., 5 < PGRs < 6 g d⁻¹) resource availability per plant, respectively. This supports contentions of a previous analysis based on mean plot data which concluded that greater KNp set per unit of PGR would primarily underlie the greater KNp of newer hybrids (Echarte et al., 2000). The threshold PGR, (x₀) was higher for older hybrids (0.82 g plant⁻¹ d⁻¹ > x₀ > 1.18 g plant⁻¹ d⁻¹) than for newer hybrids (0.52 g plant⁻¹ d⁻¹ > x₀ > 0.65 g plant⁻¹ d⁻¹) (Table 4). In accordance to these values of PGR, thresholds for kernel set, more than half of the plants of the old hybrids and only 16% of the plants of the newer hybrids were sterile at PGRs from 0.5 to 1 g d⁻¹ (Fig. 2a). Those proportions decreased to 17 and 0% for older and newer hybrids at PGRs from 1 to 1.5 g d⁻¹ (Fig. 2b). In addition, supporting a lower threshold PGR, for kernel set in newer than in older hybrids, the PGR, values below which half of the plants were sterile were lower in newer (0.82 and 0.91 g d⁻¹ for DK664 and DK752, respectively) than in older hybrids (1.58 and 1.43 g d⁻¹ for M400 and DK4F36, respectively). The degree of curvilinearity of the KN1–PGR, relationship was lower in newer than in older hybrids (parameter 𝑏₁, Table 4—a large 𝑏₁ value indicates that the curve approaches a straight line). Consequently, KNp continues to increase to greater PGRs in older hybrids (Fig. 1). A comparison of the newer hybrid DK752 with the older hybrid DKF880 concluded that greater KNp set per unit of PGRs would primarily underlie the greater KNp of newer hybrids showed that both number of kernel rows (20 vs. 14) and number of kernels per row (37 vs. 28) were greater in (Echarte et al., 2000). The threshold PGRs (x₀) was higher for older hybrids (0.82 g plant⁻¹ d⁻¹ > x₀ > 1.18 g plant⁻¹ d⁻¹) than for newer hybrids (0.52 g plant⁻¹ d⁻¹ > x₀ > 0.65 g plant⁻¹ d⁻¹) (Table 4). In accordance to these values of PGR, thresholds for kernel set, more than half of the plants of the old hybrids and only 16% of the plants of the newer hybrids were sterile at PGRs from 0.5 to 1 g d⁻¹ (Fig. 2a). Those proportions decreased to 17 and 0% for older and newer hybrids at PGRs from 1 to 1.5 g d⁻¹ (Fig. 2b). In addition, supporting a lower threshold PGR, for kernel set in newer than in older hybrids, the PGR, values below which half of the plants were sterile were lower in newer (0.82 and 0.91 g d⁻¹ for DK664 and DK752, respectively) than in older hybrids (1.58 and 1.43 g d⁻¹ for M400 and DK4F36, respectively). The degree of curvilinearity of the KN1–PGR, relationship was lower in newer than in older hybrids (parameter 𝑏₁, Table 4—a large 𝑏₁ value indicates that the curve approaches a straight line). Consequently, KNp continues to increase to greater PGRs in newer than in older hybrids (Fig. 1). A comparison of the newer hybrid DK752 with the older hybrid DKF880 showed that both number of kernel rows (20 vs. 14) and number of kernels per row (37 vs. 28) were greater in (Echarte et al., 2000).
Partitioning of Dry Matter to the Topmost Ear and Kernel Set per Unit EGR,

Growth rate of the topmost ear during the period bracketing silking was greater in the newer hybrid DK752 than in the older hybrid DKF880, across the whole range of PGRs (P < 0.05, Fig. 3a). In addition, mean PGR at each plant density was greater in the newer hybrid DK752 than in the older hybrid (data not shown). As a consequence, the proportion of plants with very low EGRs (i.e., EGR < 0.2 g d⁻¹) was greater in the older hybrid (55%) than in the newer hybrid (23%) at high plant densities (16–30 plants m⁻²). When expressed at equal EGRs, however, KN1 did not differ between the two hybrids at low and intermediate EGRs (i.e., EGR from 0 to 0.5 g d⁻¹, Fig. 3b). Therefore, these results support the contention that the greater number of kernels set per unit of PGR of the newer hybrid was not influenced by a greater kernel number set per unit of ear growth rate at relatively low resource availability per plant. In contrast, the number of kernels set per unit of ear growth rate was greater in the newer hybrid (P < 0.05, Fig. 3b) at low plant densities (i.e., EGR ≥ 0.6 g d⁻¹) because of a larger reproductive plasticity, i.e., potential kernel number per ear (Table 4). In addition, at high resource availability per plant, Vega et al. (2001a) showed that EGR, of the topmost ear is lower in prolific plants compared with nonprolific plants of the same hybrid. This suggests that a low mean EGR of the topmost ear at high resource availability per plant could be associated, in part, with a high prolificacy (i.e., large proportion of prolific plants). However, since prolificacy did not present a clear trend with the year of hybrid release (Echarte et al., 2000; Echarte and Andrade, 2003) and since at intermediate and low plant densities the oldest and the newer hybrids presented the same proportion of prolific plants (27.5 and 28.3% for DKF880 and DK752, respectively), a lower growth rate of the topmost ear in the older hybrid is not associated with a greater prolificacy.

Tassel removal, performed to diminish the dominance of the tassel over the ear, increased KN1 in the older hybrid only when PGR, ranged from 1.5 to 3 g plant⁻¹ d⁻¹ (p < 0.05; Fig. 4a). Out of this PGR range, KN1 increases in the older hybrid in relation to the control were less significant (p < 0.5). Synchronization of pollen-pollination, performed to diminish competition for assimilates among kernels within the ear, did not affect KN1 (p > 0.05, data not shown). In Exp. 3, PGR, varied between 0 and 4 g plant⁻¹ d⁻¹ and kernel number per plant varied between 0 and 680 for DKF880 and between 0 and 850 for DK752. Within each hybrid, mean PGR did not differ among treatments, i.e., PGR, was

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Hybrid</th>
<th>Year of release</th>
<th>x₀</th>
<th>a₁</th>
<th>b₁</th>
<th>R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M400</td>
<td>1978</td>
<td>1.18 a</td>
<td>448 d</td>
<td>0.31 d</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>DK4F36</td>
<td>1982</td>
<td>0.67 b</td>
<td>541 b</td>
<td>0.97 b</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>DK664</td>
<td>1993</td>
<td>0.52 c</td>
<td>852 a</td>
<td>2.00 a</td>
<td>0.87</td>
</tr>
<tr>
<td></td>
<td>DKF880</td>
<td>1965</td>
<td>0.67 b</td>
<td>420 b</td>
<td>0.67 b</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>DK752</td>
<td>1993</td>
<td>0.64 b</td>
<td>769 a</td>
<td>1.45 a</td>
<td>0.90</td>
</tr>
<tr>
<td>2</td>
<td>DKF880</td>
<td>1965</td>
<td>0.67 b</td>
<td>420 b</td>
<td>0.67 b</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>DK752</td>
<td>1993</td>
<td>0.64 b</td>
<td>769 a</td>
<td>1.45 a</td>
<td>0.90</td>
</tr>
</tbody>
</table>

† Means within a column and within an experiment followed by the same letter are not significantly different at P < 0.05.
OLD HYBRIDS NEWER HYBRIDS

Fig. 2. Frequency distributions (%) of kernel number per plant for plants growing at (a) 0.5 > PGR > 1 g d⁻¹ and (b) at 1 > PGR > 1.5 g d⁻¹ in four maize hybrids released in Argentina at different decades (data from Exp. 1).

1.55 ± 0.09, 1.56 ± 0.13 and 1.41 ± 0.09 g plant⁻¹ d⁻¹ for DKF880 and 2.14 ± 0.09, 2.28 ± 0.09 and 2.17 ± 0.11 g plant⁻¹ d⁻¹ for DK752, for detasseled, synchronous pollination and control treatments, respectively. Tassel removal resulted in greater EGRs at PGR, lower than 3 g plant⁻¹ d⁻¹ in DKF880 and did not have any effect on DK752. For the old hybrid, the increase in the growth rate of the topmost ear associated with tassel removal for PGR, between 1.5 to 3 g plant⁻¹ d⁻¹ (Fig. 4b) was associated with an increase in KN₁ per unit of plant growth rate (Fig. 4a). There were no differences (P > 0.05) in the radiation profile of detasseled and control plants in both hybrids (data not shown). The positive effect of tassel removal on kernel number in the older hybrid and the lack of response in the newer hybrid may be associated with differences in tassel size between the two hybrids. Although tassel size was not measured in this study, this trait has been shown to decline from older to newer U.S. hybrids (e.g., Tollenaar et al., 2000). Improved synchronization in floret fertilization can reduce competition among kernels within the ear and reduced competition may result in an increase in kernel set (Carúco et al., 2000; Carúco and Otegui, 2001). Increased synchronization of fertilization, however, did not improve kernel set per unit EGR, in either hybrid (P > 0.05, data not shown). In addition, the minimum assimilate requirement per kernel (Edmeades and Daynard, 1979; Edmeades et al., 1993; Vega et al., 2001a)
was not significantly different between hybrids ($P > 0.05$).

CONCLUSIONS

Results reported in the current study elucidate the mechanisms involved in differences in kernel set between older and newer hybrids. Newer Argentinean hybrids set more kernels per unit PGR than older Argentinean hybrids as indicated by (i) the lower threshold PGR, for kernel set and (ii) the greater potential kernel number at high availability of resources per plant, for newer than for older hybrids. At low and intermediate PGR, the greater kernel set per unit of PGR in newer vs. older hybrids was attributable to a greater partitioning of dry matter to the topmost ear during the period bracketing silking, whereas the number of kernels set per unit of ear growth did not differ. The KN, response to detasseling in the older hybrid, but not in the newer one, and the lack of KN, response to synchronous pollination in both hybrids supported this contention. In contrast, kernel set per unit of ear growth rate was greater in newer than in older hybrids when PGR was high. The greater partitioning of dry matter to the ear in newer hybrids will contribute to greater yield stability and harvest index stability relative to those of older hybrids when resources per plant decreases. In addition, the greater partitioning of dry matter to the ear and the greater number of kernel set per unit of ear growth rate at high PGR, for newer than for older hybrids will contribute to greater yield in newer than in older hybrids grown at low plant density or in case of an irregular plant stand (i.e., gaps in the row). The failure of others to show a significant difference between older and newer hybrids in the threshold PGR for kernel set to EGR about 0.5 g d$^{-1}$ (Fig. 3b).

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