

Transplant and a change in plant density improve sweet maize (*Zea mays* L.) yield

J. Rattin¹, J.P Valinote¹, R. Gonzalo¹, A. Di Benedetto^{1-2*}

¹Faculty of Agricultural Sciences, National University of Mar del Plata, Route 226, km. 73.5 (B7620ZAA), Balcarce, Province of Buenos Aires, Argentina.

²Faculty of Agronomy, University of Buenos Aires, Avenida San Martín 4453 (C1417DSE), Buenos Aires, Argentina.

Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

E-mail address: dibenede@agro.uba.ar (A. Di Benedetto)

ABSTRACT

Aims: Due the effect of a transplant routine on the maize plant morphology and population stand, the aim of the experiment was to determine the combined effects of three plant densities and the use of transplant on commercial yield for two sweet maize hybrids.

Study design: Canner (*su1*) and Butter Sweet (*shrunk-2*) hybrids were sown, at the same time, by direct seeded or in plastic plug trays (128 cell tray⁻¹) for transplant in middle spring and were grown under 4, 8 and 12 plants m⁻² plant densities.

Place and Duration of Study: Experiment was conducted at the INTA Balcarce Experimental Station, Argentina (37° 45' S, 58° 18' W) during the 2005-2006 and repeated during 2006-2007 growing seasons.

Methodology: Plants from direct-seeded or transplant were grown at three plant densities under a field environment. A randomized complete factorial design with three blocks was used.

Results: Results showed that transplant increase light interception and radiation use efficiency; the changes in dry weight accumulation in behalf of ears determine an increase in harvest index and yield plant⁻¹. An increase in plant density at 12 plants m⁻² would let to obtain an increase in yield ha⁻¹ as well.

Conclusion: Morphological changes which let a change in both crop architecture and yield per ha⁻¹ justify an increase in transplanted sweet maize plant density.

Keywords: harvest index, light interception, plant density, radiation use efficiency, transplant, *Zea mays*.

1. INTRODUCTION

In recent years, optimum populations for field corn in temperate climates have ranged from 79,000 to 84,000 plants ha⁻¹ [1, 2]). Such densities exceed the populations densities appropriate for sweet corn. However, Williams [3] has indicated that populations for maximum sweet corn yield vary greatly depending of the hybrid, ranging from 48,100 to 70,200 plants ha⁻¹. Although it has been indicated that transplant decreases sweet maize yield [4, 5], we have previously found that yield (g fresh weight plant⁻¹) was not significantly different between direct-seeded and transplanted plants grown at low or high populations [6, 7]. Recently, Sánchez Andonova et al. [8] showed that transplanted plants increased light interception, harvest index, and yield per unit area than direct-seeded ones.

In maize, plant density has important effects on partitioning of dry matter between vegetative and reproductive structures. Tolerance to high plant populations, along with tolerance to other biotic and abiotic stresses, and the improved resource use efficiency, constitute the determinant parameters, which contribute to improved productivity. Maize canopy was highly sensitive to plant spatial arrangement. Among canopy components, leaf growth and leaf azimuthal distribution were the traits most affected by treatments. Both processes (i.e., growth and orientation) were affected by plant perception of neighbour shoots before significant mutual shading took place, suggesting that plants have a fast reaction to the light environment [9].

In the course of development the architecture of the stand may differ, not only between varieties, also within the same variety, leading to differences in the distribution of radiation within the stand, which in turn may be responsible for differences in yield per unit area. Any alteration in plant architecture influences the energy balance of the canopy. Because of the change in plant density caused by the change in leaf area and its vertical distribution, the radiation properties may have been modified as well [10]; the amount of energy intercepted by the crop at flowering has been correlated with the allocation to reproductive structures. Plant density affected both the fraction of incident radiation that was intercepted by the crop and kernel number [11].

Radiation is the key driving force under non-limiting crop management. For analysing this, three important indices could be indicated: (i) the fraction of radiation intercepted, (ii) radiation use efficiency (RUE) and (III) harvest index (HI). Moreover, accumulation of maize dry matter was more closely related to the amount of radiation absorbed by the crop than to RUE and HI, which has largely remained constant between 0.49 and 0.51 [12].

Due the effect of a transplant routine on the maize plant morphology and population stand [13, 14, 8], the aim of the experiments was to determine the combined effects of three plant densities and the use of transplant on commercial yield for two sweet maize hybrids in a marginal maize production area to test the hypothesis that a higher plant density would increase yield on a area basis.

2. MATERIALS AND METHODS

2.1. Plant Material, Treatments and Experiments

The experiment was conducted at the INTA Balcarce Experimental Station, Argentina (37°45'S, 58°18'W) from 25th October 2005 to 21th February 2006 on a Typic Argiudoll soil with an organic matter of 5.6% in the first 25 cm depth. The experiment was repeated from 7th November 2006 to 28th February 2007. Water and nutrients were at non-limiting levels using an irrigation system which kept soil water above 50% of maximum soil available water in the first meter of depth. The experimental field was fertilized with 150 kg N ha⁻¹ (18-46-0) at the beginning of experiments. Weeds and insects were adequately controlled.

The maize mutant hybrids 'Canner' (*su1*) and 'Butter Sweet' (*sh2*) provided by Semillera Basso (Argentina) were sown in plastic plug trays (128 cells tray⁻¹; 17.37 cm³ cell⁻¹) using a commercial

growing media or direct-seeded. Transplanted plants were grown under greenhouse facilities from sowing to transplant. Transplants were conducted by hands. Final population densities were 40,000; 80,000 and 120,000 plants ha⁻¹.

2.2. Field environment

Weather records (daily maximum-minimum air temperature and global solar radiation) were recorded from a meteorological station 500 meters from the experimental site. The air temperatures ranged between 7.12-14.15°C (minimum) and 17.01-25.74°C (maximum) during the 2005-2006 experiment and between 7.61-14.15°C (minimum) and 18.99-27.43°C (maximum) during the 2006-2007 experiment. Light ranged between 17.43 and 23.69 MJ m⁻² day⁻¹ during the 2005-2006 experiment and between 16.05 and 23.17 MJ m⁻² day⁻¹ during the 2006-2007 experiment (Table 1).

Table 1: Daily solar radiation and maximum and minimum temperatures during the experiments. Monthly means for 2005-2006 and 2006-2007 experiments are plotted.

	Temperature (°C)		Irradiance (MJ m ⁻² day ⁻¹)
	Maximum	Minimum	
2005-2006			
October	17.01	7.12	17.43
November	23.64	10.36	20.50
December	23.69	10.81	23.69
January	25.74	12.96	22.66
February	25.12	14.15	19.00
2006-2007			
October	18.99	7.61	16.05
November	20.41	10.68	18.00
December	25.98	13.81	21.85
January	27.43	13.68	23.17
February	25.81	15.05	20.57

2.3. Growth Evaluations

At each harvest, plant height, individual leaf area [using a leaf area meter LI-COR FL16 (LI-COR Inc., Lincoln, NE, USA)], expanded leaves were recorded. Dry matter accumulation was determined by taking plant samples at E-T (emergence-transplant) and V₄, V₇, V₉, V_T and R₃ stages. The sample size was ten plants per block. Plants were cut at ground level, separated in stems, leaves and ears and oven dried at 80°C for ten days and weighed.

Photosynthetic active radiation (PAR) interception percentage, radiation use efficiency and growth parameters such as the relative growth rate (RGR), the rate of leaf area expansion (RLAE), the mean net assimilation rate (NAR) and the leaf area ratio (LAR) were calculated according to Sánchez Andonova et al. [8].

2.4. Statistical Analysis

We used a randomized complete factorial design with three blocks of four rows of 10 m (0.70 m apart) for each treatment; six replications were used. Data were subjected to one way ANOVA and

means were separated by Tukey's test ($P = 0.05$). Regression slopes were tested for parallelism (test for equal slope) [15].

3.1. RESULTS

3.1. Seedling emergence

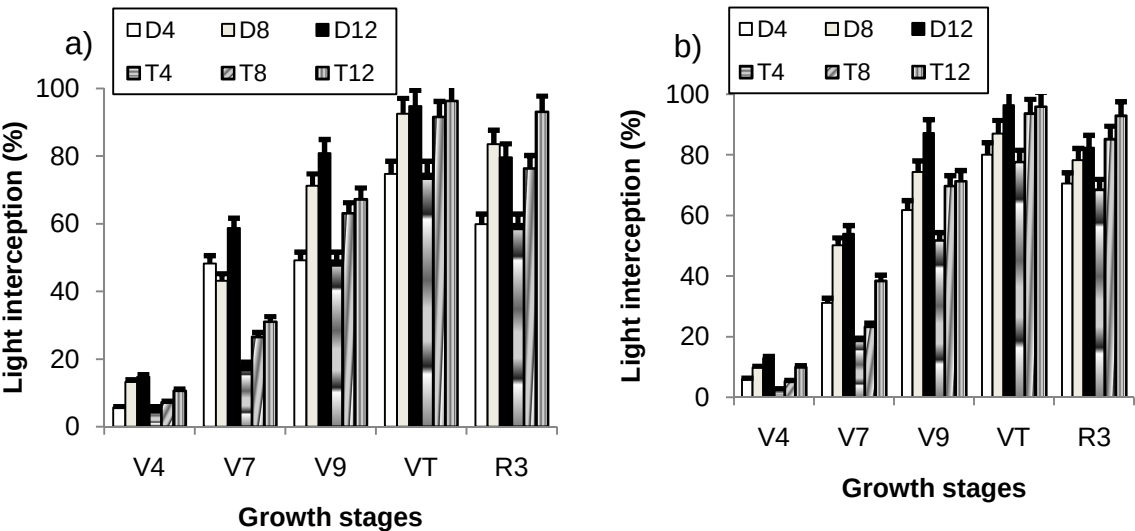
There were no significant seedling emergence percentage differences between densities for the two maize hybrids tested but when transplant vs. direct seeded were evaluated, significant differences behalf transplant were found (Table 2).

Table 2. Seedling emergence (%) for two sweet maize mutants under transplant or direct seeded at three plant densities (4, 8 and 12 plants m^{-2})(data are the main of two years: 2004-2005 and 2006-2007) (n = 6). Lower case letters indicate statistically significant differences ($P < .05$) among sowing routines for each sweet maize hybrid tested.

Hybrids	Seedling emergence (%)			
	Transplant	Direct seeded		
		4 plants m^{-2}	8 plants m^{-2}	12 plants m^{-2}
'Canner'	82.50 ^a	73.86 ^b	77.27 ^b	74.90 ^b
'Butter Sweet'	80.46 ^a	72.72 ^b	75.00 ^b	77.57 ^{ab}

3.2. Light interception

Crop light interception increased between the V_4 to pre anthesis (V_T) stages but slightly decreased to the R_3 stage for all 'Canner' and 'Butter Sweet' plant densities and cropping routines tested ($P < .001$). The lower values for the low density (4 plants m^{-2}) independently both the plant genotype and cropping routines (direct seeded vs. transplant) were found (Figure 1). There were no significant significance between transplant and direct seeded related to genotype and the two yearly experiments. On other hand, the effect of density was highly significant ($P < .001$).



ANOVA	
Significantly	
Sowing routine	***
Density	***
Hybrids	ns
Year	ns
Sowing routine x density	***
Sowing routine x hybrids	ns
Sowing routine x years	ns
Density x hybrids	ns
Density x years	ns
Hybrids x year	ns

Significance *** 0.001 'ns' No significant

Fig. 1. Light interception from earlier (V_4 and V_9) and later (V_T and R_3) stages for two 'Canner' (a) and 'Butter Sweet' (b) sweet maize mutants under direct-seeded (D) or transplant (T) method and three plant densities (4, 8 and 12 plants m^{-2}) (data are the mean of two years: 2005-2006 and 2006-2007) ($n = 6$). Standard errors are indicated. The significance of interactions (ANOVA) has been indicated as well.

3.3. Plant architecture

Plant height was higher for plants grown at a 4 plants m^{-2} density for the two sweet maize tested. We found significant differences ($P < .01$) only for the single Density effect and double effect Sowing routine x Density ($P < .05$) (Table 3).

Table 3: Changes in plant height, leaf number, total leaf area and RLAE at the R_3 stages for two sweet maize mutants either under a direct seeding or transplant routine at three plant densities (data are the mean of two years: 2005-2006 and 2006-2007) ($n = 6$). Lower-case letters indicate statistically significant differences ($P = .05$) between the three plant densities tested while capital letters indicate statistically significant differences ($P = .05$) between direct-seeded and transplanted plants for each sweet maize hybrid. The probability of the RLAE slope being zero was $P = .001$. The significance of interactions (ANOVA) has been indicated as well.

	Plant height (cm plant ⁻¹)		Leaf number (leaves plant ⁻¹)		Leaf area (cm ² plant ⁻¹)		RLAE (cm ² cm ⁻² day ⁻¹)	
	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'
Direct-seeded								
4 plants m^{-2}	200,66 ^{aA}	188,66 ^{aA}	9.88 ^{aA}	10.00 ^{aA}	3992 ^{aA}	4201 ^{aA}	0.080 ^{aA}	0.078 ^{aA}
8 plants m^{-2}	180,50 ^{bA}	180,50 ^{bA}	9.87 ^{aA}	10.66 ^{aA}	3646 ^{bA}	4059 ^{bA}	0.078 ^{bA}	0.070 ^{bA}
12 plants m^{-2}	174,00 ^{bA}	176,66 ^{bA}	9.67 ^{aA}	10.00 ^{aA}	3197 ^{cA}	3891 ^{cA}	0.075 ^{cA}	0.060 ^{cA}
Transplant								
4 plants m^{-2}	202,16 ^{aA}	187,50 ^{aA}	8.55 ^{aB}	8.55 ^{aB}	3421 ^{aB}	4230 ^{aA}	0.074 ^{aB}	0.067 ^{aB}
8 plants m^{-2}	184,83 ^{bA}	178,66 ^{bA}	8.45 ^{aB}	8.44 ^{aB}	3271 ^{bB}	3792 ^{bB}	0.070 ^{bB}	0.060 ^{bB}
12 plants m^{-2}	179,10 ^{bA}	174,30 ^{bA}	9.00 ^{aB}	8.61 ^{aB}	2923 ^{cB}	3516 ^{cB}	0.065 ^{cB}	0.056 ^{cB}

ANOVA				
Significantly				
	Plant height	Leaf number	Leaf area	RLAE
Sowing routine	ns	***	**	***
Densities	**	ns	***	***
Hybrids	ns	ns	ns	ns
Year	ns	ns	ns	ns
Sowing routine x densities	*	*	***	***
Sowing routine x hybrids	ns	*	ns	ns
Sowing routine x years	ns	ns	ns	ns
Density x hybrids	ns	ns	ns	ns
Density x years	ns	ns	ns	ns
Year x hybrids	ns	ns	ns	ns

Significance *** 0.001 ** 0.01 * 0.05 'ns' No significant

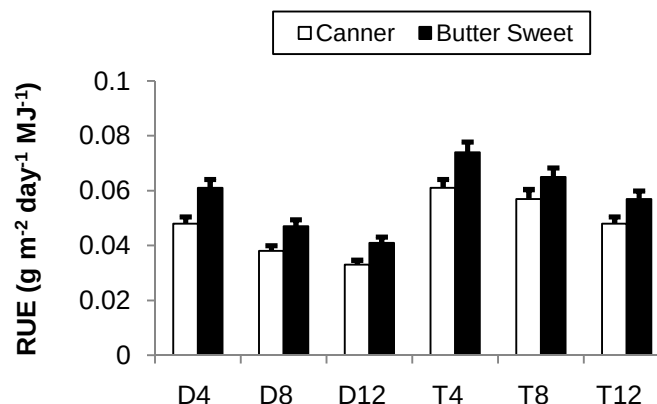
Leaf number per plant at the R₃ stage did not show significant differences for 'Canner' or 'Butter Sweet' plants between the three plant densities tested but significant differences ($P < .001$) between direct-seeded and transplant (Table 3). However, 'Butter Sweet' plants from direct-seeded had the higher values at all plant densities tested related to transplant lots. There were no significant differences related to genotype and year.

Direct-seeded 'Canner' sweet corn plants showed higher photosynthetic leaf area ($\text{cm}^2 \text{ plant}^{-1}$) at the R₃ stages for the three plant densities tested and related to the transplanted plants. An increase in plant density determined a leaf area decrease for either transplanted or direct-seeded plants (Table 3). There was statistically significances for showing routine ($P < .05$), densities, and densities x hybrids ($P < .01$) but no significances for year or hybrids.

Relative leaf area expansion rate (RLAE) was higher when a 4 plants m^{-2} was used and significantly decreased with a density increase for both hybrids tested. On the other hand, direct-seeded plants showed the highest RLAE (Table 3). High significant ($P < .001$) single effects for Sowing routine and Density were found.

3.3. Radiation use efficiency

Radiation use efficiency (RUE) (Figure 2) increased with plant density and was higher for transplants than for direct-seeded plants when 'Canner' hybrid was tested; 'Butter Sweet' hybrid only showed statistical significant differences between the two sowing routines at the higher plant density (12 plants m^{-2}). There were no significant differences related to hybrids and year.



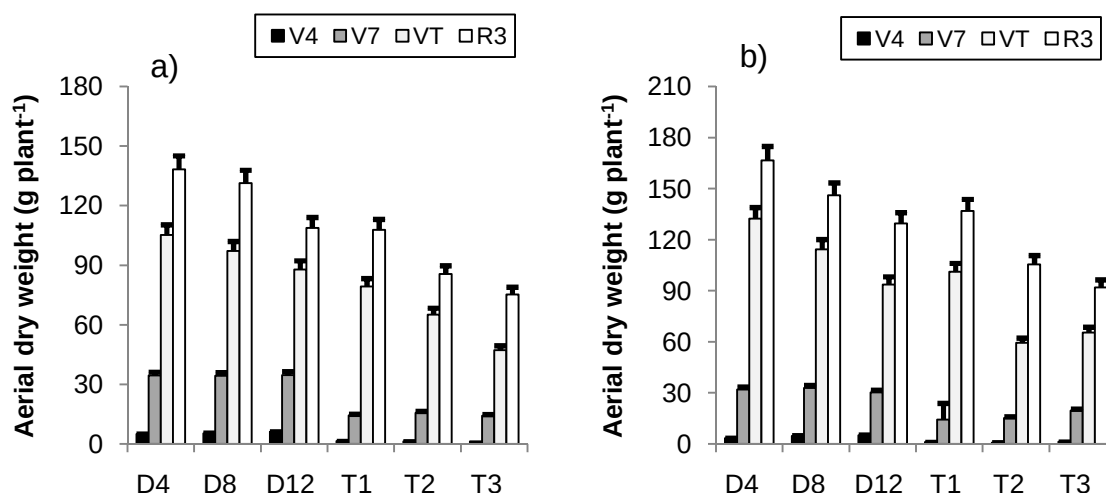
ANOVA	
Significantly	
Sowing routine	***
Density	***
Hybrids	***
Year	ns
Sowing routine x densities	***
Sowing routine x hybrids	***
Sowing routine x years	ns
Density x hybrids	***
Density x years	ns
Hybrids x year	ns

Significance *** 0.001 'ns' No significant

Fig. 2. Radiation Use Efficiency ($\text{g m}^{-2} \text{ día}^{-1} \text{ MJ}^{-1}$) for two sweet maize mutants under direct seeded (D) or transplant (T) at three plant densities (4, 8 y 12 plants m^{-2})(data are the main of two years: 2005-2006 and 2006-2007) (n = 6). Standard errors are indicated. The significance of interactions (ANOVA) has been indicated as well.

3.4. Dry weight accumulation

'Canner' plants established through direct-seeded showed higher aerial total dry weight accumulation for all the developmental stages tested related to transplanted plants (Figure 3a); the higher plant density the lower aerial dry weight (g plant^{-1}). Although a similar response for 'Butter Sweet' hybrid was found, differences between sowing routines and plant density were higher as well (Figure 3b). We found highly showing routine, density and hybrid effects ($P < .001$) but not differences related to year.



ANOVA	
Significantly	
Sowing routine	***
Density	***
Hybrids	***
Year	ns
Sowing routine x densities	***
Sowing routine x hybrids	***
Sowing routine x years	ns
Density x hybrids	***
Density x years	ns
Hybrids x year	ns

Significance *** 0.001 'ns' No significant

Fig. 3. Aerial dry weight accumulation from earlier (V_4 and V_9) and later (V_T and R_3) stages for 'Canner' (a) and 'Butter Sweet' (b) sweet maize mutants under direct-seeded (D) or transplant (T) at three plant densities (4, 8 and 12 plants m^{-2}) (data are the main of two years: 2005-2006 and 2006-2007) ($n = 6$). Standard errors are indicated. The significance of interactions (ANOVA) has been indicated as well.

When the dry weight results for 'Canner' sweet corn were partitioned to shoot, leaves and ear (Table 4), we found higher dry matter in shoots at intermediate plant densities when plants were direct-seeded; significant differences started from the V_T stage. There were no significant differences for leaf dry weight and ear dry weight and only a decrease at the higher plant density tested (12 plants m^{-2}) was found. Transplanted plants showed no differences in shoot and leaves dry weight between plant densities, but absolute values were the half for the direct-seeded plants. Ear dry weight decreased when plant density increased too. 'Butter Sweet' dry weight partitioning were some different than for 'Canner' (Table 3). Direct-seeded plants showed higher shoot dry weight at the low plant density tested (4 plants m^{-2}) and lower or no differences for ears and leaves dry weight, respectively were found. The most important dry weight changes in transplanted plants were associated with the ear dry gain. Differences between direct-seeded and transplanted dry gain were similar to the observed from the 'Canner' hybrid. We found highly showing routine, density and hybrid effects ($P < .001$) for shoot and leaf dry weight.

There are no significant differences in relative growth rate (RGR) between direct-seeded plants than in transplanted ones; however, the higher plant density the lower RGR. The last, was the result of significant higher net assimilation rate (NAR) from transplanted plants and lesser significant values for leaf area ratio (LAR) (Table 5). There were highly significant differences ($P < .001$) for the single NAR ($P < .001$) and LAR ($P < .01$) Sowing routine effect and RGR, NAR and LAR Density ($P < .001$).

Table 4. Dry weight (g plant⁻¹) partitioned as shoot, leaves and ear for two sweet maize mutants either under a direct seeding or transplant routine at three plant densities (data are the mean of two years: 2005-2006 and 2006-2007) (n = 6). The significance of interactions (ANOVA) has been indicated as well.

	Shoot dry weight (g plant ⁻¹)				Leaf dry weight (g plant ⁻¹)				Ear dry weight (g plant ⁻¹)	
	V ₄	V ₇	VT	R ₃	V ₄	V ₇	VT	R ₃	VT	R ₃
'Canner'										
Direct seeded										
4 plants m ⁻²	1.88	14.01	46.56	39.78	3.20	20.52	27.66	33.10	30.95	65.32
8 plants m ⁻²	2.00	14.44	47.36	56.39	3.45	19.94	25.46	29.31	24.38	65.60
12 plants m ⁻²	2.35	13.81	40.68	40.52	3.82	20.95	26.38	23.25	20.81	44.89
Transplant										
4 plants m ⁻²	0.41	4.00	24.57	23.85	1.04	9.40	17.87	16.43	36.90	67.50
8 plants m ⁻²	0.46	5.66	20.32	20.79	0.96	10.05	16.12	16.05	28.76	48.82
12 plants m ⁻²	0.39	4.77	17.94	20.74	0.88	9.43	13.64	14.86	15.58	39.63
'Butter Sweet'										
Direct seeded										
4 plants m ⁻²	1.17	11.85	74.92	62.78	2.16	20.17	25.63	30.45	31.73	73.32
8 plants m ⁻²	1.59	12.21	58.96	51.15	3.13	20.46	31.82	33.33	23.64	56.90
12 plants m ⁻²	1.82	11.24	43.20	34.73	3.32	19.03	25.63	31.40	24.79	63.48
Transplant										
4 plants m ⁻²	0.37	6.19	32.83	32.54	0.73	8.13	22.50	22.56	45.79	81.75
8 plants m ⁻²	0.27	4.71	22.84	26.85	0.56	10.57	16.75	21.75	19.75	56.09
12 plants m ⁻²	0.41	6.88	24.29	22.92	0.83	12.76	16.47	18.92	24.62	50.08

ANOVA			
Significantly			
	Shoot dryweight	Leaf dry weight	Ear dry weight
Sowing routine	***	***	*
Density	***	***	**
Hybrids	***	*	*
Year	ns	ns	ns
Sowing routine x density	***	***	**
Sowing routine x hybrids	***	**	**
Sowing routine x years	ns	ns	ns
Density x hybrids	***	*	*
Density x years	ns	ns	ns
Year x hybrids	ns	ns	ns

Significance *** 0.001 ** 0.01 * 0.05 'ns' No significant

Table 5. Relative growth rate (RGR), net assimilation rate (NAR) and leaf are ratio (LAR) for 'Canner' and 'Butter Sweet' sweet maize mutants either under a direct seeding or transplant routine (data are the mean of two years: 2005-2006 and 2006-2007) (n = 6). Lower-case letters indicate statistically significant differences ($P = .05$) between the three plant densities tested while capital letters indicate statistically significant differences ($P = .05$) between direct-seeded and transplanted plants for each sweet maize hybrid. The probability of the slope being zero was $P = .001$ for all growth parameters. The significance of interactions (ANOVA) has been indicated as well.

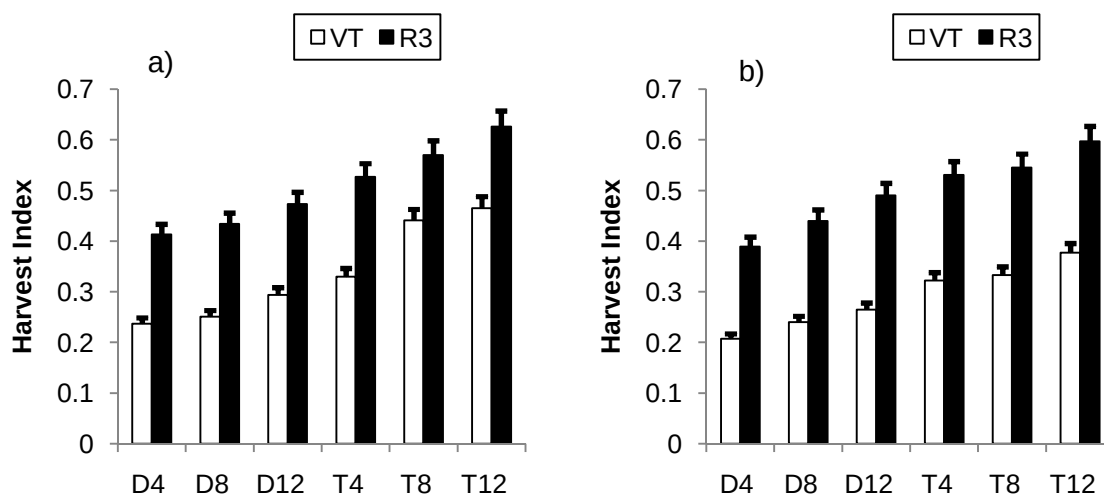
	RGR (g g ⁻¹ day ⁻¹)		NAR (g cm ⁻² day ⁻¹)		LAR (cm ² g ⁻¹)	
	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'
Direct-seeded						
4 plants m ⁻²	0.0599 ^{aA}	0.0658 ^{aA}	0.0036 ^{aA}	0.0027 ^{aA}	18.59 ^{bB}	22.97 ^{aB}
8 plants m ⁻²	0.0597 ^{aA}	0.0625 ^{bA}	0.0032 ^{aA}	0.0027 ^{aA}	16.63 ^{cB}	24.25 ^{aB}
12 plants m ⁻²	0.0566 ^{bA}	0.0602 ^{cA}	0.0028 ^{bA}	0.0026 ^{aA}	20.35 ^{aB}	23.29 ^{aB}
Transplant						
4 plants m ⁻²	0.0610 ^{aA}	0.0656 ^{aA}	0.0022 ^{aB}	0.0021 ^{aB}	27.85 ^{cA}	31.55 ^{cA}
8 plants m ⁻²	0.0590 ^{bA}	0.0634 ^{bA}	0.0020 ^{aB}	0.0017 ^{bB}	29.81 ^{bA}	33.53 ^{bA}
12 plants m ⁻²	0.0573 ^{cA}	0.0612 ^{cA}	0.0017 ^{bB}	0.0018 ^{bB}	33.47 ^{aA}	37.44 ^{aA}

ANOVA			
Significantly			
	RGR	NAR	LAR
Sowing routine	ns	***	**
Density	***	***	***
Hybrids	ns	ns	ns
Year	ns	ns	ns
Sowing routine x density	ns	***	***
Sowing routine x hybrids	ns	**	***
Sowing routine x years	ns	ns	ns
Density x hybrids	*	*	*
Density x years	ns	ns	ns
Year x hybrids	ns	ns	ns

Significance *** 0.001 ** 0.01 * 0.05 'ns' No significant

3.5. Harvest Index

Harvest index increased with plant density between either at the V_T as the R₃ stages and when a transplant routine was used (Figure 3). The same response pattern for the two hybrid tested ('Canner' and 'Butter Sweet') was found. There were high significant differences ($P < .001$) for Sowing routine and Density effects, but no significance related to hybrids and year on harvest index.



ANOVA	
Significantly	
Sowing routine	***
Density	***
Hybrids	***
Year	ns
Sowing routine x densities	***
Sowing routine x hybrids	***
Sowing routine x years	ns
Density x hybrids	***
Density x years	ns
Hybrids x year	ns

Significance *** 0.001 'ns' No significant

Fig. 4. Changes in Harvest Index from V₁ to R₃ stages for ‘Canner’ (a) and ‘Butter Sweet’ (b) sweet maize mutants under direct-seeded (D) or transplant (T) at three plant densities (4, 8 and 12 plants m⁻²) (data are the mean of two years: 2005-2006 and 2006-2007) (n = 6). Standard errors are indicated. The significance of interactions (ANOVA) has been indicated as well.

3.6. Yield

Higher ear kernel number for the ‘Canner’ hybrid was found at the lower plant density (4 plants m⁻²) for both direct-seeded and transplanted plants; differences were associated to kernel number per row (Table 6). On the other hand, the higher plant density the lower ear kernels number. We found high significant differences ($P < .001$) for Density and Sowing routine ($P < .05$) (Table 6).

Table 6: Changes in number of rows per ear and both number of kernels per row and ear at R₃ stage for ‘Canner’ and ‘Butter Sweet’ sweet maize mutants under either a direct seeding or transplant routine (data are the mean of two years: 2005-2006 and 2006-2007) (n = 6). Lower-case letters indicate statistically significant differences ($P = .05$) between the three plant densities tested while capital letters indicate statistically significant differences ($P = .05$) between direct-seeded and transplanted plants for each sweet maize hybrid.

	Rows per ear		Kernel per row		Kernels per ear	
	‘Canner’	‘Butter Sweet’	‘Canner’	‘Butter Sweet’	‘Canner’	‘Butter Sweet’
Direct-seeded						
4 plants m ⁻²	17.1 ^{aA}	17.0 ^{aA}	42.3 ^{aA}	45.7 ^{aA}	719.1 ^{aA}	630.8 ^{aB}
8 plants m ⁻²	17.3 ^{aA}	16.0 ^{aA}	30.0 ^{bA}	45.7 ^{aA}	510.3 ^{bB}	533.0 ^{bB}
12 plants m ⁻²	17.7 ^{aA}	17.1 ^{aA}	29.7 ^{bB}	36.7 ^{bB}	525.7 ^{bB}	607.6 ^{aA}
Transplant						
4 plants m ⁻²	16.3 ^{aA}	16.3 ^{aA}	38.7 ^{aA}	44.0 ^{aA}	776.9 ^{aA}	717.2 ^{aA}
8 plants m ⁻²	16.3 ^{aA}	16.6 ^{aA}	32.7 ^{bA}	38.3 ^{aB}	731.2 ^{aA}	612.8 ^{bA}
12 plants m ⁻²	15.7 ^{aA}	16.7 ^{aA}	38.7 ^{bA}	41.0 ^{aA}	623.9 ^{bA}	684.7 ^{aA}

ANOVA			
Significantly			
	Rows per ear	Kernel per row	Kernels per ear
Sowing routine	ns	*	*
Density	ns	*	**
Hybrids	ns	*	*
Year	ns	ns	ns
Sowing routine x density	ns	*	*
Sowing routine x hybrids	ns	*	*
Sowing routine x years	ns	ns	ns
Density x hybrids	ns	*	*
Density x years	ns	ns	ns
Year x hybrids	ns	ns	ns

Significance ** 0.01 * 0.05 'ns' No significant

Table 7: Earl yield for 'Canner' and 'Butter Sweet' sweet maize mutants at the R₃ stage under either a direct seeding or transplant routine (data are the mean of two years: 2005-2006 and 2006-2007) (n = 6). Lower-case letters indicate statistically significant differences (*P* = .05) between the three plant densities tested while capital letters indicate statistically significant differences (*P* = .05) between direct-seeded and transplanted plants for each sweet maize hybrid. Yield (ton fresh weight ha⁻¹) was calculated as the product of ear fresh dry weight by ear number on an area basis (ha⁻¹). Ear number in direct-seeded plants was decreased by germination-emergence losses (Table 2). Mean pos-transplant losses were 2% and 3% for 'Canner' and 'Butter Sweet' respectively.

	Yield (g fresh weight plant ⁻¹)		Yield (ton fresh weight ha ⁻¹)	
	'Canner'	'Butter Sweet'	'Canner'	'Butter Sweet'
Direct-seeded				
4 plants m ⁻²	427.0 ^{aA}	485.7 ^{aB}	12.6 ^{bB}	14.1 ^{cB}
8 plants m ⁻²	425.3 ^{aB}	420.8 ^{bA}	26.3 ^{aA}	25.3 ^{bB}
12 plants m ⁻²	305.7 ^{bA}	339.6 ^{cB}	27.5 ^{aB}	31.6 ^{aB}
Transplant				
4 plants m ⁻²	423.6 ^{aA}	515.7 ^{aA}	16.9 ^{cA}	20.6 ^{cA}
8 plants m ⁻²	317.3 ^{bA}	364.4 ^{bB}	25.4 ^{bA}	29.2 ^{bA}
12 plants m ⁻²	322.9 ^{bA}	372.3 ^{bA}	38.8 ^{aA}	44.7 ^{aA}

ANOVA		
Significantly		
	Yield (plant ⁻¹)	Yield (ha ⁻¹)
Sowing routine	**	***
Density	***	***
Hybrids	ns	*
Year	ns	ns
Sowing routine x density	**	***
Sowing routine x hybrids	*	**
Sowing routine x years	ns	ns
Density x hybrids	*	**
Density x years	ns	ns
Year x hybrids	ns	ns

Significance *** 0.001 ** 0.01 * 0.05 'ns' No significant

Earl yield (g fresh weight plant⁻¹) decreased when plant density increased with differences between direct-seeded vs. transplanted plants or hybrid tested (Table 7). On the other hand, yield (ton fresh weight ha⁻¹) which were estimated using earl yield and germination rates for direct-seeded lots, showed an increase with plant density for the both 'Canner' and 'Butter Sweet'. A similar response for the transplant lots was found. Significant yield differences (ton fresh weight ha⁻¹) between direct-seeded and transplant were found as well. Higher significant differences (*P* < .001) for Sowing routine and Density effects were found.

4. DISCUSSION

The primary objective for transplanting has been early maturity; other advantages include ensured adequate crop establishment of commercial plantings of various high-value vegetable crops [16, 17], reduced cost over direct seeding when using expensive hybrid seed, improved land use efficiency, extension of a short growing season, and improved early weed control. Previously, it has been indicated that transplant decrease sweet maize plant yield [5, 4] but, others authors [6, 7, 8] showed that there was no significant yield (g fresh weight plant⁻¹) differences between direct seeded and transplanted plants. Our results (Table 7) are in agreement with the most recent information.

Inadequate temperature, which is common following seeding in short-season areas, reduces both seedling emergence and leaf appearance rates and makes seeds and seedlings susceptible to disease organisms, leading to reduction in seedling vigour. Data from [6] showed best germination percentages from plastic plug trays and greenhouse cropping before transplant related to direct-seeded which are a pre-requisite for higher plant stand at harvest. Data of seedling emergence from Table 2 are in agreement with Rattin et al. [6].

Although, a limited plug tray volume from sowing gives a vertical root restriction which it has been previously documented [7], Sanchez Andonova et al. [8] showed that transplant do not decrease yield of each individual plant at a density of 8 plants m⁻². In recent years, optimum populations for field corn in temperate climates have ranged from 79,000 to 84,000 plants ha⁻¹ [1, 2]). Such densities exceed the populations densities appropriate for sweet corn. However, Williams [3] has indicated that populations for maximum sweet corn yield vary greatly depending of the hybrid, ranging from 48,100 to 70,200 plants ha⁻¹. Our results (Table 7) showed that commercial sweet corn yield per unit area can be increased through a transplant routine, at least, when a 120,000 plants ha⁻¹ plant density was used.

Plant height and leaf area are important in determining the percentage of solar radiation intercepted by a plant and it therefore influences plant growth and final yield. At supra optimal densities, the efficiency of the crop to convert intercepted PAR at flowering into grain sink capacity decreases. Intercepted PAR can be used to estimate potential total crop growth because these two variables are linearly related. However, as plant density increase above the optimal density and resources per plant decrease, partitioning to the ear is considerably reduced [11]. A lower both plant height and leaf area from transplanted plants let to increase plant density (Table 3). Figure 1 showed that a close intercepted PAR only is achieved during the short period of V_T (pre-anthesis phase) for the highest plant density as a result of higher RLAE. Leaf-appearance rates usually were lower at higher plant densities for field corn [18]; our data (Table 3) are not in agreement because there were no significant differences in leaf number between plant density for the two sweet maize hybrids tested; however, leaf number decreased when a transplant routine was used for 'Butter Sweet' maize hybrid. It has been indicated [19] that corn hybrids grown, in short-seasons areas such as the used for our experiments, have smaller leaf area indices, leading to lower dry matter accumulation than in hybrids grown in long-season areas, mainly because of their reduced leaf number and size. 'Canner' and 'Butter Sweet' hybrids leaf area per plant were clearly lower at higher plant densities (Table 3); but this result would be associated only with a leaf size decrease.

Since most maize genotypes tiller to only a small extent and have low reproductive and foliar plasticity when density is decreased, growth at low densities could be limited by a shortage of sinks (Fig. 3). By the other hand, such a limitation could cause assimilates to accumulate to the point that they depress photosynthesis and consequently RUE (Figure 2), with a greater response when transplant sowing routine was used. When the dry accumulation changes over time were separated in shoots, leaves and ears, a clear greater accumulation in ears was seen (Table 4); the effect was greater for transplant sowing routine. As dry matter accumulation for maize has been related to PAR interception and RUE; it has been expected that density determine large effects on dry matter partitioning between vegetative and reproductive structures such as the observed from Table 4.

Emam [20] has showed that the most sensitive yield component of maize hybrids to plant population density was the kernel number/ear and sensitivity of kernel number/ear row was slightly less than kernel number/ear. The hypothesis that the lower assimilate supply resulted from reduced light interception at higher densities has been the main reason for abortion of kernels especially at the ear tip is a good explanation for direct-seeded plants kernel number/ear (Table 6), but the fact that at the time which kernel number/ear row was determined, the competition among sinks for assimilate has been the main limiting factor to kernel number/ear row could be not be true for transplanted plants. On the other hand, kernel row number/ear of non-prolific corn hybrids appeared to be stable in response to increasing plant population density and had a negligible effect in plant yield adjustment. Since the row number of kernel on shoot apex is determined earlier than other yield components (e.g. ear number plant⁻¹), it could be suggested that during that period, the competition among sinks (i.e., florets) for assimilate has not been a considerable limiting factor.

Increases in grain yield in maize hybrids have resulted from increased dry matter accumulation because the HI has largely remained constant between 0.49 and 0.51 [12, 21]. Increased plant population density also tends to result in lower HI, but within the normal range of commercial crop densities, such reductions rarely exceed 10% of the optimum value [22]. By the other hand, Sarlangue et al. [23] have shown that short-season hybrids would be more prone to show a limitation of growth by reproductive sink capacity at low plant densities. At higher plant densities, this reproductive sink limitation would have been alleviated and harvest index increased. Results from our experiments conducted in a marginal maize production area (Balcarce-Argentina) are in agreement with Sarlangue and co-workers [23] and showed that although dry weight ear accumulation are around 40-50%, the transplant routine and the higher plant density increased HI (Fig. 4) and RUE (Fig. 2). These changes would be explained for the lesser leaf area expanded for the transplanted plants (Table 3) in agreement with Jepson and Crookston [24] who showed that an early leaves clipping increased HI. A clear varietal response: greater for 'Canner' than for 'Butter Sweet' maize hybrids have been found as well.

Canopy architecture influences many canopy processes including interactions between the crop and specific aspects of its environment. From maize crops initiated by direct seeded, spacing uniformity, timing and rate of emergence, and plant population determine a growth variability that may ultimately affect plant growth and grain yield. Uneven emergence almost always reduces grain yield with early emerged plants unable to compensate for lower yield of late-emerging plants [25]. Missing plants in the field are inevitable, where 5-15% of sown seeds normally fail to produce plants. Given that missing plants in the field is a common problem, and the neighbouring plants fail to fully compensate for yield of missing plants due to their low yield potential, the final grain yield per unit area decreases. Our results showed that both effects (missing plants and lesser plant growth rate) could be possible in the short-season area from Balcarce (Argentina) with inadequate minimal temperature when a direct-seeded routine was used and let to explain the beneficial effects of the transplant on emergence rate (Table 2) and crop yield (ton fresh weight ha⁻¹) (Table 7).

Although there was some differences between the two maize hybrids tested [standard 'Canner' (*su1*) or *shrunk-2* 'Butter Sweet' types], our results let suggest an increase in plant density (12 plants m⁻²) when transplant sowing routine was included as a tool for increasing sweet maize yield. The economic feasibility of transplant for Argentina (data not shown) when such high density was used showed that the added cost of transplant is often justifiable. On other hand, to understand the physiological mechanisms associated to the morphological changes which let a change in both crop architecture and plant density and a yield increase per unit area in transplanted plants are missing, although a key matter for a future breeding program.

5. CONCLUSION

Our results showed that the changes in canopy architecture of the transplanted sweet maize crop reduced light interception at the usual lower plant densities. Significant increases in plant density as

far as 12 plants m⁻² decrease yield per plant but optimize yield per ha⁻¹ through an increase in RUE and HI.

6. ACKNOWLEDGEMENTS

This work was supported by the University of Buenos Aires Science Program (G054 and W193) and the University of Mar del Plata Science Program (AGR 287, AGR 317 and AGR 379).

The authors gratefully acknowledge the provision of experimental sweet maize hybrids by Martín Garbarino (Semillera Basso) (Buenos Aires, Argentine) and the contribution of Fernando Andrade in providing field facilities.

REFERENCES

1. Stanger TF, Lauer JG. Optimum plant population of bt and non-bt corn in Wisconsin. *Agron. J.* 2006; 98(4):914-921.
2. Boomsma CR, Santini JB, Tollenaar M, Vyn TJ. Maize morphophysiological responses to intense crowding and low nitrogen availability: an analysis and review. *Agron. J.* 2009; 101(6):1426-1452.
3. Williams MM. Agronomics and economics of plant population density on processing sweet corn. *Field Crops Res.* 2012; 128(3):55-61.
4. Welbaum GE, Frantz JM, Gunatilaka MK, Shen Z. A comparison of the growth, establishment, and maturity of direct-seeded and transplanted *sh2* sweet corn. *Hort Sci.* 2001; 36(4):687-690.
5. Pendleton JW, Egli DB. Potential yield of corn as affected by planting date. *Agron. J.* 1969; 61(1):70-71.
6. Rattin J, Di Benedetto A, Gornatti T. The effect of transplant in sweet maize (*Zea mays* L.). I: Growth and Yield. *Int. J. Agric. Res.* 2006; 1(1):58-67.
7. Di Benedetto A, Rattin J. Transplant in sweet maize: a tool for improving productivity. *The Americas J. Plant Sci. Biotechnol.* 2008; 2(2):96-108.
8. Sánchez Andonova P; Rattin J, Di Benedetto A. Yield increase as influenced by transplanting of sweet maize (*Zea mays* L. *saccharata*). *Amer. J. Exp. Agric.* 2014; 4(11): 1314-1329.
9. Maddonni GA, Otegui ME, Cirilo AG. Plant population density, row spacing and hybrid effects on maize canopy architecture and light attenuation. *Field Crops Res.* 2001; 71(3): 183-193.
10. Anda A, Loke Z. Radiation balance components of maize hybrids grown at various plant densities. *J. Agron. Crop Sci.* 2005; 191(3): 202-209.
11. Andrade FH, Uhart SA, Frugone MI. Intercepted radiation at flowering and kernel number in maize: shade versus plant density effects. *Crop Sci.* 1993; 33(3): 482-485.
12. Ding K, Wang KJ, Jiang GM, Liu MZ, Liu SL, Gao LM. Post-anthesis changes in photosynthetic traits of maize hybrids released in different years. *Field Crops Res.* 2005; 93(1):108-115.
13. Di Benedetto A, Molinari J., Rattin J. The effect of transplant in sweet maize (*Zea mays* L.). II. Container root restriction. *Int. J. Agric. Res.* 2006; 1(6):555-563.
14. Di Benedetto A, Rattin J. Transplant in sweet maize: a tool for improving productivity. *The Americas J. Plant Sci. Biotechnol.* 2008; 2(2):96-108.
15. Motulsky H, Christopoulos A. Fitting models to biological data using lineal and nonlinear regression. A practical guide to curve fitting. Graph Pad Software Inc., San Diego, CA, USA. 2003; 351.
16. Araki A, Rattin J, Di Benedetto A, Mirave P. Temperature and cytokinin relationships on lettuce (*Lactuca sativa* L.) and celery (*Apium graveolens* L.) nursery growth and yield. *Int. J. Agric. Res.* 2007; 2(8):725-730.

525 17. Coro, M, Araki A, Rattin J, Mirave P, Di Benedetto A. Lettuce and celery responses to both
526 BAP and PBZ related to the plug cell volume. *Amer. J. Exp. Agric.* 2014; 4(10):1103-1119.
527 18. Bos HJ, Vos J, Struik PC. Morphological analysis of plant density effects on early leaf area
528 growth in maize. *Netherlands J. Agric. Sci.* 2000; 48(2): 199-212.
529 19. Begna SH, Smith DL, Hamilton RI, Dwyer LM, Stewart DW. Corn genotypic variation effects
530 on seedling emergence and leaf appearance for short-season areas. *J. Agron. Crop Sci.*
531 2001; 186(4): 267-271.
532 20. Emam Y. Sensitivity of grain yield components to plant population density in non-prolific
533 maize (*Zea mays*) hybrids. *Indian J. Agric. Sci.* 2001; 71(6): 367-370.
534 21. Liu W, Tollenaar M, Stewart G., Deen W. Response of corn grain yield to spatial and
535 temporal variability in emergence. *Crop Sci.* 2004; 44(3): 847-854.
536 22. Hay RKM. Harvest index: a review of its use in plant breeding and crop physiology. *Annals*
537 *Applied Biol.* 1995; 126(1):97-216.
538 23. Sarlangue T, Andrade FH, Calviño PA, Purcell LC. Why do maize hybrids respond
539 differently to variations in plant density? *Agron. J.* 2007; 99(4): 992-998.
540 24. Jeppson RG, Crookston RK. Effect of elevated growing-point temperature on maize growth
541 and yield. *Crop Sci.* 1986; 26(3): 595-598.
542 25. Liu W, Tollenaar M, Stewart G, Deen W. Within-row plant spacing variability does not affect
543 corn yield. *Agron. J.* 2004; 96(1): 275-280.