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The Effects of Transplant in Sweet Maize (*Zea mays* L.). I. Growth and Yield*

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Abstract: The aim of this study was to determine the suitability of the transplant routine using plastic plug trays as an alternative of direct seeded and the effect of sowing date for different sweet maize mutants. Sweet maize mutants hybrids Canner (*su1*), Butter Sweet (*sh2*) and Cheyenne (*se1*) were sown in spring and summer by direct seeded or in plastic plug trays (128 cells tray^{-1}) for transplant. Present results suggest that it was possible to obtain similar or highest yield from sweet maize mutant plants using a transplant method than direct-seeded under optimal environments. The disagreement with previous reports on the effects of the transplant routine would be associated with the use of plug plastic tray instead of the commonly polystyrene trays which would let avoid the damage to root system when seedlings were transplanted.

Key words: Direct-seeded, root restriction, sowing date, stress, sweet corn, *Zea mays*

Introduction

There are several endosperm mutations in maize (*Zea mays* L.) which, when present in the homozygous recessive state, produce qualitative and quantitative differences in kernel carbohydrate metabolism that affect flavor and storability (Coe, 1993). They include traditional sweet corn, *sugary1* (*su1*), *shrunken-2* (*sh2*) and *sugary enhancer* (*se1*). These mutants all result in higher sugar and lower starch concentrations, although the magnitude of their effects varies (Evansen and Boyer, 1986). The new cultivars at the present time dominate the fresh market sweet corn for long-distance and wholesale markets.

Despite the desirable quality attributes of *sh2*, *se1* and other endosperm genotypes, their utilization has been hindered by reduced field emergence, seedling vigor and stand uniformity, especially in cold soils (Douglass *et al*., 1993; Cline and Silvernail, 2002). Reduced stand uniformity results in heterogeneous ear maturity and reduced value and yield.

Field and sweet corn have been transplanted experimentally in an attempt to improve stands and hasten maturity (Khehra *et al*., 1990; Miller, 1972; Waters *et al*., 1990; Wyatt and Mullins, 1989). However, transplanting sweet corn remains a questionable practice because it increases production costs, often stunts plant development and decreases yield (Pendleton and Egli, 1969; Wellbaum *et al*.,

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2001). Transplant advantages include a better use of seed and space; avoid the environmental risks during the earlier low-rate phases of vegetative growth and gives earlier and more uniform flowering and yield.

There are marked differences in the survival rate of different vegetable species after transplanting, particularly if roots have been damaged, or weather conditions are unfavorable (Wien, 1997). In his classic work on transplanting, Loomis (1925) established three classes of transplanting ease. A commonly transplanted group, which usually survives the process well, includes tomato, lettuce, cauliflower and beets. An intermediate group contains celery, eggplant, onions and pepper. The third category comprises species that are difficult to transplant and includes beans, corn, cucumbers and melons.

The aim of this study was determine the suitability of the transplant routine using plastic plug trays as an alternative of direct seeded and the effect of sowing date for different sweet maize mutants.

Materials and Methods

The experiments were conducted at the INTA Balcarce Experimental Station, Argentina (37°45′S, 58° 18′W and altitude 130 m) during the 2002-2003 and 2003-2004 growing seasons on a typic argiudol soil with an organic matter of 5.6% in the first 25 cm depth. 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). Weeds and insects were adequately controlled.

In 2002, maize mutants hybrids Canner *(su1)*, Butter Sweet *(sh2)* and Cheyenne *(se1)* provided by Semillería Basso (Argentina) were sown on 25 October and 30 December by direct seeded (D) or in plastic plug trays (128 cells tray^{-1}) (T) using a river waste-base media. Transplanted plants were grown under greenhouse facilities from sowing to the two-leaf expanded stage (near 15 days from sowing). Final population density for both treatments was 80,000 plants ha^{-1}. The experiment, repeated in 2003 beginning on 26 November and 2 January (2004).

The experiment design was a split plot, with hybrids as main plots and establishment routines (direct seeded and transplant) as subplots. The subplots consisted of four rows of 10 m (one border row on each side) and rows were 0.70 m apart.

Weather records (daily maximum-minimum air temperature and global solar radiation) were obtained from a meteorological station 500 m from the experimental site. Emergence dates were recorded.

Dry matter accumulation was determined by taking plant samples at stages V_6, V_9; V_T and R_3 for 2002-2003 experiments and V_6, V_7, V_9, V_T and R_3 for 2003-2004 experiments according to Ritchie and Hanway (1982). The sample size was 10 plants per row, leaving appropriate border rows and border plans within the rows. Plants were cut at ground level, oven dried at 60°C for 10 days and weighed. Plant height (from ground level to basal tassel branches) and leaf number were determined at all sampled stages.

Data were processed by analysis of variance procedures and appropriate standard errors of the means were calculated.

Results

Total leaf area was higher for ‘Canner’, ‘Butter Sweet’ and ‘Cheyenne’ mutants crops initiated by direct-seeded than by transplant (Fig. 1A-C). First sowing date showed higher leaf area than second sowing date too. ‘Canner’ maize mutant showed the highest differences in leaf area between sowing methods and sowing date at R_3 stage.

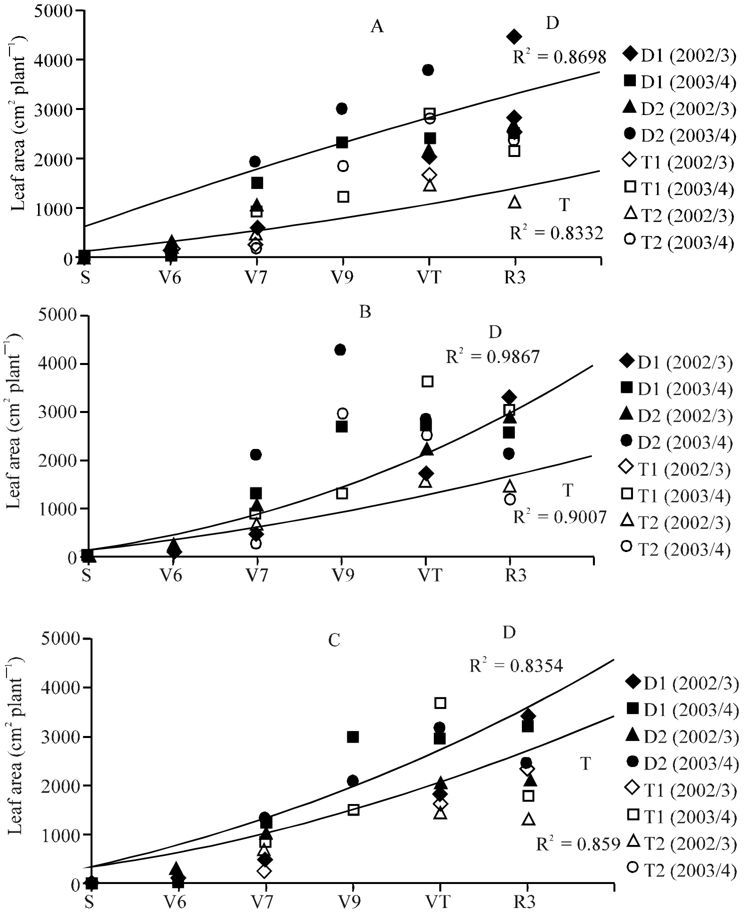

Fig. 1: Leaf area increase through developmental stage for 'Canner' (A), 'Butter Sweet' (B) and 'Cheyenne' (C) sweet maize mutants under direct-seeded (D) or transplant (T) method and two sowing date (1, 2)

Shoot dry weight was the highest for direct-seeded plants under optimal sowing date for *su1* (Canner), *sh2* (Butter Sweet) and *se1* (Cheyenne) maize mutants hybrids (Fig. 2A-C). By other hand, first sowing date showed higher values than second sowing date.

There were no differences in kernel number per ear between crop initiation method and sowing dates (Table 1). This was the result of similar kernel per row and rows per ear. Lower kernel number from transplanted plants was only found for the *se1* (Cheyenne) maize mutant during the first sowing date of 2003-2004 experiment.

The 2002-2003 experiment showed the highest final ear yield (g fresh weight plant^{-1}) at R_3 stage for the three maize mutant transplanted plants during the first sowing date (Table 2). This result was repeated in 2003-2004 experiment only for 'Butter Sweet'; while there were no yield differences for

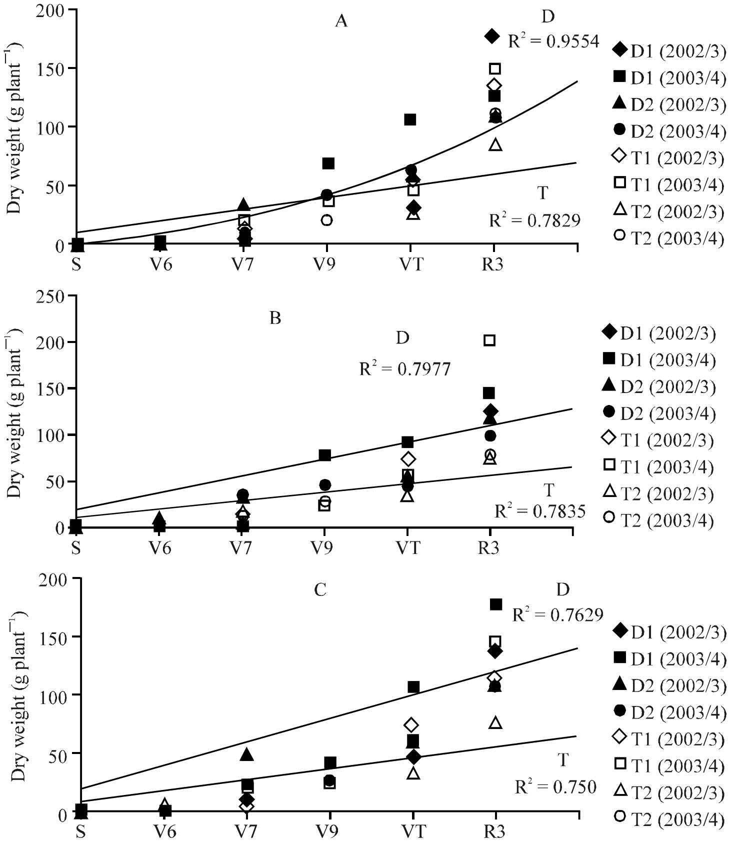

Fig. 2: Dry weight accumulation for 'Canner' (A), 'Butter Sweet' (B) and 'Cheyenne' (C) sweet maize mutants under direct-seeded (D) or transplant (T) method and two sowing date (1, 2)

Table 1A: Number of kernels per ear, row and number of rows per ear at R_3 stage for three sweet maize hybrids, at direct seeded or transplant for two sowing date (2002-2003)

	Rows per ear		Kernel per row		Kernel per ear	
	Direct seeded	Transplant	Direct seeded	Transplant	Direct seeded	Transplant
	First sowing date					
Canner	16.7 Aa	16.7 Aa	36.8 Aa	32.0 Aa	616.3 Aa	535.7 Aa
Butter sweet	14.1 Ab	16.2 Ba	36.6 Aa	30.2 Aa	514.1 Aa	488.8 Aa
Cheyenne	18.0 Aa	16.7 Ba	27.5 Aa	30.3 Aa	495.5 Aa	507.5 A
	Second sowing date					
Canner	16.7 Aa	16.0 Aa	26.6 Ab	31.3 Aa	444.6 Ab	503.3 Aa
Butter sweet	16.0 Aa	16.8 Aa	25.9 Bb	33.2 Aa	413.5 Ab	559.3 Aa
Cheyenne	17.6 Aa	14.7 Ab	28.2 Aa	31.2 Aa	494.9 Aa	454.5 Aa

Capital letter (s) indicate statistically significant differences ($p \leq 0.05$) for hybrids between direct seeded and transplant within sowing dates and lower case letter (s) indicate statistically significant differences ($p \leq 0.05$) among sowing dates for each treatment

Table 1B: Number of kernels per ear, row and number of rows per ear at R_3 stage for three sweet maize hybrids, at direct seeded or transplant for two sowing date (2003-2004)

	First sowing date					
	Rows per ear		Kernel per row		Kernel per ear	
	Direct seeded	Transplant	Direct seeded	Transplant	Direct seeded	Transplant
Canner	17.6 Aa	16.8 Aa	35.1 Aa	29.3 Ba	616.4 Aa	487.8 Ba
Butter sweet	14.8 Aa	16.7 Aa	37.9 Aa	34.4 Aa	560.4 Aa	573.8 Aa
Cheyenne	16.2 Aa	15.3 A	38.0 Aa	29.4 B	616.9 Aa	449.1 B
	Second sowing date					
Canner	16.4 Aa	16.9 Aa	27.3 Ab	25.6 Ab	442.1 Ab	533.3 Aa
Butter sweet	16.1 Aa	16.0 Aa	24.2 Ab	24.6 Ab	389.6 Ab	432.0 Ab
Cheyenne	15.1 a		29.6 b		446.9 b	

Capital letter (s) indicate statistically significant differences ($p \le 0.05$) for hybrids between direct seeded and transplant within sowing dates and low-case letter (s) indicate statistically significant differences ($p \le 0.05$) among sowing dates for each treatment

Table 2: Ear yield (g fresh weight $plant^{-1}$) at R_3 stage for three sweet maize hybrids at direct seeded or transplant for two sowing date during 2 years

	First sowing date				Second sowing date			
	2002-2003		2003-2004		2002-2003		2003-2004	
	Direct seeded	Transplant	Direct seeded	Transplant	Direct seeded	Transplant	Direct seeded	Transplant
Canner	200.1 Ba	327.5 Aa	213.1 Aa	250.0 Ab	174.5 Ba	233.4 Aa	190.8 Aa	238.3 Aa
Butter sweet	214.0 Ba	336.5 Aa	235.0 Ba	285.6 Aa	176.7 Aa	178.6 Aa	161.4 Aa	177.2 Aa
Cheyenne	195.4 Bb	304.7 Aa	280.2 Aa	216.7 Bb	212.3 Aa	204.8 A	207.5 a	

Capital letter (s) indicate statistically significant differences ($p \le 0.05$) for hybrids between direct seeded and transplant within sowing dates and lower case letter (s) indicate statistically significant differences ($p \le 0.05$) among years for the same treatment and sowing date

Table 3: Harvest Index at R_3 stage for three sweet maize hybrids at direct seeded or transplant for two sowing date during 2 years

	First sowing date				Second sowing date			
	2002-2003		2003-2004		2002-2003		2003-2004	
	Direct seeded	Transplant	Direct seeded	Transplant	Direct seeded	Transplant	Direct seeded	Transplant
Canner	0.316 Bb	0.519 Aa	0.437 Aa	0.487 Aa	0.343 Bb	0.456 Aa	0.415 Aa	0.470 Aa
Butter sweet	0.454 Ba	0.548 Aa	0.455 Aa	0.447 Ab	0.374 Aa	0.377 Ab	0.368 Ba	0.508 Aa
Cheyenne	0.336 Bb	0.491 Aa	0.431 Aa	0.454 Aa	0.433 Aa	0.424 A	0.418 a	

Capital letter (s) indicate statistically significant differences ($p \le 0.05$) for hybrids between direct seeded and transplant within sowing dates and lower case letter (s) indicate statistically significant differences ($p \le 0.05$) among years for the same treatment and sowing date

'Canner', a 'Cheyenne' higher yield from direct-seeded plants was found. The second sowing date gives similar yield for the most initiation method, year and maize mutants.

When Harvest Index (HI) on a fresh weight base at R_3 stage was analyzed (Table 3), results are similar to obtained for ear yield, this is, highest or the same values for transplanted plants in 2002-2003 and 2003-2004 experiments, respectively for *su1* (Canner), *sh2* (Butter Sweet) and *se1* (Cheyenne) maize mutants hybrids. Second sowing date showed no differences for direct-seeded vs. transplant, except for 'Canner' in the 2002-2003 experiment.

Table 4: Daily solar radiation, maximum and minimum temperature. Monthly mean for 2002-2003 and 2003-2004 experiments

	Temperature (°C)		solar radiation
	Maximum	Minimum	(MJ m^{-2} day^{-1})
2002-2003			
October	20.49	9.07	16.90
November	22.14	11.39	19.28
December	25.51	13.39	23.34
January	28.76	14.21	23.04
February	26.56	14.23	19.10
March	24.70	13.48	15.80
April	18.70	8.86	9.37
2003-2004			
October	21.00	6.00	16.90
November	15.00	10.00	19.28
December	26.00	12.25	23.34
January	31.40	15.67	23.04
February	24.54	13.27	19.10
March	25.80	12.83	15.80

Solar radiation and air temperature during the experiments (Table 4) did not seem to have limited potential maize crop growth for the first sowing date. However, weather conditions during the second sowing date decreased, mainly for the kernel-filling stage.

Discussion

The quality of sweet maize has been enhanced in recent years by the introduction of mutant genes affecting carbohydrate metabolism in the endosperm in place of the standard *sugary* (*su1*) gene. The commonly indicated less establishment capacity for the new maize mutants could not be confirmed in our experiments because there were only minor statistical significant differences in total leaf area (Fig. 1), total dry weight (Fig. 2), leaf number and plant height (data not shown) until V_7 stage for the direct-seeding routine under optimal sowing date.

Maize grain yield is related to light interception, to radiation-use efficiency and to photoassimilate partitioning. Radiation interception varies from seedling emergence to crop harvest and depends largely on the canopy leaf area (Watiki *et al*., 1993). Leaf area development is described as a function of air temperature. Since temperature affects many plant processes, including nutrient uptake, water absorption, photosynthesis, respiration and translocation of photosynthate, it is not surprising that temperature is considered the most important environmental factor governing plant development. Mean air temperature was above the thresholds that may affect radiation-use efficiency (16°C) or biomass partitioning to grains (19°C) (Wilson *et al*., 1995) and solar radiation was highest the levels registered in a cool and cloudy high latitude environment of northern Europe (Otegui and Bonhomme, 1998) for the first sowing date (Table 4). During the second sowing date solar radiation and mean air temperature significantly decreased for the kernel-filling stage.

The most important result of this work was that it was possible to obtain high yield from sweet maize mutant plants using a transplant method and highest than direct-seeded under optimal environments (Table 2). These results are not in agreement with previous reports (Pendleton and Egli, 1969; Wellbaum *et al*., 2001). The primary objective for transplanting sweet corn is easily maturity; if growers can produce sh_2 mutants before the competition in a particular market does, the extra crop value may justify the greater production costs of transplanting.

Harvest index, or grain weight divided by total shoot weight, is considered stable for maize grown in the absence of environmental constraint. Nevertheless, modifications introduced by genotype and environment could be expected, as those induced in dry matter partitioning by temperature during early stages of growth as a ratio of grain to biomass yield, the harvest index of cereal crops can be affected by any factor which influences the components of yield to different extents. Increased plant population density, by favoring biomass production over grain, also tends to result in lower harvest index, but within the normal range of commercial crop densities, such reductions rarely exceed 10% of the optimum value (Hay, 1995). Present results are not in agreement because we found an increase in harvest index using a transplant routine (Table 3). However, it takes into account that harvest index for sweet maize included the ear at a R_3 stage.

Biomass accumulation and partitioning to reproductive structures are critical aspects of plant fitness (Andrade *et al*., 1999). In many plant species, dry matter partitioning to reproductive organs is a stable and highly heritable trait (Sadras *et al*., 1997). The mechanisms underlying reproductive partitioning are, however, poorly understood. In maize, plant density has important effects on partitioning of dry matter between vegetative and reproductive structures. The effect of an increase in plant density radiation on dry matter partitioning between vegetative and reproductive structures are expected (Andrade *et al*., 1993). Present results showed that a root restriction (transplant treatment) for sweet maize mutants would change photoassimilate partitioning at behalf to reproductive structures (Table 3) even at higher plant densities (8 plants m^{-2}) that the usually suggested for this crop (4-6 plants m^{-2}).

Pendleton and Egli (1969) proposed that one explanation for the transplants yielding no more than the early seedlings may lie in their shorter plant height and less leaf surface. It has been indicated (Loomis, 1925; Waters *et al*., 1990; Wellbaum *et al*., 2001) that maize does not transplant well because pruned roots do not branch and root replacement is generally poor compared with crops such as cabbage or tomato. The inability of maize roots to regenerate after transplanting resulted in stunted plants. The root system of a maize seedling has seminal roots that consist of the radicle or primary root and a variable number of lateral roots that arise adventitiously at the base of the first internode of the stem, just above the scutellar node. The seminal root initials are present in the embryo and are the most important for early growth and establishment.

Wellbaum *et al.* (2001) has shown that seminal roots were broken during transplanting as they were pulled from transplant growing in polystyrene trays, indicating that this material was not optimal for maize transplant production. However, similar results [less total leaf area (Fig. 1)] were found in plants growing from plastic plug trays which showed intact root systems at the transplant stage. At transplant, sweet corn seedlings showed a well developed root system with white roots and without damage but the plug cell base determined horizontal root growth around it (picture not shown). Root restriction stress related to a small plug cell volume could be limited biomass accumulation during the vegetative stages. This effect has been indicated for other plants under intensive propagation systems (Di Benedetto and Klasman, 2004). Although physiological mechanisms are unclear, both synthesis and translocation of hormones such as auxins and citokinins from root apices would be involved and related to a change in root verticality as a restriction from the plug cell base.

The productivity of maize is constrained by the relative plasticity of the response to environmental stresses. Plant plasticity to abiotic stresses has recently been described as being either morphological or phenotypic in character (Vyn and Hooker, 2002). The understanding of the response of maize to particular short- and long-term stresses is limited even further by interactions with other stresses in the crop such as the root restriction imposed by small plug cell trays when a transplant routine was used.

Plants were harvested at specific stages of vegetative development as measured by mature leaf number. Since leaf appearance rate changed with temperature, the time between sowing and each of the harvests and hence the duration of growth, also varied. Delayed sowings are generally accompanied by increased temperatures during the growing season, which accelerate crop development and decrease accumulated solar radiation (Cirilo and Andrade, 1994; Otegui *et al*., 1995) resulting in less biomass production. Our results are in agreement with previous reports because R_3 stage for both direct-seeding and transplant plants was achieved 7-13 days later, respectively for the second vs. first sowing date (data not shown).

Variation in sowing date in maize modifies the radiative and thermal conditions during growth. The amount of incident radiation and the proportion of this radiation that is intercepted by the crop directly determine crop growth rate. Temperature affects the duration of crop growth and consequently the time during which incident radiation can be intercepted and transformed to dry matter. Temperature also affects final leaf number (Tollenaar and Hunter, 1983) and leaf canopy development (Hesketh and Warrington, 1989) which define crop leaf area index. Therefore, these factors determine the proportion of the incident radiation that is intercepted by the crop. Present results are in agreement with Cirilo and Andrade (1994) which have indicated that significant differences in crop growth and development would be found when sowing date is changed. Late sowing date would be limited by the assimilation leaf source (Fig. 1).

Recently, process-oriented studies of leaf development have shown that under non-drought conditions, each leaf has a well-defined growth rate, which is a function of temperature and a maximum leaf area, which is a function of position on the plant. Thus, in the absence of water stress, leaf area development can be described by relatively simple temperature functions (Dale *et al*., 1980). However, the ‘root restriction’ stress generated by plug cell determines changes in leaf growth. On account of leaf area decreased (Fig. 1) but not leaf number (data not shown), the individual leaves were smaller for the transplant.

Clipping of early leaves has been shown to increase Harvest Index (HI) of maize *Zea mays* L. In a study with sweet maize, Crockett and Crookston (1980) measured an average 20% increase in HI following early leaf clipping. The increase was found to result from a greater reduction in stove mass than in ear mass (Crockett and Crookston, 1980, 1981). Results from Table 3 are in agreement although the effect of transplant would be related with another growth restriction such as sowing date.

Clipping reduces stove because photosynthetic leaf area is removed and vegetative development is retarded, it is possible that early clipping must induce a change in the microclimate of the corn plant, specifically in the temperature of the growing point region. Jepson and Crookston (1986) showed that the growing point temperature of maize was significantly increased by early leaf clipping. We also observed that early growing point heating was followed by an alteration in the partitioning of dry matter that favored the ear rather than stove.

We have not recorded growing point temperature in our experiments by which we have not sure if it was related to a change in leaf growth for the transplanted plants, but although transplant determine a decrease in biomass accumulation, mechanism would be different for clipping plants because this treatment commonly decreases yield (Eghareyba *et al*., 1976) and transplant increases it (Fig. 1). By other hand, the use of transplanted plants would be suggest for basic physiological experiments related to the study of source-sink relationship mechanisms because transplant change the source (leaf area) for intact plants (unclipped) growing under the same abiotical environment.

The aim of this reserch was to study the effect of a change in the establishment routine (transplant) on yield of different sweet maize mutants. Due to our results showed similar yield on unstressed environment (first sowing date) (Table 2) it is clear that transplant would be an alternative to direct-seeding when plastic plug cell trays was used. Although transplant would increase establishment costs the change in plant architecture associated to smaller leaf area accumulation rate let would increase plant density (in fact our experiments were developed at a higher plant density than usually suggested) but this matter require another experimental design and is the base for the following research.

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