Influence of row spacing reduction on maize grain yield in regions with a short summer[1]

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Abstract – The interest in reducing maize row spacing in the short growing season regions of Brazil is increasing due to potential advantages such as higher radiation use efficiency. This experiment was conducted to evaluate the effect of row spacing reduction on grain yield of different maize cultivars planted at different dates. The trial was conducted in Lages, in the State of Santa Catarina, Brazil, during 1996/97 and 1997/98 growing seasons, in a split-split plot design. Early (October 1st) and normal (November 15) planting dates were tested in the main plot; two morphologically contrasting cultivars (an early single-cross and a late double-cross hybrids) were evaluated in the split plots and three row widths (100, 75 and 50 cm) were studied in the split-split plots. The reduction of row spacing from 100 to 50 cm increased linearly maize grain yield. The yield edge provided by narrow rows was higher when maize was sown earlier in the season. Differences in hybrid cycle and plant architecture did not alter maize response to the reduction of row spacing.

Index terms: *Zea mays*, hybrids, sowing date, crop management.

Influência da redução do espaçamento entre linhas no rendimento do milho em regiões de verões curtos

Resumo – O interesse em reduzir o espaçamento entre linhas do milho tem aumentado nas regiões brasileiras com estação estival de crescimento reduzida, devido a vantagens potenciais, tais como a maior eficiência de uso da radiação solar. Este experimento foi realizado para avaliar o efeito da redução de espaçamentos entre linhas no rendimento de grãos, em diferentes épocas de semeadura e cultivares de milho. O experimento foi conduzido em Lages, SC, durante os anos agrícolas de 1996/97 e 1997/98, em delineamento de parcelas sub-subdivididas. Uma época de semeadura antecipada (1º de outubro) e uma normal (15 de novembro) foram testadas na parcela principal; duas cultivares morfologicamente contrastantes (híbrido simples superprecoce e híbrido duplo tardio foram utilizados nas subparcelas e três espaçamentos entrelinhas (100, 75 e 50 cm) foram usados nas sub-subparecelas. A redução do espaçamento de 100 para 50 cm aumentou linearmente o rendimento de grãos. Os aumentos no rendimento obtidos pela utilização de menor espaçamento entre linhas foram maiores na semeadura antecipada. O tipo de arquitetura da planta e o ciclo do híbrido utilizado não interferiram na resposta do milho à redução do espaçamento entre linhas.

Termos para indexação: *Zea mays*, híbridos, época de semeadura, manejo de cultura.

Introduction

A significant fraction of Brazilian growers sow maize using row spacings ranging from 90 to 100 cm (Flesh & Vieira, 1999). However, the interest in planting maize at narrower than conventional row widths is occurring in Southern Brazil, particularly among farmers who work with plant densities higher than 50,000 plants/ha and usually accomplish grain yields greater than 6,000 kg/ha (Sangoi et al., 1998).

Decreasing the distance between neighbor rows at any particular plant population has several potential advantages. First, it reduces competition among plants within rows for light, water and nutrients due to a more equidistant plant arrangement (Olson & Sander, 1988; Porter et al., 1997). The more favorable planting pattern provided by closer rows enhances maize growth rate early in the season (Bullock et al., 1988), leading to a better intercep-

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[1] Accepted for publication on August 18, 2000.

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tion of sun light, a higher radiation use efficiency and a greater grain yield (Westgate et al., 1997).

Secondly, the maximization of light interception derived from early canopy closure also reduces light transmittance through the canopy (McLachlan et al., 1993). The smaller amount of sun light striking the ground decreases the potential for weed interference, specially for shade intolerant species (Gunsolus, 1990; Teasdale, 1995; Johnson et al., 1998).

Thirdly, the quicker shading of soil surface during early part of the season results in less water being lost by evaporation (Karlen & Camp, 1985). This is specially important under favorable soil surface moisture conditions because it allows maize plants to maximize photosynthesis and the proportion of water that is used in growth processes rather than evaporated from the soil (Lauer, 1994). Furthermore, the earlier crop cover provided by smaller row widths is instrumental to enhance soil protection, diminishing water runoff and soil erosion (Mannering & Johnson, 1969; Sangoi et al., 1998).

The idea of cultivating maize using narrow rows has been discussed and experimented by farmers recurrently over the last 30 years without being effectively introduced in a large scale (Swoboda, 1996). Currently, several factors may facilitate the dissemination of such cultural practice. Hybrids introduced in the 90's tolerate high plant populations much better than genotypes used in the past (Almeida & Sangoi, 1996; Almeida et al., 2000). This is an important feature because the greater benefits of reducing maize row width occur at high plant populations (Sangoi, 1996). Moreover, nowadays growers have a broad chemical weed control arsenal available, which makes post emergence cultivation optional. Eliminating cultivation reduces labor, fuel, and circumvents the need to modify the cultivator and purchase narrow tires and rims (Paszkiewicz, 1996). In addition to that, equipment changes are becoming less prohibitive. Manufactures are ready to deliver equipment for narrow row production, as long as it proves to be cost-effective and profitable to maize growers.

The row spacing reduction may be positive mainly to early planted maize in the highlands of Southern Brazil (Sangoi et al., 1998). The combination of latitude (25 to 30°S) and altitude (800 to 1,200 m above the sea level) that characterizes this region decreases the number of available heat units for crop growth and shrinks the growing season length (Sangoi, 1993). The cool temperatures registered in early spring slow down maize development, limiting light interception, favoring erosion and making weed control more difficult. Narrowing down row width may be a way to minimize such problems.

This experiment was carried out with the following objectives: to evaluate if the use of narrower than conventional row spacing improves maize grain yield; to verify whether there is an effect of planting date on the response of maize to narrow rows; and to investigate if cultivar cycle and architecture interferes on the plant behavior at different row spacings.

Material and Methods

The experiment was conducted in the city of Lages, SC, Brazil, during the 1996/97 and 1997/98 growing seasons. The experimental site was located at 930 m above sea level, 27°52' latitude South and 50°18' longitude West. The climate of the region is classified by Köppen as Cfb, presenting mild summers, cold winters and adequate rainfall during the whole year. Soil study site was an Oxisol (Hapludox).

A combination of three factors was studied in the trial: planting date, cultivar and row spacing. The experimental design was a split-split plot with the main plots arranged in randomized complete blocks. Each treatment was replicated four times. Two planting dates were tested in the main plot: October 1st and November 15, representing early and normal planting times for the region, respectively. Two contrasting genotypes in terms of cycle and plant architecture were studied in the split plots: Ag 9014, an early short single-cross hybrid; and Ag 1051, a late tall double-cross hybrid. Three row widths were studied in the split-split plots: 100, 75 and 50 cm. Each split-split plot consisted of four rows. Individual plot rows were 6 m long.

A conventional tillage method, involving one plowing plus two disking operations, was used to prepare the soil. Phosphorus, potassium and nitrogen were applied during the planting day at rates of 120, 100 and 30 kg/ha, respectively. Fertilization was performed according to the results of soil test analysis and following the recommendations of Comissão de Fertilidade do Solo RS/SC (1995) for maize growers who aim to produce more than 6,000 kg/ha of grains.

The experiment was hand-planted intending to achieve a plant density of 75,000 plants/ha. Three seeds were dropped per hill to assure the desired stand on each treatment. The space between two adjacent hills within each row was 26.6, 17.7 and 13.3 cm for the row widths of 50, 75 and 100 cm, respectively. Marked strings were used during planting to position the seeds properly on each treatment.

A combination of atrasine (1,400 g/ha of a.i.) and metolachlor (2,100 g/ha of a.i.) was sprayed right after planting to control weeds prior to their emergence. Plots were also hand-hoed to suppress weed competition after their emergence as needed. When plants presented four fully expanded leaves (stage V4, according to Ritchie & Hanway, 1993), thinning was performed to adjust the population to the desired level. A nitrogen dose of 100 kg/ha was side-dressed to the soil using urea when plants had six fully expanded leaves.

All the evaluations were made in the two central rows on each plot. Early in the season, the leaf tips of the fourth and eighth leaf of five plants randomly chosen inside each split-split plot were marked with a non-washable ink. Those plants were used to correctly determine the total number of expanded leaves produced on each treatment.

Anthesis and silking were estimated when hybrids reached flowering, by counting the number of days required for 50% and 90% of the plants to present pollen shed and have visible silks, respectively. Leaf area and leaf area index were evaluated at two growth stages: V10 and silking. Leaf area was estimated measuring length and maximum width of every leaf of five randomly chosen plants. The area of each leaf (A) was calculated by the formula: $A = 0{,}75 \times \text{length} \times \text{width}$, following method presented by Tollenaar (1992). Leaf area index was calculated summing the leaf area of the five plants-sample and dividing it by the theoretical ground space occupied for them.

Plant and ear height were measured on five plants of each plot when they reached R3, the milk stage (Ritchie & Hanway, 1993). The plant standability was analyzed one day before harvesting of each hybrid. Plants were considered lodged when the angle between the stem and the ground level was less than 45%. Stalks were considered broken when a significant rupture in the stem tissue was observed below the point of insertion of the upper ear in the stem. The values of these two variables were expressed as a percentage of the total number of plants present in the two central rows.

Harvesting was done by hand when the leaves of each hybrid senesced entirely. The two central rows of each split-split plot were harvested, representing an area of 12, 9 and 6 m^2 for the row spacings of 100, 75 and 50 cm, respectively. Ears were dehusked, dried, shelled and weighed. Dry grain weight values were converted to an area of one hectare and adjusted to a standard moisture of 13%. A subsample of 200 grains was taken and re-weighed. The value obtained was multiplied by 5 and converted to a moisture of 13% to express the weight of 1,000 grains. The number of grains per ear was estimated indirectly through the relationship between weight of 200 grains, weight of total number of kernels and number of ears harvested within each split plot. Weight of grains per ear was obtained dividing total grain weight by the number of ears harvested on each plot.

An analysis of variance was performed. F values for main treatment effects and their interaction were considered significant at the $P<0.05$ level. Whenever a particular factor or interaction of factors significantly influenced a variable, means were separated using the t test at the 0.05 probability level, following method presented by Riboldi (1993). For variables where the single effect of row spacing or its interaction with planting date or with the hybrid was significant, a regression analysis was performed and the linear and quadratic effects were calculated.

Results and Discussion

The growing seasons of 1996/97 and 1997/98 presented an even and abundant rainfall distribution, specially during the months of December, January and February, which bracketed the late vegetative, flowering and grain filling periods of maize in this trial (Tables 1 and 2). The adequate water availability during maize critical growth stages, associated with a high level of soil fertility, contributed for maize to set a high number of heavy grains per ear, leading to the great grain yield values obtained in the experiment (Figures 1, 2 and 3).

Maize set more grains per ear and filled heavier grains in 1996/97 than in 1997/98 (Figures 1 and 2). Consequently, grain yield was higher in the first than in the second growing season, regardless of hybrid, planting date and row spacing (Figure 3). The yield difference between years was probably related to the seasonal variations in temperature, insolation and solar radiation. Generally speaking, the growing season of 1997/98 was cooler and cloudier than the previous season (Table 1). The number of insolation hours from November to March was 39% higher in the first growing season. Under well-watered conditions and ample nutrition, maize yield has been shown to be closely related to the amount of solar radiation intercepted by the crop (Tollenaar & Bruulsema, 1988; Muchow et al., 1990). Therefore the larger availability of solar radiation probably allowed plants to set more grains per ear and to produce heavier grains in 1996/97 than in 1997/98 (Figures 1 and 2).

Grain yield, number of grains per ear and weight of 1,000 grains were significantly affected by the single effect of row spacing or its interaction with planting date (Table 3). The row spacing reduction from 100 to 50 cm increased linearly the number of grains per ear, grain weight and maize grain yield (Figures 1, 2 and 3). Within the range of row widths

Table 1. Monthly variations of pluvial precipitation, temperature and insolation during the growing seasons of 1996/97 and 1997/98. Lages, SC.

Month	Pluvial precipitation (mm)	Air temperature (ºC)	Insolation (hours)
		1996/97	
September	182	14.0	180.8
October	113	16.8	149.6
November	85	19.0	224.2
December	161	21.3	215.4
January	350	21.9	194.8
February	340	21.9	151.7
March	43	19.6	232.8
April	26	17.1	229.6
		1997/98	
September	164	14.9	143.9
October	336	15.4	73.7
November	275	18.4	121.8
December	170	20.5	189.0
January	163	21.1	165.2
February	347	20.3	118.5
March	218	18.8	135.8
April	70	16.5	84.7

Table 2. Planting date effects on agronomic traits of maize, in two growing seasons, in Southern Brazil. Lages, SC(1).

Agronomic trait	Planting date of 1996/97 season		Planting date of 1997/98 season	
	10/01	11/15	10/01	11/15
Emergence-anthesis (days)	86.4a	68.7b	88.5a	70.8b
Emergence-silking (days)	97.1a	75.6b	99.3a	77.2b
Total leaf number	20.9b	22.8a	20.2b	21.6a
Leaf area (cm^2)	6,118b	7,258a	5,463b	6,915a
Lear area index	5.1b	5.6a	4.4b	5.5a
Plant height (cm)	273b	286a	231b	258a
Ear insertion height (cm)	128b	144a	98b	129a
Standability (%)	2.0b	4.6a	3.1b	4.8a

(1)Means of two cultivars and three row widths; means followed by the same small letter in the row, within each growing season, were not significantly different by the t test (P<0.05).

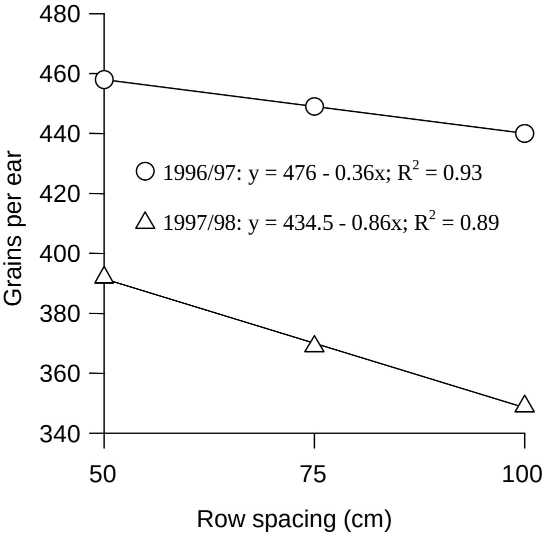

Figure 1. Row spacing effect on the number of grains per ear of maize in Southern Brazil, during the growing seasons of 1996/97 and 1997/98. Lages, SC.

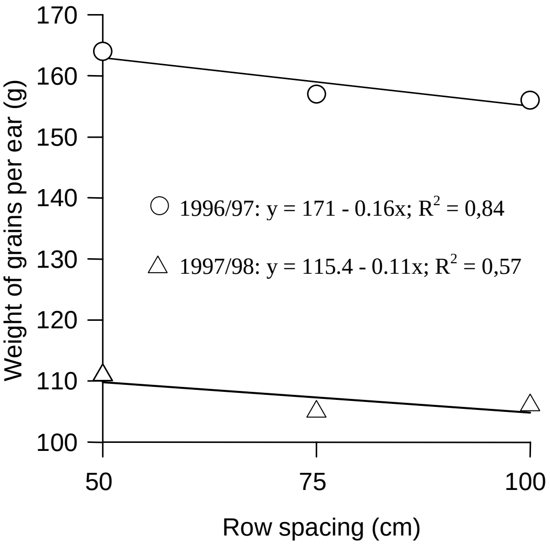

Figure 2. Row spacing effect on the weight of grains per ear of maize in Southern Brazil, during the growing seasons of 1996/97 and 1997/98. Lages, SC.

evaluated in the trial, there was an enhancement in grain yield that varied from 96 to 284 kg/ha, depending on the growing season and planting date, for each 10 cm of row spacing reduction (Figure 3). There was a significant interaction between row spacing and planting date, regarding to grain yield (Table 3). The advantage of using narrow rows was higher when maize was sown earlier in the growing season, specially in 1996/97.

The greater number of grains per ear, weight of grains and production per area presented by maize when sowed in narrowed than conventional row spacings is in agreement with the results obtained by Fulton (1970), Bullock et al. (1988) and Murphy et al. (1996). The yield edge promoted by the use of narrow rows may be related to a higher interception of solar radiation and a greater radiation use efficiency. Row spacing did not interfere significantly with leaf area and leaf area index at V10 and silking either separately or interacting with planting date and hybrid (Table 3). Therefore, the higher yields obtained with the use of narrow rows can not be attributed to a different pattern of leaf area development or a larger leaf surface area to intercept solar radiation. On the other hand, it is likely that the greater distance between adjacent plants within rows obtained with the use of narrow rows enhanced maize ability to convert the intercepted solar radiation to grain production. Several authors have noted that dry matter production in maize is related more closely to the utilization of solar radiation than to its interception (Daughtry et al., 1983; Tollenaar & Bruulsema, 1988; Westgate et al., 1997).

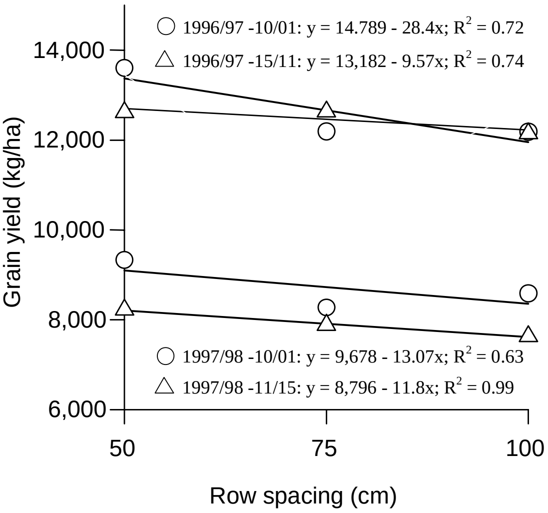

Figure 3. Planting date and row spacing effects on grain yield of maize in Southern Brazil, during the growing seasons of 1996/97 and 1997/98. Lages, SC.

The smaller competition among plants within rows for light, water and nutrients due to a more equidistant plant arrangement probably enhanced carbohydrate availability for the plant to set more grains per ear and produce heavier grains when row spacing was reduced form 100 to 50 cm (Figures 1 and 2). Therefore, the increases in those yield components contributed to the higher productivity presented by narrowed sown maize.

The higher response of grain yield to the reduction of row spacing presented by early planted maize is probably related to the effects of planting date on plant growth and development. When hybrids were sown in the beginning of October, they faced lower soil and air temperatures during their vegetative stages (Table 1). The smaller number of thermal units accumulated per day made plants grow slower when sown in October, increasing the number of days for each genotype to reach flowering (Table 2). The slower pattern of growth and development lead to the production of smaller and less leafy plants at anthesis (Table 2). As a consequence of that, leaf area and leaf area index were smaller in October than in November. The same kind of morphological and phenological effects caused by low temperatures have been reported previously by Al-Darby & Lowery (1987), Bolero et al. (1996) and Sangoi (1996).

Joining all the effects of planting date on maize phenotype with the greater impact of row spacing on grain yield when maize was sown in the beginning of spring, it may be postulated that the better plant distribution provided by narrow rows is more beneficial when the occurrence of low temperatures impose some limitation to leaf area and biomass production. This kind of trend was reported by Westgate et al. (1997) who emphasized that the use of narrow rows may be specially critical to enhance radiation use efficiency and grain yield in the relatively cool, short growing season regions typical of the Northern Corn Belt of the US.

Regardless of planting date, hybrid Ag 9014 required less days to reach flowering, was smaller, produced less leaves and had a lower leaf area and leaf area index than Ag 1051 (Table 4). There were significant correlation coefficients among leaf area, number of leaves, plant height and the number of days required for maize to reach the silking stage (Table 5). Despite the great morphological differences detected between hybrids, there was no significant interaction between row spacing and cultivar for grain yield, indicating that the productivity of both genotypes reacted similarly to the reduction of row spacing (Figure 3). There was also no significant correlation among grain yield, number of green leaves or plant height and the emergence-silking interval during both years (Table 5). This shows that there is potential to enhance maize grain yield with the use of narrow rows for early and late genotypes. The lack of interaction between row spacing and morphologically contrasting genotypes may be due to the fact that the hybrids used in the trial had a similar kind of leaf display. According to Westgate et al. (1997), the odds of identifying differences in cultivar response to the reduction of row spacing are greater when hybrids with different capacities for altering leaf display angles or with a whorled leaf display are compared.

The yield improvement obtained herein with the use of narrower than conventional row spacing has

Table 3. Mean squares and variation coefficients (VC for error A, B and C) for the major traits evaluated in the trial.

Source of variation	d.f.	Grain yield	Ears per plant	Grains per ear	Grain weight	Leaf area	Plant height	Emerg-silking	Leaf number
					1996/97				
Replication	3	2,134,923	0.0035	2,332	2,200	216,417	541	4.7	0.004
Planting date	1	456,885	0.0032	760	10,063	2,390,942*	2,912*	3,980*	42.1*
Error A	3	1,802,285	0.0037	1,072	5,955	326,513	323	3.9	0.86
Cultivar	1	574,437	0.0020	7,996	6,417	8,105,742*	748*	1,052*	76.6*
Plant x cultivar	1	204,232	0.0015	667	32	316,712	20	2.7	0.31
Error B	6	1,591,914	0.0019	3,723	1,989	245,422	16	2.1	0.07
Row spacing	2	3,884,390*	0.00077	11,254*	6,131*	202,278	248	0.7	0.01
Linear	1	7,209,563*	-	8,374*	10,102*	-	-	-	-
Quadratic	1	559,218	-	2,880	2,160	-	-	-	-
Residue	24	1,157,344	-	2,223	2,601	-	-	-	-
Plant x row sp.	2	4,088,258*	0.00032	5,702	1,493	196,507	54	0.6	0.29
Cultivar x row sp.	2	234,053	0.0010	471	2,406	91,026	89	0.8	0.073
Pl. x cul. x row	2	227,505	0.0011	462	2,825	5,970	125	2.0	0.04
Error C	24	1,157,344	0.00088	2,223	2,601	122,922	90	1.2	0.16
V.C. A (%)	-	4.4	0.8	9.8	8.9	3.3	2.6	1.6	1.7
V.C. B (%)	-	5.8	2.5	8.4	7.3	4.0	1.7	5.0	0.7
V.C. C (%)	-	8.5	3.0	14.8	14.5	5.4	3.4	4.0	1.8
					1997/98				
Replication	3	1,669,043	0.0010	3,966	1,042	461,428	417	5.8	0.003
Planting date	1	3,403,377	0.00025	2,338	5,002	25,303,931*	9,185*	5,830*	38.3*
Error A	3	951,569	0.0013	2,404	1,157	185,124	126	6.4	1.2
Cultivar	1	2,416,967	0.0018	2,310	176	27,320,433*	32,823*	1,989*	68.2*
Plant x cultivar	1	4,162,463	0.0013	6,745	320	126,552	130	4.5	0.28
Error B	6	1,363,948	0.0012	2,933	484	728,583	12	2.6	0.11
Row spacing	2	2,179,550*	0.00030	5,150*	1,670*	245,370	39	0.9	0.02
Linear	1	3,091,341*	-	8,180*	2,426*	-	-	-	-
Quadratic	1	1,267,760	-	2,120	914	-	-	-	-
Residue	24	440,140	-	1,486	468	-	-	-	-
Plant x row sp.	2	3,472,929*	0.00019	3,230	289	741,568	22	0.9	0.39
Cultivar x row sp.	2	182,373	0.00056	225	199	115,661	90	4.1	0.085
Pl. x cul. x row	2	760,696	0.00090	4,815	505	149,696	18	0.4	0.06
Error C	24	440,160	0.0012	1,486	468	265,037	40	1.6	0.11
V.C. A (%)	-	4.8	1.5	5.4	4.7	2.8	1.8	1.1	2.0
V.C. B (%)	-	8.1	2.0	8.4	4.3	7.9	0.8	1.0	1.2
V.C. C (%)	-	7.9	3.6	10.4	7.4	8.3	2.6	1.4	2.1

*Significant treatment effect at the P<0.05 level.

not been consistently reported elsewhere. Results from studies conducted by Forcella et al. (1992), Teasdale (1995), Merotto Júnior et al. (1997) e Westgate et al. (1997) showed no positive impact on grain yield of planting maize in narrow rows. The mixed results published in the literature may be attributed to several factors, such as the choice of hybrid, plant population, soil fertility ant the weather pattern during the experimental period.

Table 4. Agronomic traits of two maize hybrids in growing seasons of 1996/97 and 1997/98, in Southern Brazil. Lages, SC(1).

Agronomic trait	Growing season of 1996/97		Growing season of 1997/98	
	Ag 9014	Ag 1051	Ag 9014	Ag 1051
Emergence-anthesis (days)	74.8b	80.1a	76.6b	82.8a
Emergence-silking (days)	80.1b	91.2a	81.8b	94.7a
Total leaf number	20.9b	22.8a	20.0b	22.2a
Leaf area (cm^2)	6,677b	7,498a	5,435b	6,944a
Lear area index	5.0b	5.6a	4.3b	5.5a
Plant height (cm)	245b	314a	230b	259a
Ear insertion height (cm)	110b	165a	94b	132a

(1) Means of two planting dates and three row widths; means followed by the same small letter in the row, within each growing season, were not significantly different by the t test ($P<0.05$).

The use of narrow rows has the potential to improve maize grain yield, particularly when high plant populations are established because the combination of dense stands and wide rows favor an intense intra-row competition for environmental resources (Sangoi, 1996). On the other hand, a limiting factor to grow maize at high plant population is barrenness (Sangoi, 1996). The failure of plants to produce viable ears is stimulated by water deficit and poor soil fertility (Sangoi & Salvador, 1998). In the present study, the number of ears produced per plant ranged from 0.96 to 1.02 and was not affected significantly by planting date, hybrid and row spacing (Table 3). The ear indexes close to 1.0 indicated a very low percentage of barren plants even with the high plant population used in the trial (75,000 plants/ha).

Therefore, it can be postulated that a combination of high soil fertility, adequate water distribution during the growing cycle, the use of genetically superior hybrids not prone to barrenness, sown at high plant populations, are combined factors that help to explain the positive effects of reducing row spacing on improving radiation use efficiency and enhancing maize grain yield in the current paper.

Table 5. Coefficients of correlation among grain yield, number of grains per ear, grain weight, number of ears per plant, leaf area, number of leaves per plant, plant height and days from emergence to silking of two maize hybrids, at two planting dates and three row spacings. Lages, SC.

Variable	Grain yield	Grains per ear	Grain weight	Ears per plant	Leaf area	Plant height	Number of leaves	Emergence-silking
					1996/97			
Grain yield	-	0.62*	0.12	0.01	0.30	0.07	-0.01	0.02
Grains per ear	0.62*	-	-0.57*	-0.25	0.49*	0.50*	0.33*	0.30
Grain weight	0.12	-0.57*	-	-0.15	-0.23	-0.50*	-0.25	-0.20
Ears per plant	0.01	0.25	-0.15	-	-0.15	-0.20	-0.30	-0.30
Leaf area	0.30	0.49*	-0.23	-0.15	-	0.40*	0.48*	0.44*
Plant height	0.07	0.50*	-0.50*	-0.20	0.40*	-	0.74*	0.70*
Number of leaves	-0.01	0.33*	-0.25	-0.30	0.48*	0.74*	-	0.96*
Emergence-silking	0.02	0.30	-0.20	-0.30	0.44*	0.70*	0.96*	-
					1997/98			
Grain yield	-	0.69*	0.16	0.43*	-0.20	-0.29	-0.28	0.09
Grains per ear	0.69*	-	-0.58*	0.17	0.18	-0.01	-0.01	-0.18
Grain weight	0.16	-0.58*	-	0.01	-0.38*	-0.16	-0.12	0.11
Ears per plant	0.43*	0.17	0.01	-	-0.22	-0.43*	-0.53*	-0.22
Leaf area	-0.20	0.18	-0.38*	-0.22	-	0.84*	0.71*	0.45*
Plant height	-0.29	-0.01	-0.16	-0.43*	0.84*	-	0.85*	0.62*
Number of leaves	-0.28	-0.01	-0.12	-0.53	0.71*	0.85*	-	0.79*
Emergence-silking	0.09	-0.18	0.11	-0.22	0.45*	0.62*	0.79*	-

*Significant differences at the $P<0.05$ level.

The potential to recommend a reduction in the row spacings presently used by most maize growers in Southern Brazil must be evaluated not only from a yield response perspective but also considering the overall economics of the system. There are many modifications and alterations that need to be considered to correctly determine the real benefits derived from the use of narrow rows (Paszkiewicz, 1996; Porter et al., 1997). Planters, sprayers, cultivators, corn heads, tractor rims and tires may need to be modified. Additionally, some important inputs applied directly to the planting rows, such as fertilizers and insecticides may change as row spacing is reduced. Those adaptations will increase production costs in a short-range term and need to be counterbalanced with the potential advantages provided by narrow rows.

The results depicted in this study indicate that yield increases may pay for added inputs and machinery modifications in a long range term for producers that grow maize in regions with a short growing season, at high plant densities, under high levels of soil fertility and favorable weather conditions, which allow them to accomplish elevated grain yields.

Conclusions

1. The use of narrower than conventional row spacing improves maize grain yield in the regions with a short summer in Southern Brazil.
2. The advantages of using narrow rows are greater when maize is sown early in the growing season.
3. Hybrid cycle and plant architecture do not interfere with maize response to the reduction of row spacing.

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