Effect of seeding date and seeding rate on flea beetle damage and agronomic performance of open-pollinated and hybrid Argentine canola under different tillage practices in 2001-2006

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ABSTRACT

Fifteen field tests were conducted in 2001-2006 to investigate the effect of seeding date and seeding rate on flea beetle damage and performance of Argentine canola in conventional tillage (CT) and minimum tillage (MT). Certified No. 1 seed lots of an open-pollinated (op) cultivar (‘SW Arrow’ or ‘SP Banner’) and hybrid cultivar (‘InVigor 2663' or ‘InVigor 5020') were planted in six-row plots at six different seeding rates (8, 16, 25, 33, 41 and 49 seeds/m-row) using 0.30 m row-spacing and 1.0-2.5 cm planting depth. Depending on 1000-seed weight, seeding rates ranged from 0.7-5.8 lb/acre (0.8-6.5 kg/ha) in the op cultivars and from 0.8-7.5 lb/acre (0.9-8.4 kg/ha) in the hybrid cultivars. Tests in MT were seeded in early to mid May when soil temperatures averaged 7-17˚C and in late May or early June when soil temperatures averaged 14-21˚C. Agronomic assessments focused on % seedling establishment, plants/m^2, shoot dry weight, biomass accumulation and seed yield. Gross and net returns with different seeding rates of each cultivar were also determined.

Flea beetle damage was relatively low in all field tests. With the exception of 2006, flea beetle damage was not significantly different in cultivars of op and hybrid Argentine canola. With the exception of 2005, damage was 3-12% higher in CT than in MT. Damage in MT ranged from 1-8% when plots were seeded early and from 1-5% when plots were seeded late. Seeding rate had no significant effect in flea beetle damage in most tests with CT (3/5 tests) and all tests with MT (10/10 tests). With CT, damage in 2003 and 2006 was 2-3% higher when cultivars were seeded at the lowest rate rather than at the highest rate.

Seedling establishment varied depending on the year, tillage practice and planting date. Establishment in most tests was not significantly different in the op and hybrid cultivars. Establishment in CT plots averaged 60 ±1% with very dry conditions in 2002 and 90 ± 2% with very moist conditions in 2005 and 2006. Establishment in 2002-2006 averaged 81% in the op cultivars and 84% in the hybrid cultivars. Establishment in early- and late-seeded MT plots averaged 43 ± 2% and 52 ± 1%, respectively, with very dry conditions in 2001 and 75 ± 1% and 88 ± 1%, respectively, with very moist conditions in 2006. Establishment in early- and late-seeded MT plots in 2001-2006 averaged 61% and 70%, respectively, in the op cultivars and 64% and 74%, respectively, in the hybrid cultivars. Results indicated that early seeding reduces establishment by 9-10%. Seeding rate had no significant effect on % establishment of either cultivar in all tests with CT or MT.

Seedling densities varied depending on the year, cultivar, tillage practice, planting date and seeding rate. Densities after 21-24 days in CT (n=6 rates) averaged 16-17 seedlings/m-row with very dry conditions in 2002 and 24-26 seedlings/m-row in the remaining tests. Densities in 2002-2006 averaged 23 seedling/m-row in the op cultivars and 24 seedlings/m-row in the hybrid cultivars. In early-seeded MT plots, seedling counts after 20-24 days averaged 12-13 seedlings/m-row in 2001 compared to 18-22 seedlings/m-row in 2004-2005. In late-seeded MT plots, seedling densities

averaged 14-17 seedlings/m-row in 2001 and 2003 compared to 19-25 seedlings/m-row in 2004-2006. Over five years, seedling densities of the op and hybrid cultivars averaged 17 and 18 seedlings/m-row, respectively, in early MT plots and 20 and 21 seedlings/m-row, respectively, in late MT plots. Plant densities in all tests increased in direct proportion with an increase in seeding rate. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, plant densities in CT averaged 21, 46, 67, 89, 107 and 129 plants/m² in the op cultivars and 22, 45, 68, 90, 112 and 138 plants/m² in the hybrid cultivars. Minimum plant densities for re-seeding were reached or exceeded with a seeding rate of 16 seeds/m-row in the op cultivars and 8 seeds/m-row in the hybrid cultivars. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, plant densities of the op cultivars in 2001-2006 averaged 15, 29, 49, 63, 87 and 99 plants/m² in early MT plots and 20, 38, 55, 74, 96 and 112 plants/m² in late MT plots. With identical seeding rates, plant densities of the hybrid cultivars in 2001-2006 averaged 17, 36, 53, 67, 83 and 106 plants/m² in early MT plots and 20, 38, 58, 79, 103 and 118 plants/m² in late MT plots. In early MT plots, minimum plant densities for re-seeding were reached or exceeded with a seeding rate of 25-33 seeds/m-row in the op cultivars and 16 seeds/m-row in the hybrid cultivars. In late MT plots, minimum plant densities for re-seeding were exceeded with a seeding rate of 16-25 seeds/m-row in the op cultivars and 16 seeds/m-row in the hybrid cultivars.

Shoot dry weight of Argentine canola after 15, 22 and 29 ± 2 days varied depending on the year, cultivar, tillage practice and planting date. Shoot weights in CT plots were lowest in 2002 and highest in 2003 and 2006. Shoot weights in early and late MT plots were lowest in 2004 and highest in 2003. In each tillage system, shoot weights were 1.4-1.5 times higher in the hybrid cultivars than in the op cultivars. Shoot weights in MT plots were 2.2-2.5 times higher when cultivars were seeded late rather than early. Seeding rate had no effect on shoot weights of either cultivar in most tests with CT or MT.

Shoot biomass of op and hybrid cultivars after 15, 22 and 29 ± 2 days varied depending on the year, cultivar, tillage practice, planting date and seeding rate. Shoot biomass in CT plots was lowest with dry conditions in 2002 and highest with very moist conditions in 2006. Shoot biomass in early- and late-seeded MT plots was lowest with dry conditions in 2001 and cool conditions in 2004. Over 5 years, shoot biomass after 15, 22 and 29 ± 2 days in CT and MT was, on average, 1.4-1.6 times higher in the hybrid cultivars than in the op cultivars. Shoot biomass in MT plots was 2.3-3.0 times higher when cultivars were seeded late rather than early. In most instances, shoot biomass on each of the three sampling dates increased linearly as seeding rates increased. With the exception of 2003, the shoot biomass of hybrid cultivars seeded at 25 or 33 seeds/m-row was equal to that of the op cultivars seeded at 49 seeds/m-row.

Seed yields varied depending on the year, cultivar, tillage practice and planting date. Yields of op and hybrid cultivars in CT ranged from 130 g/m² (23 bu/acre) in 2003 to 382 g/m² (68 bu/acre) in 2005. With the exception of 2003, yields were, on average, 23% higher in the hybrid cultivars (273 g/m², 48.7 bu/acre) than in the op cultivars (222 g/m², 39.7 bu/acre). In early and late MT plots, yields ranged from 72 g/m² (12 bu/acre) in 2001 to 342 g/m² (61 bu/acre) in 2005. Yields in early-seeded MT plots were 22% higher in the hybrid cultivars (256 g/m², 45.7 bu/acre) than in the op cultivars (210 g/m², 37.6 bu/acre). Yields in the late-seeded MT plots were 19% higher in the hybrid cultivars (215 g/m², 38.3 bu/acre) than in the op cultivars (181 g/m², 32.2 bu/acre). Planting in early to mid May rather than late May or early June improved yields by 17% in the op cultivars and by 19% in the hybrid cultivars.

In CT, seeding rate had a significant effect on yield in 4/5 tests on op cultivars and 5/5 tests on hybrid cultivars. Depending on the year, yields in each cultivar increased either linearly or curvilinearly as seeding rates increased. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields in 2002-2006 averaged 178, 220, 222, 239, 235 and 240 g/m², respectively, in the op cultivars and 237, 269, 281, 282, 285 and 284 g/m², respectively, in the hybrid cultivars. Optimum yields in the op cultivars were attained with a seeding rate of 33 seeds/m-row (3.6 lb/acre, 4.0 kg/ha) and plant density of 85-90 plants/m². Optimum yields in the hybrid cultivars were attained with a seeding rate of 25 seeds/m-row (3.2 lb/acre, 3.6 kg/ha) and plant density of 65-70 plants/m².

In early MT plots, seeding rate had a significant effect on yield in 2/5 tests on op cultivars and 4/5 tests in hybrid cultivars. Yields increased linearly or curvilinearly as seeding rates increased. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields in 2001-2006 averaged 191, 206, 214, 219, 219 and 214 g/m², respectively, in the op cultivars and 236, 261, 262, 264, 257 and 257 g/m², respectively, in the hybrid cultivars. Optimum yields in the op cultivars were attained with a seeding rate of 33 seeds/m-row (3.5 lb/acre, 3.9 kg/ha) and plant density of 60-65 plants/m². Optimum yields in the hybrid cultivars were attained with a seeding rate of 16 seeds/m-row (2.1 lb/acre, 2.4 kg/ha) and plant density of 35-40 plants/m².

In late MT plots, seeding rate had a significant effect on yield in 4/5 tests on op cultivars and 1/5 tests on hybrid cultivars. Yields increased linearly or curvilinearly as seeding rates increased. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields in 2001-2006 averaged 157, 172, 184, 186, 194 and 191 g/m² in the op cultivars and 201, 212, 215, 220, 223 and 217 g/m² in the hybrid cultivars. Optimum yields in the op cultivars were attained with a seeding rate of 41 seeds/m-row (4.4 lb/acre, 4.9 kg/ha) and plant density of 95-100 plants/m². Optimum yields in the hybrid cultivars were attained with seeding rates of 33 seeds/m-row (4.3 lb/acre, 4.8 kg/ha) and plant population of 80 plants/m².

Seeding rate and plant density had a pronounced effect on gross and net returns from the op cultivars in each tillage system. Calculations were based on a canola price of $7.50/bu and cost of $4.00/lb for Certified No. 1 seed. Depending on seeding rate, gross returns from the op cultivars over 5 years ranged from $237.80/acre-$320.30/acre in CT plots, from $255.00/acre-$292.50/acre in early MT plots and from $209.30/acre-$258.80/acre in late MT plots. After subtracting seed costs, net returns in CT plots ranged from $234.20/acre-$304.40/acre. A seeding rate of 3.6 lb/acre (4.0 kg/ha) and plant density of 90 plants/m² provided the highest net returns in CT. Net returns from op cultivars ranged from $251.40/acre-$278.50/acre in early-seeded MT plots and from $205.70-$241.20/acre in late-seeded MT plots. A seeding rate of 3.5 lb/acre (3.9 kg/ha) and plant density of 60-65 plants/m² provided the highest net return in early MT plots. A seeding rate of 4.4 lb/acre (4.9 kg/ha) and plant density of 95-100 plants/m² provided the highest net return from op cultivars in late-seeded MT plots.

Seeding rate and plant density also had a pronounced effect on gross and net returns from the hybrid cultivars in each tillage system. Calculations were based on a canola price of $7.50/bu and cost of $7.50/lb for Certified No.1 seed. Depending on seeding rate, gross returns from the hybrid cultivars in 5 tests ranged from $316.50/acre-$380.30/acre in CT plots, from $315.00/acre-$352.50/acre in early MT plots and from $268.50/acre-$297.80/acre in late MT plots. Net returns in CT plots ranged from $308.20/acre-$351.00/acre. A seeding rate of 3.2 lb/acre (3.6 kg/ha) and plant density of 65-70 plants/m² provided the highest net return in CT plots. Net returns from hybrid cultivars ranged from $294.80/acre-$333.00/acre in early MT plots and from $241.50/acre-$267.00/acre in late MT plots. A seeding rate of 2.1 lb/acre (2.4 kg/ha) and plant density of 35-40 plants/m² provided the highest net return from hybrid cultivars in both early- and late-seeded MT plots.

Recommended seeding rates for canola production in western Canada are 5-8 lb/acre or 5.6-9.0 kg/ha. Results in the current study indicate that high quality seed lots of op and hybrid Argentine canola can be planted at lower than recommended rates without compromising economic returns. With early seeding in MT, a 1.5-4.5 lb/acre reduction in seeding rate for op cultivars would reduce seed costs by $6-18/acre ($14.80-44.46/ha) and reduce seed treatment use by 30-55%. Similarly, with early seeding in MT, a 2.9-5.9 lb/acre reduction in seeding rate for hybrid cultivars would reduce seed costs by $21.75-44.25/acre ($53.72-109.30/ha) and reduce seed treatment use by 55-70%.

INTRODUCTION

Environmental conditions, seed quality and seeding practices are known to have a substantial effect on establishment and seed yield of Argentine canola, *Brassica napus* (Anonymous 2002, Thomas 2003). Depending on growing conditions and seed quality, stand establishment can range from 15-80% (Elliott *et al.* 2005, 2007a-c). In the latter studies, establishment was lowest with reduced tillage, heavy-textured soil, below average rainfall and cool soil. Seed lots with high germination, low electrical conductivity and high seed weight provided the best establishment, highest shoot growth and highest seed yield (Elliott *et al.* 2007a-c). With the variation in establishment, recommended seeding rates for Argentine canola in western Canada range from 5-8 lb/acre or 5.6-9.0 kg/ha (Thomas 2003). Guidelines in the Canola Growers Manual also indicate that plant stands of 40-200 plants/m² are required for high seed yield. Re-seeding of conventional open-pollinated (op) cultivars and herbicide-tolerant hybrid cultivars is recommended when plant densities fall below 32-43 plants/m² and 11-22 plants/m², respectively. Higher seed yields can be attained by planting large seed (Elliott *et al.* 2007a,b), planting hybrid cultivars rather than op cultivars (Harker *et al.* 2003), seeding early rather than seeding late (Anonymous 2002, Blackshaw *et al.* 2005, Chen *et al.* 2005) and seeding at higher rates (Dosdall *et al.* 1998, Harker *et al.* 2003, Blackwell *et al.* 2005). Dosdall *et al.* (1998) found that seeding rates of 9-11 kg/ha provided the highest yields. Harker *et al.* (2003) reported that yields were higher with seeding rates of 150-200 seeds/m² than with rates of 100 seeds/m². In contrast, yields of yellow mustard, *Sinapis alba*, were not significantly different with plant densities between 75 and 300 plants/m² (McKenzie *et al.* 2006). Chen *et al.* (2005) also found that relatively low seeding rates (32-65 seeds/m²) were sufficient for high yields in Argentine canola.

The primary objective of this study was to determine the effect of seeding rate on the agronomic performance of op and hybrid Argentine canola in conventional tillage and minimum tillage. In the latter tests, seed lots were planted into relatively cool soil in early May and into warmer soils in late May or early June. Experiments focused on identifying seeding rates and plant densities that provide the highest seed yield and best economic returns in each tillage system. The effects of seeding rate on flea beetle damage, stand establishment, shoot growth and biomass accumulation were also investigated.

EXPERIMENTAL METHODS

Land preparation

Field tests were conducted in conventional tillage (CT) and minimum tillage (MT) in 2001-2006 at the Agriculture and Agri-Food Canada Research Farm, Saskatoon Research Centre. Tests in CT were seeded May 19-30. Tests in MT were seeded in early May (May 11-16) and in late May or early June (May 24 -June 2). Fertility requirements were based on yearly soil test recommendations for canola production. In plots under CT, a fertilizer blend (N/P/K/S) was banded into summer fallow at a 5-10 cm depth in the fall or early spring. In plots under MT, the fertilizer was side-banded into tilled wheat stubble at planting. In plots under CT, a pre-plant herbicide (Treflan™, trifluralin, 480g a.i./L) was applied in the fall or early spring at 1.7-2.2 L product/ha and incorporated with a cultivator and harrows. In plots under MT, a pre-plant herbicide (Roundup™, glyphosate, 356 g a.i./L or Roundup Ultra™, glyphosate, 540 g a.i./L) was applied at 1.2 or 1.0 L product/ha in 2001-2003 and 2006. A post-emergent herbicide (Select™, clethodim, 240 g a.i./L) was applied at 120-190 ml product/ha in 2004, 2005 and 2006. A post-emergent herbicide (Muster™, 75% ethametsufuron-methyl) was also applied in 2004 at 24 g product/ha. Precipitation and soil temperatures at 2.5 cm depth were recorded daily in each test (Table 1).

Seeding rate

Field tests were conducted annually on certified seed lots of an open-pollinated Argentine cultivar (SW Arrow or SP Banner) and hybrid Argentine cultivar (InVigor 2663 or InVigor 5020). Seed lots were treated with a commercial seed treatment (Helix®, thiamethoxam, 200 g ai/100 kg seed) and planted in six-row plots at six different rates (50, 100, 150, 200, 250 and 300 seeds per 6.1 m row) using 0.30 m row-spacing and 1.0-2.5 cm planting depth. The seeding rates were equivalent to 8, 16, 25, 33, 41 and 49 seeds/m-row. Seeding rates of each cultivar in lb/acre or kg/ha varied yearly depending on 1000-seed weight (Table 2). Tests in CT were planted with a double-disc press drill equipped with on-row packers. Tests in MT were planted with a hoe drill with on-row packers. Each test was replicated four times using a randomized split-plot design with cultivars as main plots and seeding rate as subplots.

Damage and agronomic assessments

Flea beetle damage to 20 cotyledons from each subplot was assessed using a 10-point rating scale that corresponded to the percentage of cotyledon surface eaten by flea beetles (Palaniswamy *et al*. 1992). Damage was assessed 14 and 21 days after seeding (DAS). Seedlings along a centre row of each subplot were counted 13-14 and 20-24 DAS. Shoot growth was evaluated by harvesting 10 plants from the outer rows of each subplot 13-17, 20-24 and 27-31 DAS. Samples were placed in plastic bags, labeled and transported to the laboratory in coolers. Shoots were cleaned and weighed to determine shoot fresh weight. Samples were dried at 60°C for 4 - 7 d to assess shoot dry weight. Shoot biomass was calculated from the number of seedlings/m-row and shoot fresh weight. The four centre rows of each subplot were swathed and harvested at maturity with a small-plot combine to determine seed yield.

Statistical analyses

Data were analyzed using the General Linear Model procedure (SAS Institute 1999). Data from each test were analyzed as a split-plot design with cultivars as main plots and seeding rate as subplots. Data from each cultivar were analyzed separately when the cultivar by seeding rate interaction was significant ($P \leq 0.05$). Analysis of variance was used to compare cultivar means. Fisher's protected LSD test ($P \leq 0.05$)

and orthogonal contrasts for linear, quadratic and cubic trends were used to assess the effect of seeding rate on flea beetle damage, plant densities, shoot growth, biomass and seed yield.

RESULTS AND DISCUSSION

Field conditions

Field conditions varied depending upon the year, tillage practice and planting date (Table 1). Moisture conditions at planting were relatively poor in 2001, 2002 and 2003 and above-average in 2005 and 2006. Soil temperatures at planting depth in CT ranged from 8°C in 2004 to 22°C in 2006. Corresponding temperatures in MT ranged from 7-17°C in plots seeded May 13-16 and from 14-21°C in plots seeded May 28-June 2. Soil temperatures increased 4-7°C when seeding was delayed for 13-17 days. Precipitation in July-August was lower in 2001 (58 mm), 2003 (79 mm) and 2006 (62 mm) than in 2002 (145 mm), 2004 (148 mm) and 2005 (107 mm).

Seed weights and seeding rates

Thousand-seed weights differed among seed lots of open-pollinated (op) and hybrid Argentine canola (Table 2). Seed weights ranged from 3.21-4.04 g in seed lots of the op cultivars and from 3.39-5.18 g in seed lots of the hybrid cultivars. With the exception of 2003, seed weights were higher in the hybrid cultivars than in the op cultivars. Differences in seed weights between cultivars were greater in 2004-2006 (0.95-1.29 g difference) than in 2002 (0.65 g difference) or 2003 (0.10 g difference). Over the range of rates tested (8-49 seeds/m-row), seeding rates of the op cultivars ranged from 0.7-4.4 lb/acre (0.8-4.9 kg/ha) in 2001 to 1.0-5.8 lb/acre (1.1-6.5 kg/ha) in 2006. Corresponding rates of the hybrid cultivars ranged from 0.8-4.8 lb/acre (0.9-5.4 kg/ha) in 2003 to 1.3-7.5 lb/acre (1.4-8.4 kg/ha) in 2006.

Flea beetle damage

Previous studies have shown that flea beetle damage may be affected by tillage practices, planting date, seeding rate and seed size or seed weight (Milbrath *et al*. 1995, Dosdall *et al*. 1999, Dosdall and Stevenson 2005, Elliott *et al*. 2007a, b). In the present study, flea beetle damage was relatively low in all field tests (Table 3). With the exception of 2006, flea beetle damage was not significantly different in cultivars of op and hybrid Argentine canola. Contrary to previous findings (Elliott *et al*. 2007a, b), differences in seed size and seed weight between the two breeding types had no effect on flea beetle damage. With the exception of 2005, flea beetle damage was 3-12% higher in CT than in MT. In previous studies, flea beetle damage was also higher when canola was grown in CT than in zero tillage (Milbrath *et al*. 1995, Dosdall *et al*. 1999). Under CT, flea beetle damage after 21 days varied yearly, ranging from less than 1% in 2005 to 15% in 2002. Under MT, damage ranged from 1-8% when plots were seeded May 13-16 and from 1-5% when plots were seeded May 28-June 2. Milbrath *et al*. (1995) reported that flea beetle numbers on oilseed crucifers tend to decline when planting is delayed from mid May until mid June. However, Dosdall and Stevenson (2005) found that planting date had no effect on flea beetle damage to spring-sown canola. In the current study, planting date had no effect on flea beetle damage to canola grown under MT in 2004, 2005 and 2006. Damage averaged 2% or less in these tests. In contrast, when damage reached 5-8% in 2003, damage was 2-3% higher when canola was planted in mid-May rather than in late May.

Seeding rate had no significant effect on flea beetle damage in most tests under CT (3/5 tests) and all tests under MT (10/10 tests). However, in plots with CT, damage in 2003 and 2006 was 2-3% higher when cultivars were seeded at the lowest rate rather than at the highest rate. Dosdall and Stevenson (2005) also found that flea beetle damage tended to decline with an increase in seeding rate. In the latter study, canola seeds were not treated with an insecticide and were planted at relatively high seeding rates (7.5-12.5 kg/ha) and plant densities (120-240 plants/m^2).

Seedling establishment

Limited information has been published on the relationship between seeding rate and establishment of canola seedlings under different growing conditions and tillage practices. In the present study, seedling establishment after 13-24 days (n = 6 seeding rates) varied depending on the year, tillage practice and planting date (Table 4). Establishment in CT after 21-22 days averaged 59-61% with very dry conditions in 2002 and 89-92% with very moist conditions in 2005 and 2006. Establishment was 3-5% higher in the hybrid cultivar than in the op cultivar in 2004 and 2006. In other years establishment was not significantly different in the two cultivars or breeding types. Establishment in 2002-2006 averaged 81% in the op cultivars and 84% in the hybrid cultivars. Establishment of op and hybrid cultivars was not significantly different after 20-24 days in all tests with MT. Establishment in early MT plots averaged 41-45% with dry conditions in 2001 and 74-76% with very moist conditions in 2006. Over 5 years, establishment in early-seeded plots averaged 61% in the op cultivars and 64% in the hybrid cultivars. Establishment in late MT plots averaged 51-53% with dry conditions in 2001 and 88% with very moist conditions in 2006. Establishment in late-seeded plots averaged 70% in the op cultivars and 74% in the hybrid cultivars. Results indicated that early planting reduced seedling establishment by 9-10%. In contrast, Dosdall and Stevenson (2005) found that plant densities and establishment were higher in early-seeded plots than in late-seeded plots.

Seeding rate had no significant effect on % establishment of op and hybrid cultivars in all tests with CT or MT.

Seedling densities

Seedling densities (n = 6 seeding rates) varied depending on the year, cultivar, tillage practice and planting date (Table 5). Counts after 21-24 days in CT averaged 16-17 seedlings/m-row in 2002 compared to 24-26 seedlings/m-row in the remaining tests. Seedling densities were significantly higher in the hybrid cultivar than in the op cultivar in 2004 and 2006 but not in other years. Densities over 5 years averaged 23 seedlings/m-row in the op cultivars compared to 24 seedlings/m-row in the hybrid cultivars. Seedling counts after 20-24 days in early MT plots averaged 12-13 seedlings/m-row in 2001 compared to 16 seedlings/m-row in 2003 and 18-22 seedlings/m-row in 2004, 2005 and 2006. Seedling densities were higher in the hybrid cultivar than in the op cultivar in 2005 but not in other years. Counts after 20-22 days in late MT plots averaged 14-17 seedlings/m-row in 2001 and 2003 compared to 19-25 seedlings/m-row in 2004-2006. Counts were significantly higher in the hybrid cultivar than in the op cultivar in 2004 and 2005. Over 5 years, seedling densities of the op and hybrid cultivars averaged 17 and 18 seedlings/m-row, respectively, in early MT plots and 20 and 21 seedlings/m-row, respectively, in late MT plots.

Seeding rate had a significant effect on plant densities in all tests under CT (Figure 1). In each cultivar, plants/m^2 after 21-24 days increased linearly in direct proportion with an increase in seeding rate. Based on current guidelines for canola (Thomas 2003), minimum plant densities for re-seeding an op cultivar (32-43 plants/m^2) were reached or exceeded with a seeding rate of 16 seeds/m-row in each test. Minimum plant densities for re-seeding a hybrid cultivar (11-22 plants/m^2) were reached or exceeded with a seeding rate of 8 seeds/m-row in each test. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, plant densities over 5 years averaged 21, 46, 67, 89, 107 and 129 plants/m^2 in the op cultivars and 22, 45, 68, 90, 112 and 138 plants/m^2 in the hybrid cultivars.

Seeding rate had a significant effect on plant densities in early MT plots (Fig. 2). Plants/m^2 after 20-24 days increased linearly or curvilinearly as seeding rates increased. Minimum plant densities for re-seeding an op cultivar were attained with a seeding rate of 33 seeds/m-row under dry conditions in 2001 and 25 seeds/m-row under moist conditions in 2003-2006. Minimum plant densities for re-seeding a hybrid cultivar were exceeded with a seeding rate of 16 seeds/m-row in each test. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, plant densities in 2001-2006 averaged 15, 29, 49, 63, 87 and 99 plants/m^2 in the op cultivars and 17, 36, 53, 67, 83 and 106 plants/m^2 in the hybrid cultivars. Depending on seeding rate, plant densities were 2-7 plants/m^2 higher in the hybrid cultivars than in the op cultivars.

Seeding rate had a significant effect on plant densities in late MT plots (Fig. 3). Minimum plant densities for re-seeding an op cultivar were attained with a seeding rate of 16 seeds/m-row with warm moist conditions in 2005 and 2006 and 25 seeds/m-row with dry conditions in 2002 and cool conditions in 2004. Minimum plant densities for re-seeding a hybrid cultivar were exceeded with a seeding rate of 16 seeds/m-row in each test. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, plant densities in 2001-2006 averaged 20, 38, 55, 74, 96 and 112 plants/m^2 in the op cultivars and 20, 38, 58, 79, 103 and 118 plants/m^2 in the hybrid cultivars. Differences in plant densities between the op and hybrid cultivars were greater at the two highest seeding rates than at the two lowest rates.

Shoot dry weights

Shoot dry weights of Argentine canola after 13-31 days varied depending on the year, cultivar, tillage practice and planting date (Table 6). Shoot weights in CT were lowest in 2002 and highest in 2003 and 2006. With the exception of 2003, shoot weights on each of the three sampling dates were significantly higher in the hybrid cultivars than in the op cultivars. Over 5 years, shoot weights after 14, 20-21 and 27-28 days were 1.4-1.5 times higher in the hybrid cultivars than in the op cultivars. Shoot dry weights in early and late MT plots were lowest in 2004 and highest in 2006. With the exception of 2003, shoot weights were significantly higher in the hybrid cultivars than in the op cultivars. Over 5 years, shoot weights after 13-17, 20-24 and 27-31 days were 1.3-1.5 times higher in the hybrid cultivar than in the op cultivar. Shoot weights were 2.2-2.5 times higher when cultivars were seeded in late May than in early May.

In most instances, seeding rate had no effect on the shoot dry weight of the op and hybrid cultivars in CT (Figs. 4 and 5). However, there were three exceptions. With higher seeding rates, shoot weights of the op cultivar followed a curvilinear trend (cubic) after 20 and 28 days in 2006. Higher seeding rates reduced the shoot weight of the op cultivar after 21 days in 2003 and reduced the shoot weight of the hybrid cultivar after 27 days in 2005.

With the exception of three tests, seeding rate had no effect on the shoot dry weight of the two cultivars in early and late MT plots (Figs. 6-9). With higher seeding rates, shoot weights of the hybrid cultivar followed a curvilinear trend after 29 days in the late planting in 2001. With higher seeding rates, shoot weights of the hybrid cultivar increased after 28 days in the early planting in 2004. Higher seeding rates had the opposite effect on shoot weights of the hybrid cultivar after 20 days in the late planting in 2005.

Shoot biomass

Shoot biomass of the two cultivars varied depending on the year, cultivar, tillage practice and planting date (Table 7). In CT, shoot biomass after 14-28 days was lowest with dry conditions in 2002 and highest with very moist conditions in 2006. With the exception of 2003, shoot biomass on all sampling dates was significantly higher in the hybrid cultivar than in the op cultivar. Over 5 years, shoot biomass after 14, 20-21 and 27-28 days was 1.4-1.6 times higher in the hybrid cultivars than in the op cultivars. Shoot biomass in early and late MT plots was lowest with dry conditions in 2001 and cool conditions in 2004. Over 5 years, shoot biomass after 13-17, 20-24 and 27-31 days was 1.4-1.6 times higher in the hybrid cultivars than in the op cultivars. Shoot biomass was 2.3-3.0 times higher when cultivars were seeded in late May rather than in early May.

Seeding rate had a significant effect on biomass accumulation in all tests under CT (Figs. 10 and 11) and MT (Figs. 12-15). In most instances, shoot biomass after 13-17, 20-24 and 27-31 days increased linearly as seeding rates increased. With the exception of 2003, the shoot biomass of the hybrid cultivars seeded at 25 or 33 seeds/m-row was equal to that of the op cultivars seeded at 49 seeds/m-row (Figs. 11, 13 and 15).

Seed yield

Previous investigations have shown that seed yields of *Brassica* crops are influenced by environmental conditions, seeding date and cultivar selection. Seeding date had no effect on canola yields when precipitation was below normal (Dosdall and Stevenson 2005). However, under favourable conditions, seeding in April rather than mid-May improved yields by 37% in yellow mustard (McKenzie *et al*. 2006) and by 43-63% in Argentine canola (Chen *et al*. 2005). Seeding in early May rather than in late May improved canola yields by 14% (Anonymous 2002). In more recent studies, seeding in April rather than in May improved canola yields by 13-400% (Blackshaw *et al*. 2005) and economic returns by $78-85/ha (Smith *et al*. 2006). Lower yields with delayed seeding have been attributed to lower accumulated GDD and reduced availability of resources later in the growing season (Bullied *et al*. 2006). In the current study, yields of Argentine canola (n = 6 seeding rates) varied depending on the year, cultivar, tillage practice and planting date (Table 8). Yields of op and hybrid cultivars in CT ranged from 130 g/m^2 (23 bu/acre) in 2003 to 313-382 g/m^2 (56-68 bu/acre) in 2005. With the exception of 2003, yields were significantly higher in the hybrid cultivars than in the op cultivars. Yields over 5 years in CT were 23% higher in the hybrid cultivars (273 g/m^2, 48.7 bu/acre) than in the op cultivars (222 g/m^2, 39.7 bu/acre). Harker *et al*. (2003) also found that a hybrid cultivar out-yielded an op cultivar by 22%. With the exception of 2003, higher yields in the hybrid cultivar may have been partly due to a higher seed weight. Thousand-seed weights averaged 4.50 g in the hybrid cultivars compared to 3.71 g in the op cultivars. In studies on sized seeds of op and hybrid cultivars of *B. napus*, yields increased by 24% with a 0.7 g increase in 1000-seed weight (Elliott *et al*. 2007b). In early and late MT plots, yields ranged from 72-137 g/m^2 (12-24 bu/acre) in 2001 to 259-342 g/m^2 (46-61 bu/acre) in 2005. Yields in early-seeded plots were 22% higher in the hybrid cultivars (256 g/m^2, 45.7 bu/acre) than in the op cultivars (210 g/m^2, 37.6 bu/acre). Yields in late MT plots were 19% higher in the hybrid cultivars (215 g/m^2, 38.3 bu/acre) than in the op cultivars (181 g/m^2, 32.2 bu/acre). Planting in early May rather than late May or early June improved yields by 17% in the op cultivars (29.9 g/m^2, 5.3 bu/acre) and by 19% in the hybrid cultivars (41.3 g/m^2, 7.3 bu/acre). In 15 tests in CT and MT, the hybrid cultivars out-yielded the op cultivars by 19-23%. In MT plots, planting in early May rather than late May or early June improved yields of the op and hybrid cultivars by 17-19%.

The effects of seeding rate on yield of *Brassica* crops are conflicting and poorly understood. Dosdall *et al*. (1998) reported that maximum canola yields were obtained with wide row-spacings and high seeding rates (7-11 kg/ha). Blackshaw *et al*. (2005) also found that in 3/7 tests, a 9 kg/ha seeding rate provided a higher yield than a 6 kg/ha seeding rate. However, economic returns were higher with a 6 kg/ha rate than with a 9 kg/ha rate (Smith *et al*. 2006). Under relatively dry conditions, canola yields were 7% higher with seeding rates of 150 and 200 seeds/m^2 than a seeding rate of 100 seeds/m^2 (Harker *et al*. 2003). However, 100 and 150 seeds/m^2 rates were more profitable than a 200 seeds/m^2 rate (Padhyay *et al*. 2006). In contrast, McKenzie *et al*. (2006) found no significant difference in yields of yellow mustard seeded at 75-300 plants/m^2. Chen *et al*. (2005) also concluded that a relatively low seeding rate (32-65 seeds/m^2) was sufficient to produce high yields in Argentine canola. In CT plots, seeding rate had a significant effect on yield in 4/5 tests on op cultivars and 5/5 tests on hybrid cultivars (Fig. 16). With higher seeding rates, yields of op cultivars increased linearly in 2005 and curvilinearly in 2003, 2004 and 2006. The highest yields were obtained with a seeding rate of 33 seeds/m-row in 2002 and 2003, 41 seeds/m-row in 2006 and 49 seeds/m-row in 2004 and 2005. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields of op cultivars in 2002-2006 averaged 178, 220, 222, 239, 235 and 240 g/m^2, respectively. Yields increased between 8 and 33 seeds/m-row then stabilized at higher seeding rates. Optimum yields in op cultivars were attained with a seeding rate of 33 seeds/m-row (3.6 lb/acre, 4.0 kg/ha) and plant density of 89 plants/m^2. With higher seeding rates, yields of hybrid cultivars in CT increased linearly in 2004 and 2005 and curvilinearly in 2001, 2003 and 2006. The highest yields were obtained with a seeding rate of 33 seeds/m-row in 2006, 41 seeds/m-row in 2002 and 2004, and 49 seeds/m-row in 2003 and 2005. Yields with seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row averaged 237, 269, 281, 282, 285 and 284 g/m^2, respectively, in 2002-2006. Yields increased between 8 and 25 seeds/m-row then stabilized at higher rates. Optimum yields in hybrid cultivars were attained with a seeding rate of 25 seeds/m-row (3.2 lb/acre, 3.6 kg/ha) and plant density of 68 plants/m^2.

In early MT plots, seeding rate had a significant effect on yield in 2/5 tests on op cultivars and 4/5 tests on hybrid cultivars (Fig. 17). With higher seeding rates, yields of op cultivars increased curvilinearly in 2003 and linearly in 2006. The highest yields were obtained with a seeding rate of 33 seeds/m-row in 2003 and 2005, 41 seeds/m-row in 2004, and 49 seeds/m-row in 2006. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields of op cultivars in 2001-2006 averaged 191, 206, 214, 219, 219 and 214 g/m^2, respectively. Yields increased between 8 and 33 seeds/m-row then stabilized at higher seeding rates. Optimum yields in op cultivars in early MT plots were attained with a seeding rate of 33 seeds/m-row (3.5 lb/acre, 3.9 kg/ha) and plant density of 63 plants/m^2. With higher seeding rates, yields of hybrid cultivars increased linearly in 2003 and curvilinearly in 2001, 2004 and 2006. The highest yields were obtained with a seeding rate of 16 seeds/m-row in 2001, 2004 and 2005, 33 seeds/m-row in 2003 and 41 seeds/m-row in 2006. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields of hybrid cultivars in 2001-2006 averaged 236, 261, 262, 264, 257 and 257 g/m^2, respectively. Yields increased between 8 and 16 seeds/m-row then stabilized at higher seeding rates. Optimum yields in hybrid cultivars were attained with a seeding rate of 16 seeds/m-row (2.1 lb/acre, 2.4 kg/ha) and plant density of 36 plants/m^2.

In late MT plots, seeding rate had a significant effect on yield in 4/5 tests on op cultivars and 1/5 tests on hybrid cultivars (Fig. 18). With higher seeding rates, yields of op cultivars increased linearly in 2003, 2004 and 2005 and curvilinearly in 2006. The highest yields were obtained with a seeding rate of 25 seeds/m-row in 2001, 33 seeds/m-row in 2006 and 41-49 seeds/m-row in 2003, 2004 and 2005. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields of op cultivars in 2001-2006 averaged 157, 172, 184, 186, 194 and 191 g/m^2, respectively. Yields increased between 8 and 41 seeds/m-row then were constant. Optimum yields in op cultivars were attained with a seeding rate of 41 seeds/m-row (4.4 lb/acre, 4.9 kg/ha) and plant density of 96 plants/m^2. Yields of hybrid cultivars in late plantings increased curvilinearly with higher seeding rates in 2006. The highest yields were obtained with a seeding rate of 8 seeds/m-row in 2004, 33 seeds/m-row in 2001 and 2003 and 41-49 seeds/m-row in 2005 and 2006. With seeding rates of 8, 16, 25, 33, 41 and 49 seeds/m-row, yields of hybrid cultivars in 2001-2006 averaged 201, 212, 215, 220, 223 and 217 g/m^2, respectively. Yields increased between 8 and 41 seeds/m-row then stabilized. Optimum yields in hybrid cultivars were attained with a seeding rate of 33 seeds/m-row (4.3 lb/acre, 4.8 kg/ha) and plant populations of 79 plants/m^2.

Economic returns

Seeding rate and plant density had a pronounced effect on gross and net economic returns from op cultivars in 2001-2006 (Table 9). Gross returns in CT ranged from $237.80/acre at the lowest seeding rate (<0.9 lb/acre, 1.0 kg/ha) and lowest plant density (21 plants/m^2) to $320.30/acre at the highest seeding rate (49 seeds/m-row, 5.3 lb/acre, 5.9 kg/ha) and highest plant density (129 plants/m^2). After subtracting seed costs ($4.00/lb seed), net returns from op cultivars ranged from $234.20/acre at the lowest seeding rate to $304.40/acre with a 33 seeds/m-row rate. Results indicated that a seeding rate of 3.6 lb/acre (4.0 kg/ha) and plant density of 89 plants/m^2 provided the highest net return from op cultivars in CT.

In early MT plots, gross returns from op cultivars ranged from $255.00/acre at the lowest seeding rate (<0.9 lb/acre, 1.0 kg/ha) and lowest plant density (15 plants/m^2) to $292.50/acre at seeding rates of 33-41 seeds/m-row (3.5-4.4 lb/acre, 3.9-4.0 kg/ha) and plant densities of 63-87 plants/m^2. Net returns ranged from $251.40/acre at the lowest seeding rate to $278.50/acre with a 33 seeds/m-row rate. Analyses indicated that a seeding rate of 3.5 lb/acre (3.9 kg/ha) and plant density of 63 plants/m^2 provided the highest net return from op cultivars in early MT plots.

In late MT plots, gross returns from op cultivars ranged from $209.30/acre at the lowest seeding rate (<0.9 lb/acre, 1.0 kg/ha) and lowest plant density (20 plants/m^2) to $258.80/acre with a seeding rate of 41 seeds/m-row (4.4 lb/acre, 4.9 kg/ha) and plant density of 96 plants/m^2. Net returns ranged from $205.70/acre at the lowest seeding rate to $241.20/acre with a 41 seeds/m-row rate. Results indicated that a seeding rate of 4.4 lb/acre (4.9 kg/ha) and plant density of 96 plants/m^2 provided the highest net return from op cultivars in late MT plots.

Seeding rate and plant density had a substantial effect on gross and net returns from hybrid cultivars in 2001-2006 (Table 10). Gross returns in CT ranged from

$316.50/acre at the lowest seeding rate (<1.1 lb/acre, 1.2 kg/ha) and lowest plant density (22 plants/m^2) to $380.30/acre at a seeding rate of 41 seeds/m-row (5.4 lb/acre, 6.0 kg/ha) and plant density of 112 plants/m^2. After subtracting seed costs ($7.50/lb seed), net returns ranged from $308.20/acre at the lowest seeding rate to $351.00/acre with a 25 seeds/m-row rate. Analyses indicated that a seeding rate of 3.2 lb/acre (3.6 kg/ha) and plant density of 68 plants/m^2 provided the highest net return from hybrid cultivars in CT.

In early MT plots, gross returns from hybrid cultivars ranged from $315.00/acre at the lowest seeding rate (<1.1 lb/acre, 1.2 kg/ha) and lowest plant density (17 plants/m^2) to $352.50/acre at a seeding rate of 33 seeds/m-row (4.3 lb/acre, 4.8 kg/ha) and plant density of 67 plants/m^2. Net returns ranged from $294.80 acre at the highest seeding rate (6.4 lb/acre, 7.2 kg/ha) to $333.00/acre with a 16 seeds/m-row rate. Results indicated that a seeding rate of 2.1 lb/acre (2.4 kg/ha) and plant density of 36 plants/m^2 provided the highest net return from hybrid cultivars in early MT plots.

In late MT plots, gross returns from hybrid cultivars ranged from $268.50/acre at the lowest seeding rate and lowest plant density (20 plants/m^2) to $297.80/acre at a seeding rate of 41 seeds/m-row (5.4 lb/acre, 6.0 kg/ha) and plant density of 103 plants/m^2. Net returns ranged from $241.50/acre at the highest seeding rate (6.4 lb/acre, 7.2 kg/ha) to $267.00/acre at a 16 seeds/m-row rate. Results indicated that a seeding rate of 2.1 lb/acre (2.4 kg/ha) and plant density of 38 plants/m^2 provided the highest net return from hybrid cultivars in late MT plots.

Recommended seeding rates for canola production in western Canada are 5-8 lb/acre or 5.6-9.0 kg/ha (Thomas 2003). In the current study, economic returns from op and hybrid canola cultivars varied greatly depending on environmental conditions, tillage practices, planting date and seeding rate. In tests with CT, a seeding rate of 33 seeds/m-row (3.6 lb/acre, 4.0 kg/ha) and plant density of 90 plants/m^2 provided the highest net return ($304.40/acre) from op cultivars. A seeding rate of 25 seeds/m-row (3.2 lb/acre, 3.6 kg/ha) and plant density of 70 plants/m^2 provided the highest net return ($351.00/acre) from hybrid cultivars. In MT, net returns were 17-19% higher when cultivars were planted in early May rather than late May or early June. In early MT plots, a seeding rate of 33 seeds/m-row (3.5 lb/acre, 3.9 kg/ha) and plant density of 65 plants/m^2 provided the highest net return ($278.50/acre) from op cultivars. A seeding rate of 16 seeds/m-row (2.1 lb/acre, 2.4 kg/ha) and plant density of 35-40 plants/m^2 provided the highest net return ($333.00/acre) from hybrid cultivars. In late MT plots, a seeding rate of 41 seeds/m-row (4.4 lb/acre, 4.9 kg/ha) and plant density of 95-100 plants/m^2 provided the highest net return ($241.20/acre) from op cultivars. A seeding rate of 16 seeds/m-row (2.1 lb/acre, 2.4 kg/ha) and plant densities of 35-40 plants/m^2 provided the highest net return from hybrid cultivars. Studies indicated that high quality seed lots of op and hybrid Argentine canola can be planted at lower than recommended rates without compromising economic returns. With early seeding in MT, a 1.5-4.5 lb/acre reduction in seeding rate for op cultivars would reduce seed and production costs by $6-18/acre ($14.80-44.46/ha). A 2.9-5.9 lb/acre reduction in seeding rate for hybrid cultivars would reduce seed and production costs by $21.75-44.25/acre ($53.72-109.30/ha). Seeding rates also affect pesticide use. Most Certified No. 1 canola seed is treated with a commercial seed dressing containing fungicides and an insecticide (Anonymous 1997). Lower seeding rates would reduce pesticide inputs for op and hybrid cultivars by 30-55% and 55-70%, respectively.

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Table 1. Summary of planting dates, soil temperatures, moisture conditions and precipitation in seeding rate trials in 2001-2006 [1]

	Conventional tillage (CT)		Minimum tillage (MT)					Precipitation (mm)		
Year	PD	Temp.	early PD	Temp.	late PD	Temp.	Moisture conditions	January-April	May-June	July-August
2001	-	-	May 11	-	May 24	-	dry	12.5	59.9	58.2
2002	May 30	21° C	-	-	-	-	very dry	31.8	53.7	144.7
2003	May 22	14° C	May 14	14° C	May 29	21° C	dry	73.8	35.0	78.5
2004	May 20	8° C	May 13	7° C	May 28	14° C	moist	74.1	106.7	148.5
2005	May 20	15° C	May 14	9° C	May 31	17° C	very moist	86.5	188.0	107.0
2006	May 19	22° C	May 16	17° C	June 2	21° C	very moist	107.0	147.8	62.0

[1] PD = planting date. Average daily soil temperature at 25-mm depth. Precipitation data from Environment Canada.

Table 2. Summary of seeding rates for open-pollinated (op) and hybrid (h) Argentine canola in 2001-2006.

Breeding type	Cultivar	Year	1000-seed wt. (g)	Seeds/m-row (lb/acre)						Seeds/m-row (kg/ha)					
				8	16	25	33	41	49	8	16	25	33	41	49
op	SW Arrow	2001	3.21	0.70	1.4	2.2	2.9	3.7	4.4	0.78	1.6	2.5	3.2	4.1	4.9
	SP Banner	2002	3.49	0.80	1.6	2.4	3.2	4.0	4.8	0.90	1.8	2.7	3.6	4.5	5.4
	“	2003	3.49	0.80	1.6	2.4	3.2	4.0	4.8	0.90	1.8	2.7	3.6	4.5	5.4
	“	2004	3.82	0.90	1.8	2.7	3.7	4.6	5.5	1.00	2.0	3.0	4.1	5.2	6.2
	“	2005	3.71	0.90	1.8	2.7	3.6	4.5	5.3	1.00	2.0	3.0	4.1	5.2	6.2
	“	2006	4.04	0.95	1.9	2.9	3.9	4.8	5.8	1.06	2.1	3.2	4.4	5.4	6.5
h	InVigor 2663	2001	4.02	0.90	1.8	2.8	3.7	4.6	5.5	1.00	2.0	3.0	4.1	5.2	6.2
	“	2002	4.14	0.95	1.9	2.9	3.8	4.7	5.7	1.06	2.1	3.2	4.4	5.4	6.5
	“	2003	3.39	0.80	1.6	2.4	3.2	4.0	4.8	0.90	1.8	2.7	3.6	4.5	5.4
	InVigor 5020	2004	4.77	1.15	2.3	3.4	4.6	5.7	6.9	1.29	2.6	3.8	5.2	6.4	7.7
	“	2005	5.00	1.20	2.4	3.6	4.8	6.0	7.2	1.34	2.7	4.0	5.4	6.7	8.1
	“	2006	5.18	1.25	2.5	3.7	5.0	6.2	7.5	1.40	2.8	4.1	5.6	6.9	8.4

Table 3. Flea beetle damage to open-pollinated (op) and hybrid (h) Argentine canola seeded into conventional tillage (CT) and minimum tillage in early May (MTE) or late May (MTL) in 2001-2006. [1]

Year	Breeding type	Cultivar	Damage - CT (%)		Damage - MTE (%)		Damage - MTL (%)	
			14 DAS	21 DAS	14 DAS	21 DAS	14 DAS	21 DAS
2001	op	SW Arrow	-	15.5a	0.4a	1.4a	1.5a	2.6a
	h	InVigor 2663	-	14.6a	0.4a	1.4a	1.4a	2.7a
2003	op	SP Banner	6.5a	10.8a	0.8a	8.0a	0.7a	5.3a
	h	InVigor 2663	7.5a	11.6a	0.8a	8.6a	0.6a	5.3a
2004	op	SP Banner	1.4a	6.4a	0.7a	1.3a	-	1.8a
	h	InVigor 5020	1.7a	7.0a	0.8a	1.0a	-	1.5a
2005	op	SP Banner	0.9a	0.9a	0.3a	1.2a	0.9a	1.2a
	h	InVigor 5020	1.3a	0.4a	0.5a	1.3a	0.6b	0.6a
2006	op	SP Banner	-	11.1a	-	0.7a	-	2.0a
	h	InVigor 5020	-	10.7b	-	1.6b	-	1.1b
all	op	Arrow/Banner	2.9	8.9	0.6	2.5	1.0	2.6
	h	InVigor	3.5	8.9	0.6	2.8	0.9	2.2

[1] For each year, means within columns followed by the same letter are not significantly different (ANOVA, $P \geq 0.05$). Means are an average of six seeding rates. Tests in CT conducted on SP Banner in 2002 not 2001.

Table 4. Seedling establishment of open-pollinated (op) and hybrid (h) Argentine canola seeded into conventional tillage (CT) and minimum tillage in early May (MTE) or late May (MTL) in 2001-2006. [1]

Year	Breeding type	Cultivar	Establishment - CT (%)		Establishment - MTE (%)		Establishment - MTL (%)	
			13-14 DAS	21-22 DAS	13-14 DAS	20-24 DAS	13-14 DAS	20-22 DAS
2001	op	SW Arrow	2.2a	58.6a	2.4a	41.1a	42.1a	51.8a
	h	InVigor 2663	2.9a	61.0a	3.4a	45.5a	43.9a	52.8a
2003	op	SP Banner	52.5a	83.5a	55.9a	56.7a	61.9a	60.6a
	h	InVigor 2663	52.6a	82.8a	57.5a	57.3a	63.1a	60.8a
2004	op	SP Banner	85.5a	86.5a	47.9a	62.3a	63.4a	67.7a
	h	InVigor 5020	90.4b	91.1b	59.9a	69.6a	76.0a	77.5a
2005	op	SP Banner	90.3a	90.1a	62.9a	63.7a	82.3a	82.0a
	h	InVigor 5020	90.4a	92.1a	71.8b	72.7a	86.6a	86.4a
2006	op	SP Banner	88.1a	88.8a	58.3a	74.2a	82.1a	88.1a
	h	InVigor 5020	90.1a	92.2b	63.4a	75.5a	85.0a	88.1a
all	op	Arrow/Banner	64.1	81.2	46.3	60.7	64.7	69.6
	h	InVigor	65.7	83.9	51.2	64.1	71.4	73.6

[1] For each year, means within columns followed by the same letter are not significantly different (ANOVA, $P \geq 0.05$). Means are an average of six seeding rates. Tests in CT conducted on SP Banner in 2002 not 2001.

Table 5. Seedlings/m-row in open-pollinated (op) and hybrid (h) Argentine canola seeded into conventional tillage (CT) and minimum tillage in early May (MTE) or late May (MTL) in 2001-2006. [1]

Year	Breeding type	Cultivar	Seedlings/m-row - CT		Seedlings/m-row - MTE		Seedlings/m-row - MTL	
			13-14 DAS	21-24 DAS	13-14 DAS	20-24 DAS	13-14 DAS	20-22 DAS
2001	op	SW Arrow	0.8a	16.6a	0.8a	11.9a	12.0a	14.7a
	h	InVigor 2663	0.7a	17.8a	1.0a	12.7a	13.4a	15.7a
2003	op	SP Banner	14.9a	24.3a	16.3a	16.5a	18.0a	17.8a
	h	InVigor 2663	15.5a	24.1a	16.5a	16.3a	18.1a	17.7a
2004	op	SP Banner	24.7a	24.7a	14.4a	18.5a	17.3a	19.1a
	h	InVigor 5020	26.0a	26.1b	17.3b	20.2a	21.6b	22.4b
2005	op	SP Banner	26.0a	25.4a	18.2a	18.7a	23.6a	23.4a
	h	InVigor 5020	25.8a	26.3a	20.5b	21.0b	24.9a	24.8b
2006	op	SP Banner	25.7a	25.6a	16.8a	21.6a	23.5a	24.8a
	h	InVigor 5020	26.2b	26.4b	18.1a	21.7a	24.4a	25.0a
all	op	Arrow/Banner	18.4	23.3	13.3	17.4	18.9	20.0
	h	InVigor	18.8	24.1	14.7	18.4	20.5	21.1

[1] For each year, means within columns followed by the same letter are not significantly different (ANOVA, $P \geq 0.05$). Means are an average of six seeding rates. Tests in CT conducted on SP Banner in 2002 not 2001.

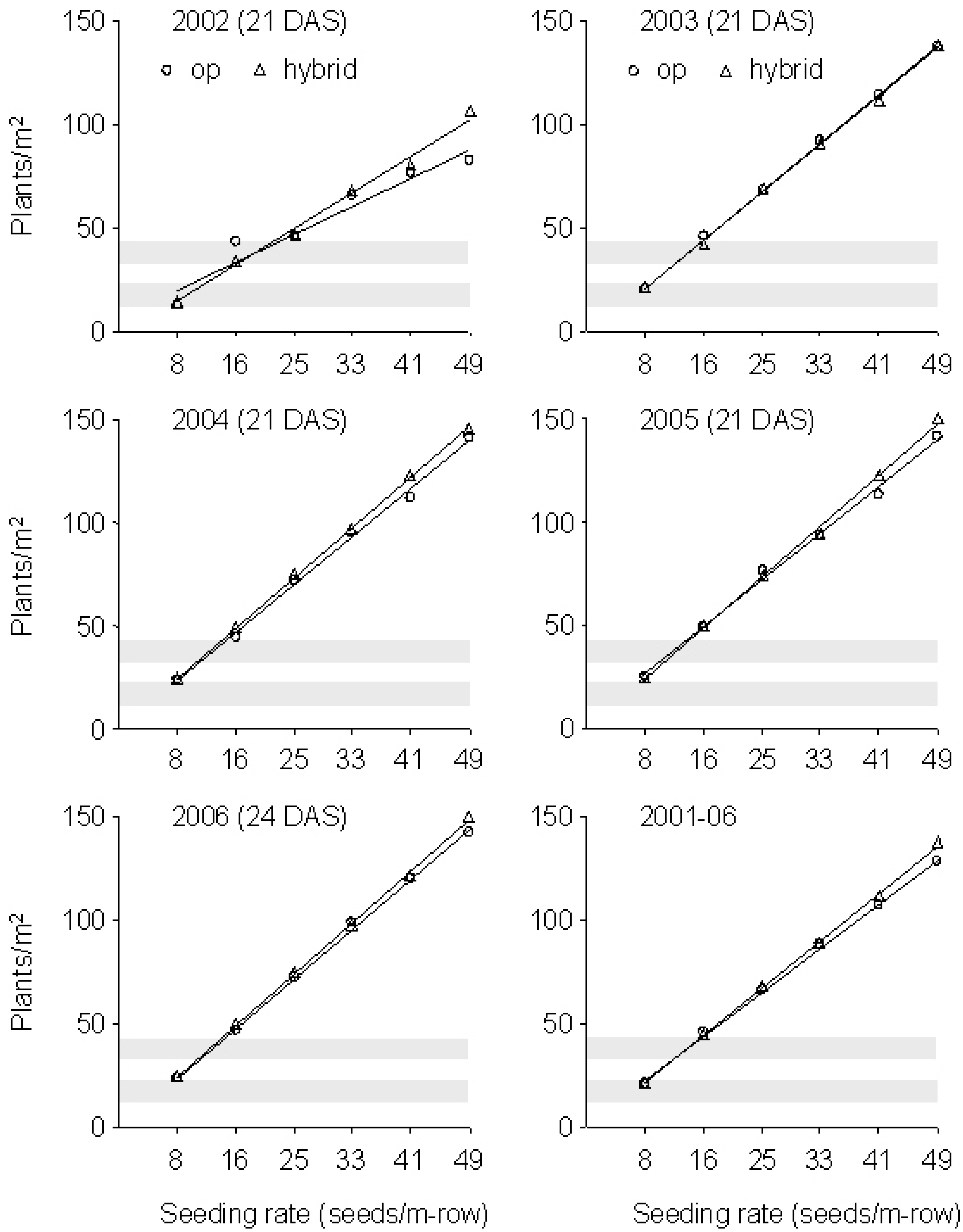

Figure 1. Relationship between seeding rate and plants/m^2 of open-pollinated (op) and hybrid Argentine canola seeded into conventional tillage (CT) in 2002-2006. Plants/m^2 were assessed 21-24 days after seeding (DAS). Shaded areas show minimum plant densities for op cultivars (32-43 plants/m^2) and hybrid cultivars (11-22 plants/m^2) (Thomas 2003).

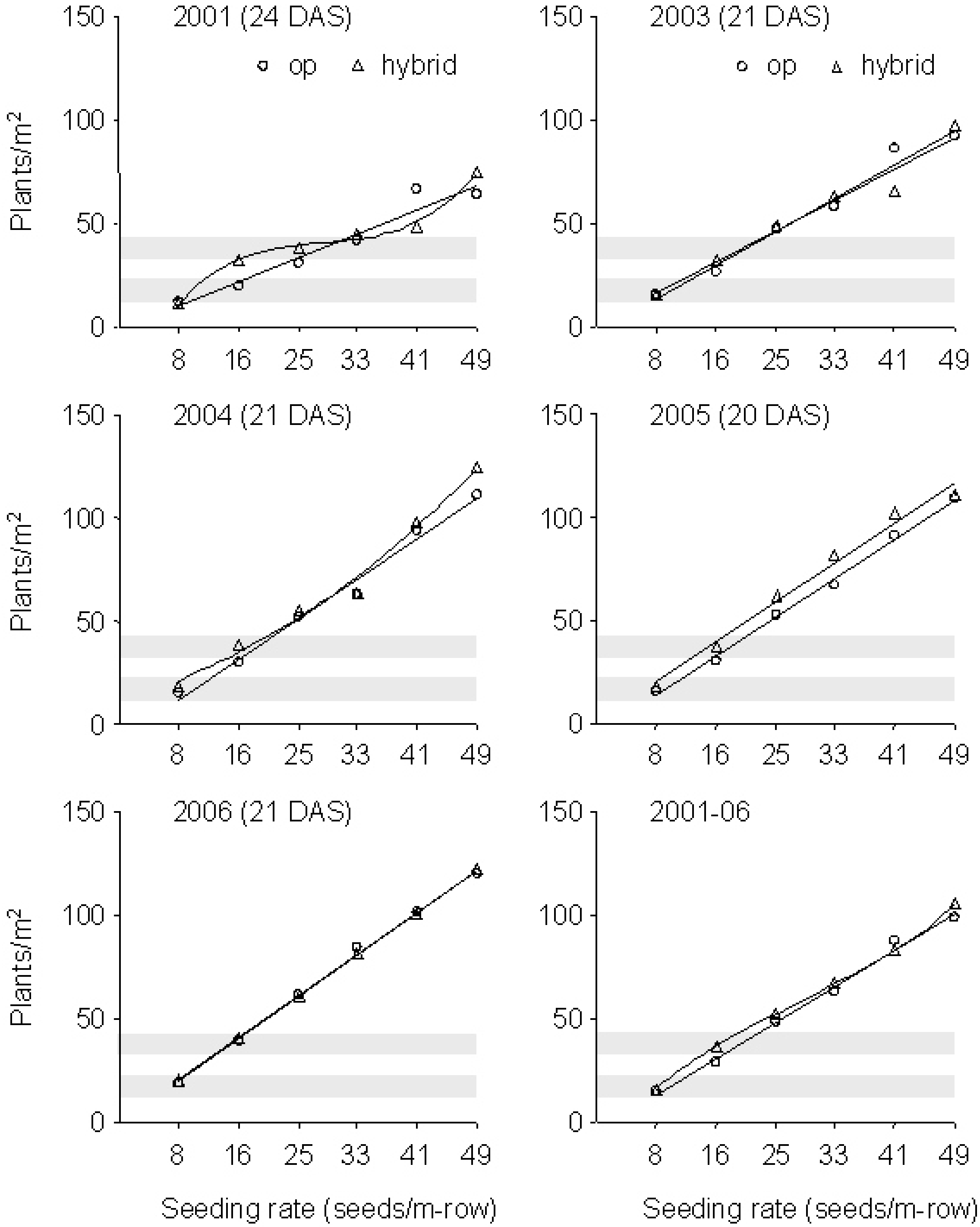

Fig. 2. Relationship between seeding rate and plants/m^2 of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in early May in 2001-2006. Plants/m^2 were assessed 20-24 days after seeding (DAS). Shaded areas show minimum plant densities for op cultivars (32-43 plants/m^2) and hybrid cultivars (11-22 plants/m^2) (Thomas 2003).

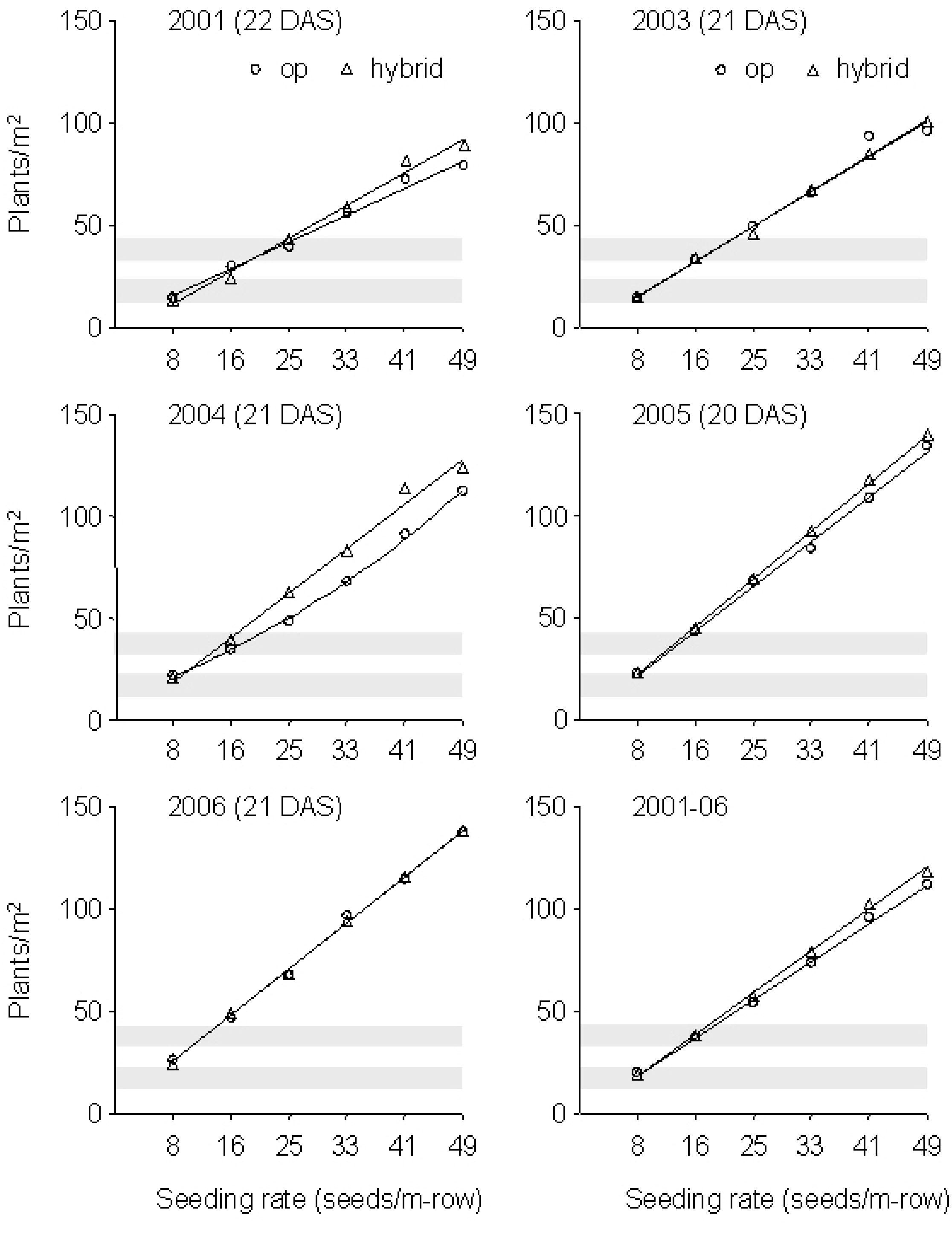

Fig. 3. Relationship between seeding rate and plants/m^2 of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in late May in 2001-2006. Plants/m^2 were assessed 20-22 DAS. Shaded areas show minimum plant densities for op cultivars (32-43 Plants/m^2) and hybrid cultivars (11-22 plants/m^2) (Thomas 2003).

Table 6. Shoot dry weight of open-pollinated (op) and hybrid (h) Argentine canola seeded into conventional tillage (CT) and minimum tillage in early May (MTE) or late May (MTL) in 2001-2006. [1]

Year	Breeding type	Cultivar	Shoot dry wt. - CT (mg/plant)			Shoot dry wt. - MTE (mg/plant)			Shoot dry wt. - MTL (mg/plant)		
			14 DAS	20-21 DAS	27-28 DAS	13-17 DAS	20-24 DAS	27-31 DAS	13-17 DAS	20-22 DAS	27-29 DAS
2001	op	SW Arrow	-	8.1a	28.2a	3.7a	15.3a	107.5a	11.3a	54.9a	331.2a
	h	InVigor 2663	-	12.4a	36.3b	5.2b	22.6b	177.8b	15.6b	80.4a	482.6a
2003	op	SP Banner	22.6a	92.2a	394.0a	7.8a	43.0a	194.8a	9.8a	65.6a	318.0a
	h	InVigor 2663	23.9a	119.3b	507.4a	7.8a	51.1a	226.9a	9.5a	72.3a	357.0a
2004	op	SP Banner	5.2a	20.1a	62.0a	3.3a	14.1a	61.7a	14.3a	30.0a	139.0a
	h	InVigor 5020	8.2b	32.9b	101.5b	4.6b	22.5b	110.5a	19.1b	49.8b	236.1b
2005	op	SP Banner	10.9a	45.6a	268.8a	4.6a	18.0a	83.0a	12.1a	84.1a	342.8a
	h	InVigor 5020	18.5b	70.6b	468.5b	6.2b	26.9b	127.8b	15.9b	133.0b	544.4b
2006	op	SP Banner	14.3a	92.9a	396.2a	6.3a	44.3a	210.8a	11.5a	70.2a	540.2a
	h	InVigor 5020	21.6b	155.5b	599.1b	10.1b	79.4b	366.3b	17.5b	106.1b	863.8b
all	op	Arrow/Banner	13.3	51.8	229.8	5.1	26.9	131.6	11.8	61.0	334.2
	h	InVigor	18.1	78.1	342.6	6.8	40.5	201.9	15.5	88.3	496.8

[1] For each year, means within columns followed by the same letter are not significantly different (ANOVA, $P \geq 0.05$). Means are an average of six seeding rates.Tests in CT conducted on SP Banner in 2002 not 2001.

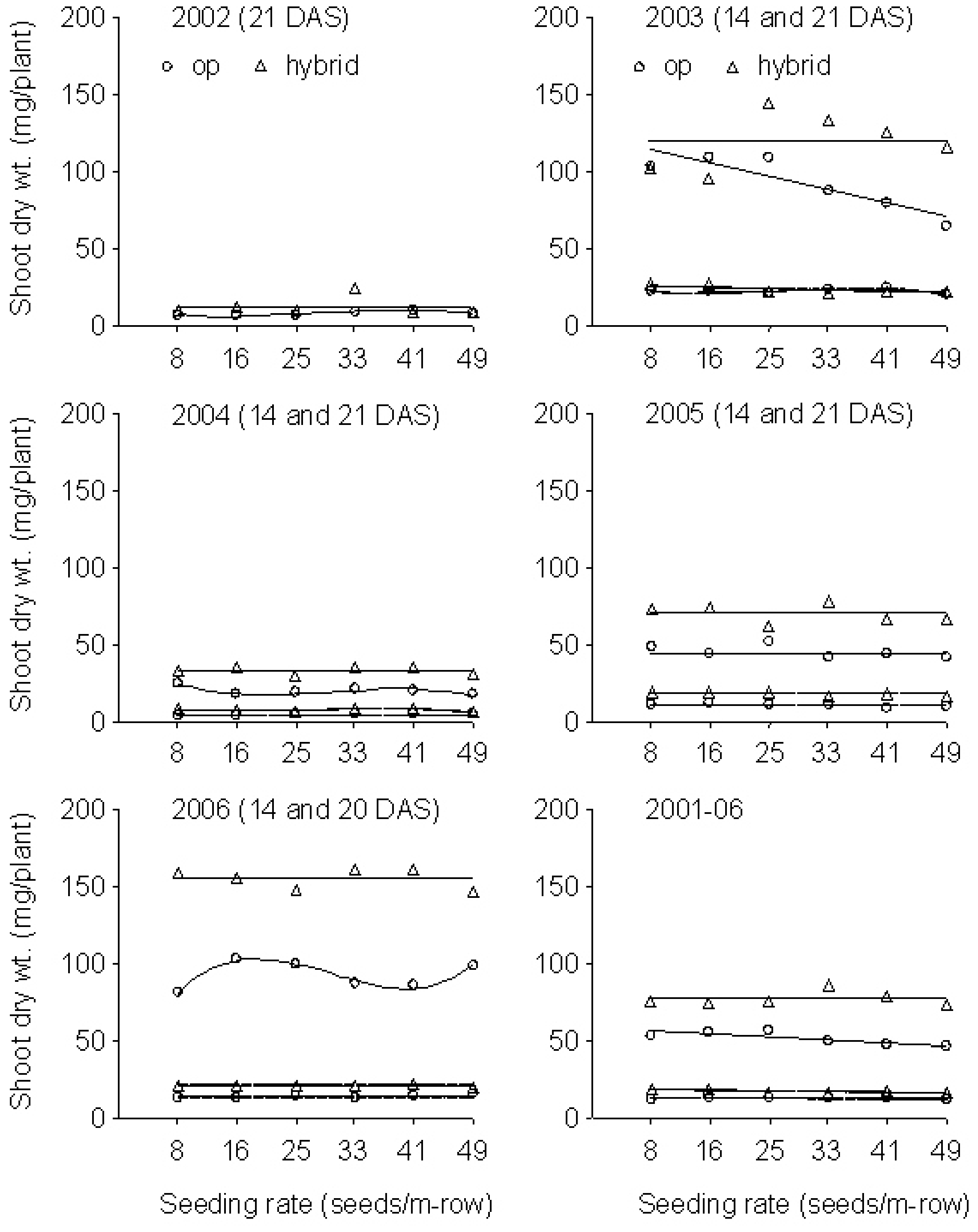

Fig. 4. Relationship between seeding rate and shoot dry weight of open-pollinated (op) and hybrid Argentine canola seeded into conventional tillage (CT) in 2002-2006. Weights were assessed 14 DAS (dotted lines) and 20-21 DAS (solid lines).

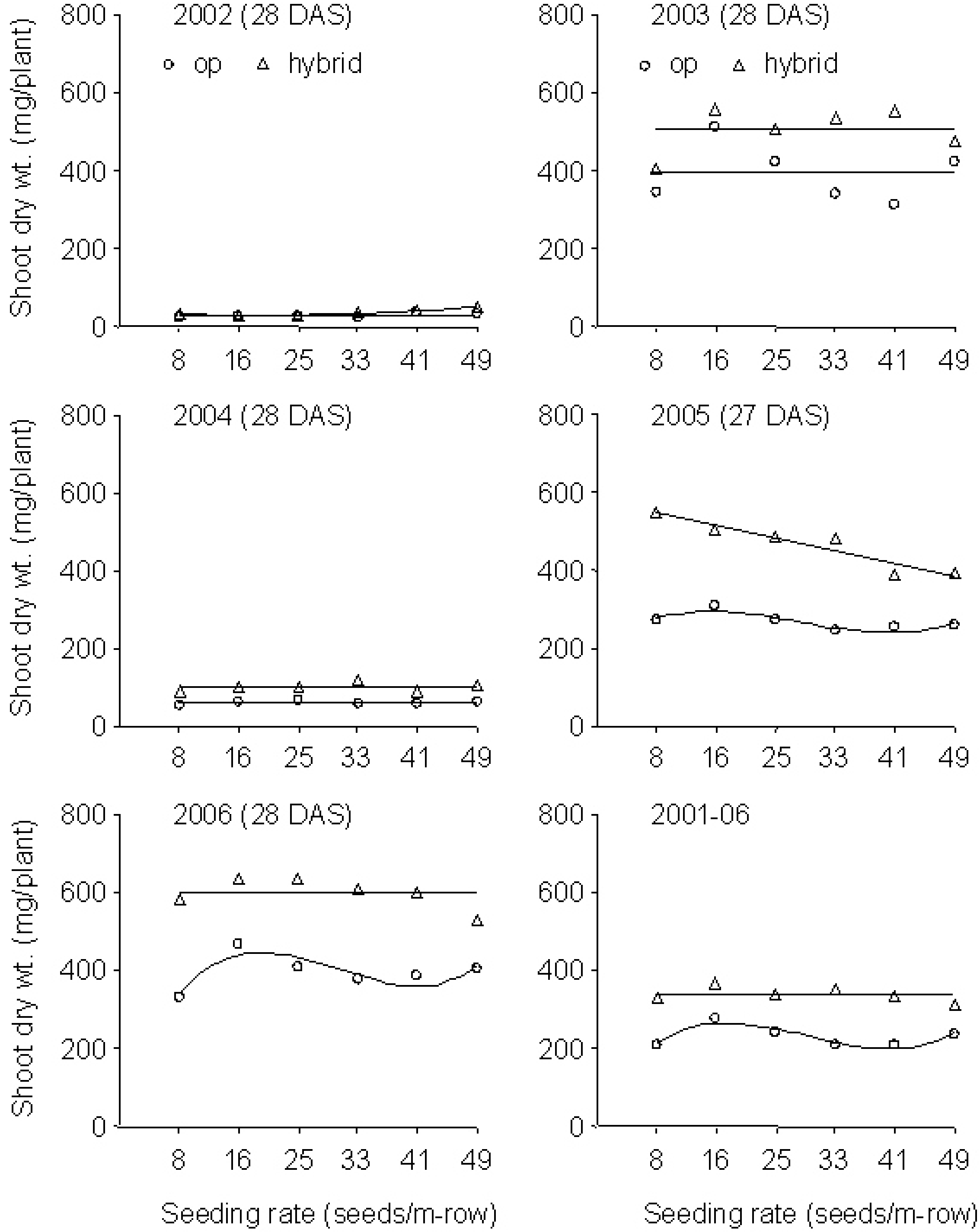

Fig. 5. Relationship between seeding rate and shoot dry weight of open-pollinated (op) and hybrid Argentine canola seeded into conventional tillage (CT) in 2002-2006. Weights were assessed 27-28 DAS.

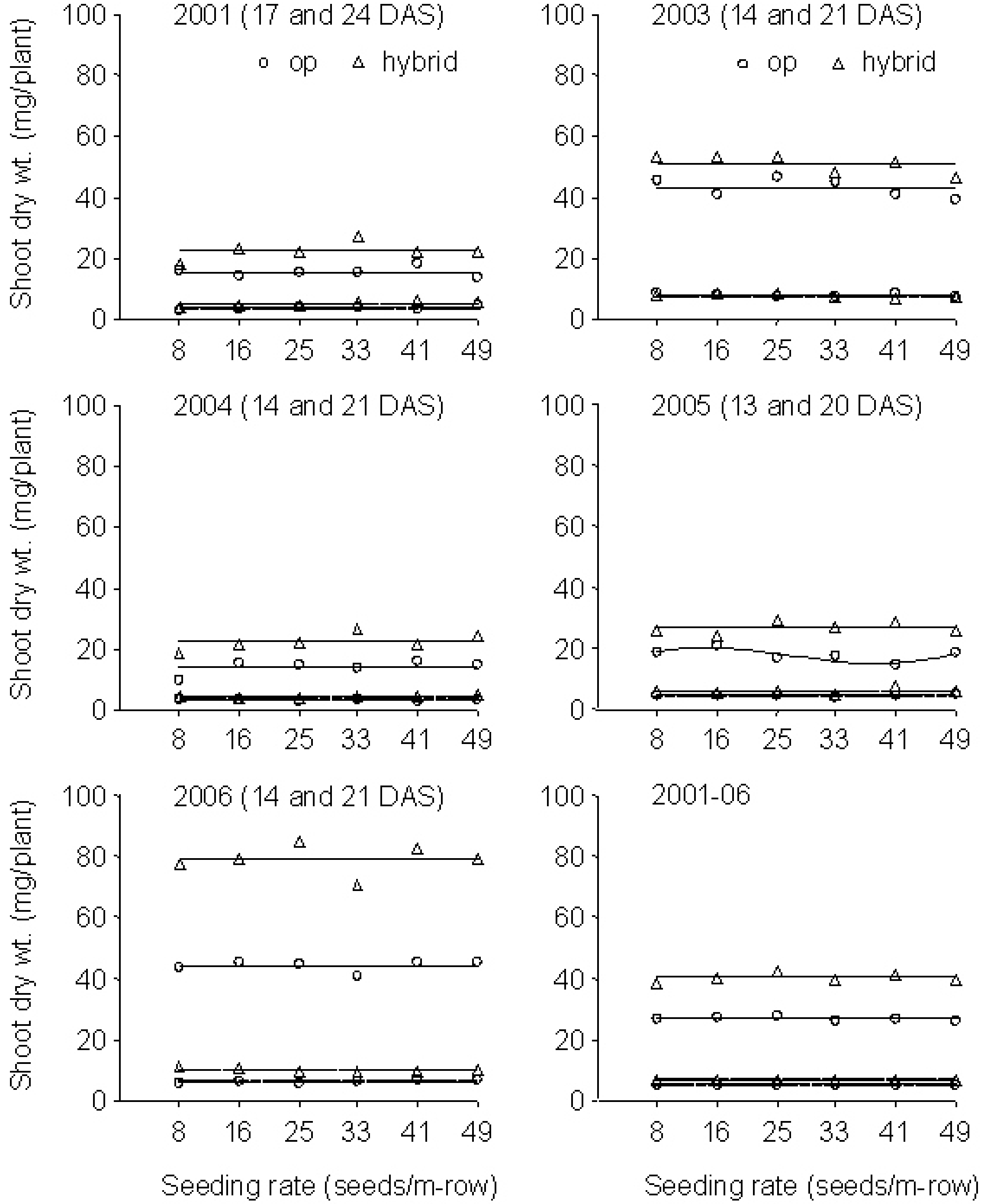

Fig. 6. Relationship between seeding rate and shoot dry weight of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in early May in 2001-2006. Weights were assessed 13-17 DAS (dotted lines) and 20-24 DAS (solid lines).

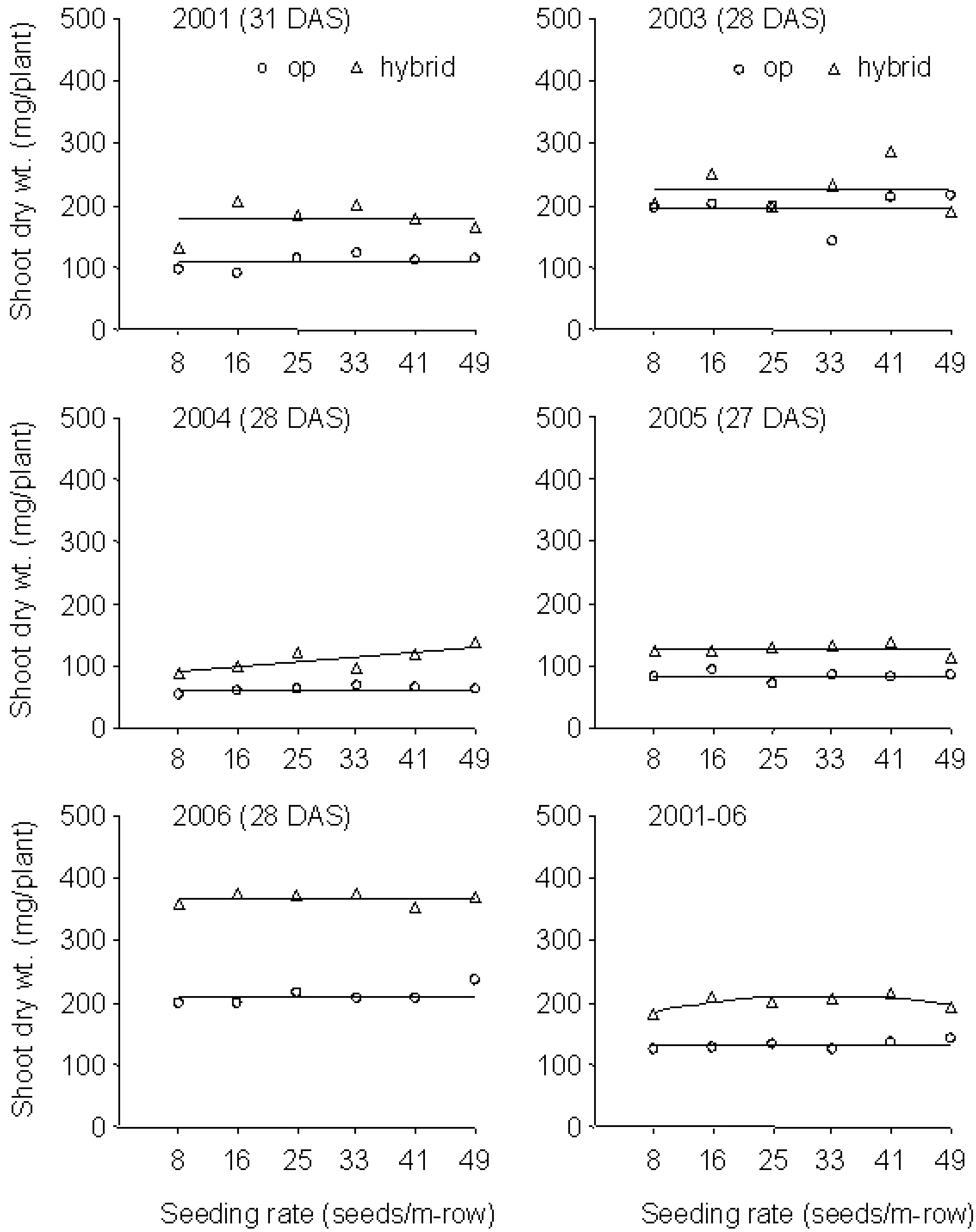

Fig. 7. Relationship between seeding rate and shoot dry weight of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in early May in 2001-2006. Weights were assessed 27-31 DAS.

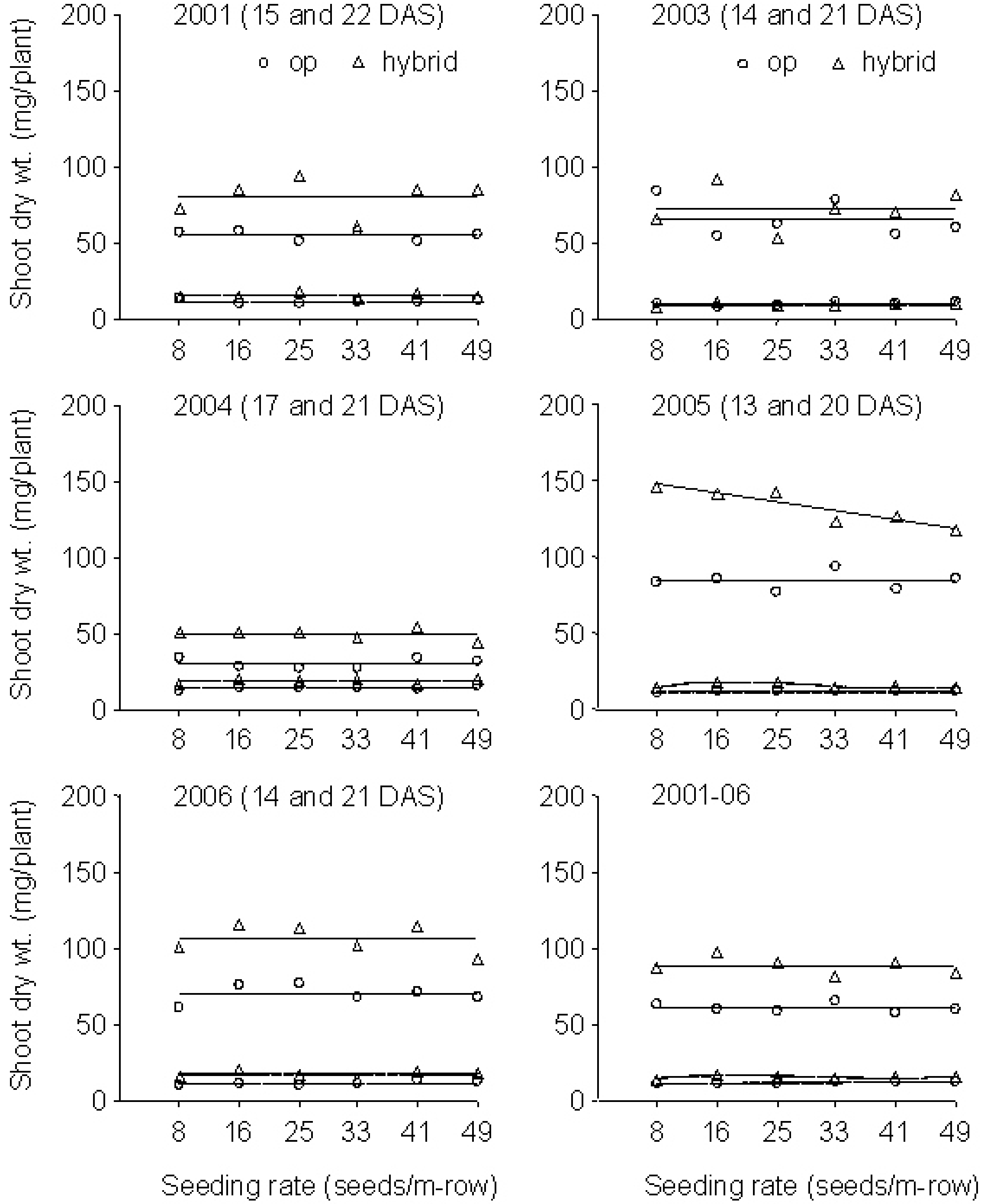

Fig. 8. Relationship between seeding rate and shoot dry weight of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in late May in 2001-2006. Weights were assessed 13-17 DAS (dotted lines) and 20-22 DAS (solid lines).

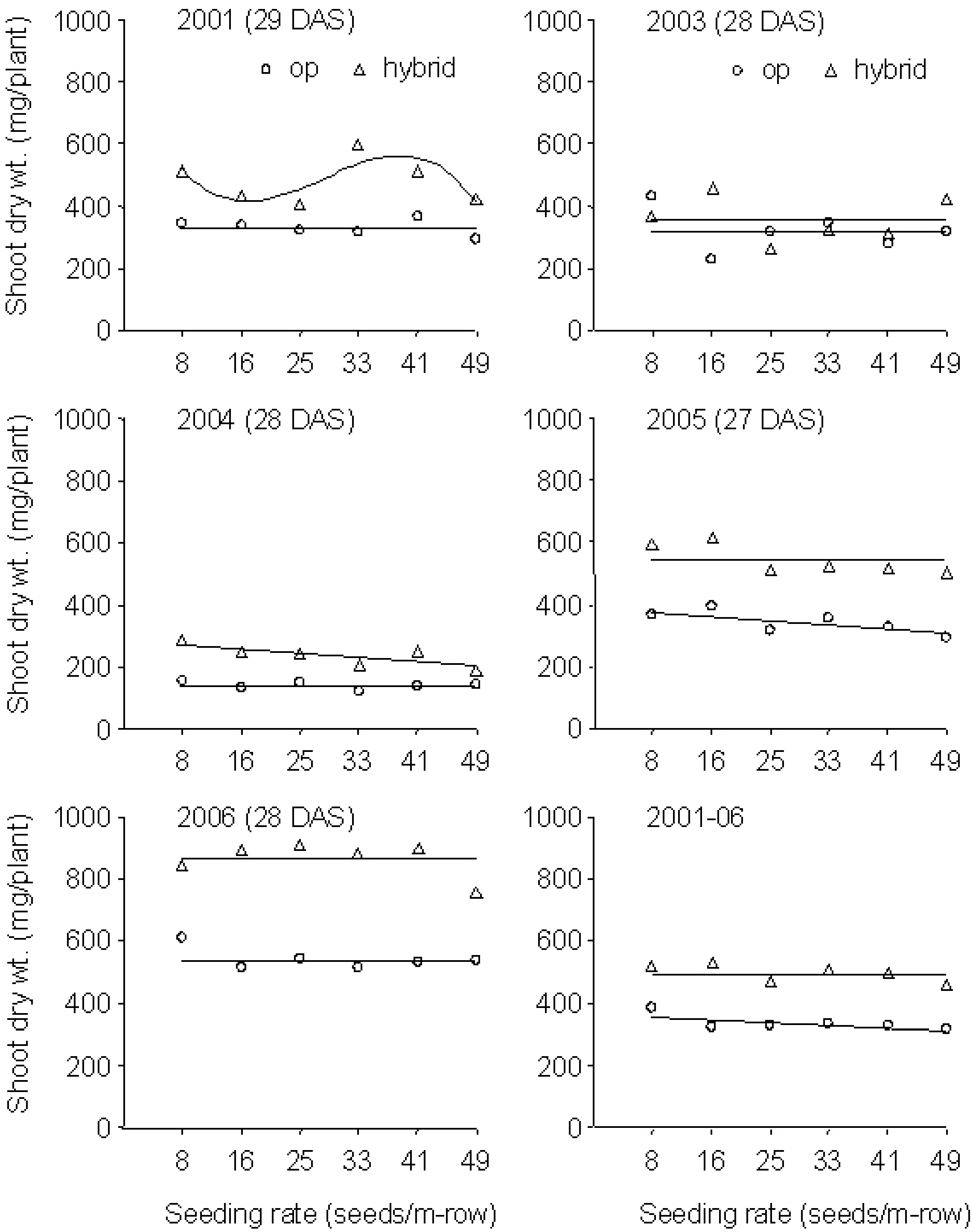

Fig. 9. Relationship between seeding rate and shoot dry weight of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in late May in 2001-2006. Weights were assessed 27-29 DAS.

Table 7. Shoot biomass of open-pollinated (op) and hybrid (h) Argentine canola seeded into conventional tillage (CT) and minimum tillage in early May (MTE) or late May (MTL) in 2001-2006. [1]

Year	Breeding type	Cultivar	Shoot biomass - CT (g/m-row)			Shoot biomass - MTE (g/m-row)			Shoot biomass - MTL (g/m-row)		
			14 DAS	20-21 DAS	27-28 DAS	13-17 DAS	20-24 DAS	27-31 DAS	13-17 DAS	20-22 DAS	27-29 DAS
2001	op	SW Arrow	-	1.3a	4.0a	0.3a	1.7a	11.9a	1.2a	7.4a	46.6a
	h	InVigor 2663	-	1.5a	5.8b	0.6b	2.6b	21.0b	1.8a	11.6a	73.0a
2003	op	SP Banner	3.8a	21.3a	83.0a	1.2a	7.1a	38.3a	1.9a	11.0a	51.5a
	h	InVigor 2663	3.8a	29.4b	104.7a	1.1a	7.7a	41.3a	1.8a	12.3a	59.2a
2004	op	SP Banner	1.3a	4.8a	13.7a	0.4a	2.5a	13.3a	2.6a	5.0a	24.4a
	h	InVigor 5020	2.0b	8.5b	24.8b	0.8b	4.5b	27.1b	4.5b	9.3b	47.4b
2005	op	SP Banner	3.0a	13.4a	70.3a	0.8a	3.5a	14.4a	2.5a	18.3a	80.9a
	h	InVigor 5020	5.1b	22.0b	126.3b	1.2b	6.1b	24.8b	3.4b	30.7b	142.8b
2006	op	SP Banner	3.8a	23.9a	126.9a	1.2a	9.6a	46.2a	3.2a	16.3a	137.0a
	h	InVigor 5020	5.9b	43.1b	200.7b	1.9b	17.8b	82.2b	5.0b	24.8b	223.5b
all	op	Arrow/Banner	3.0	12.9	59.6	0.8	4.9	24.8	2.3	11.6	68.1
	h	InVigor	4.2	20.9	92.4	1.1	7.7	39.3	3.3	17.7	109.2

[1] For each year, means within columns followed by the same letter are not significantly different (ANOVA, $P \geq 0.05$). Means are an average of six seeding rates. Tests in CT conducted on SP Banner in 2002 not 2001.

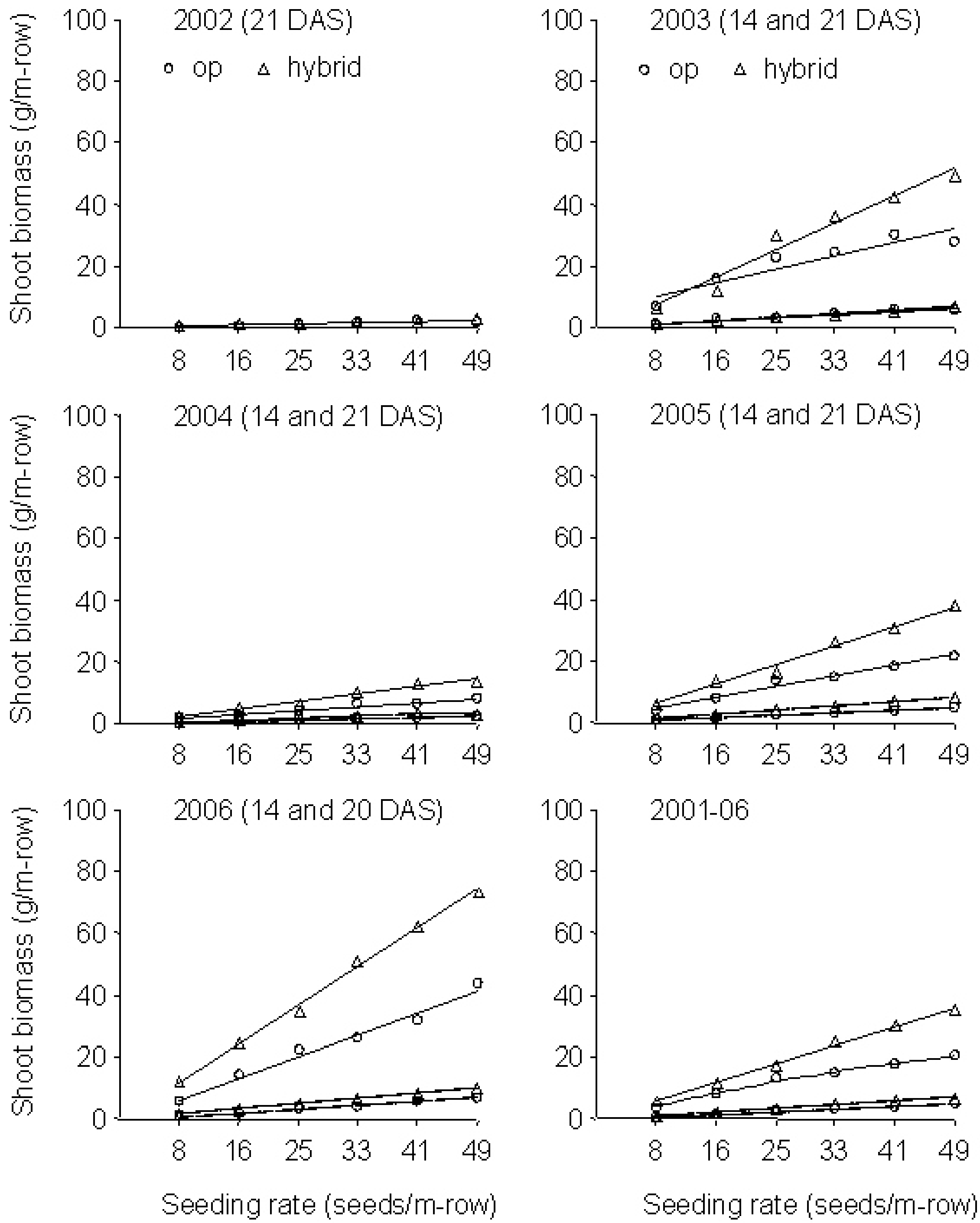

Fig. 10. Relationship between seeding rate and shoot biomass of open-pollinated (op) and hybrid Argentine canola seeded into conventional tillage (CT) in 2002-2006. Biomass was assessed 14 DAS (dotted lines) and 20-21 DAS (solid lines).

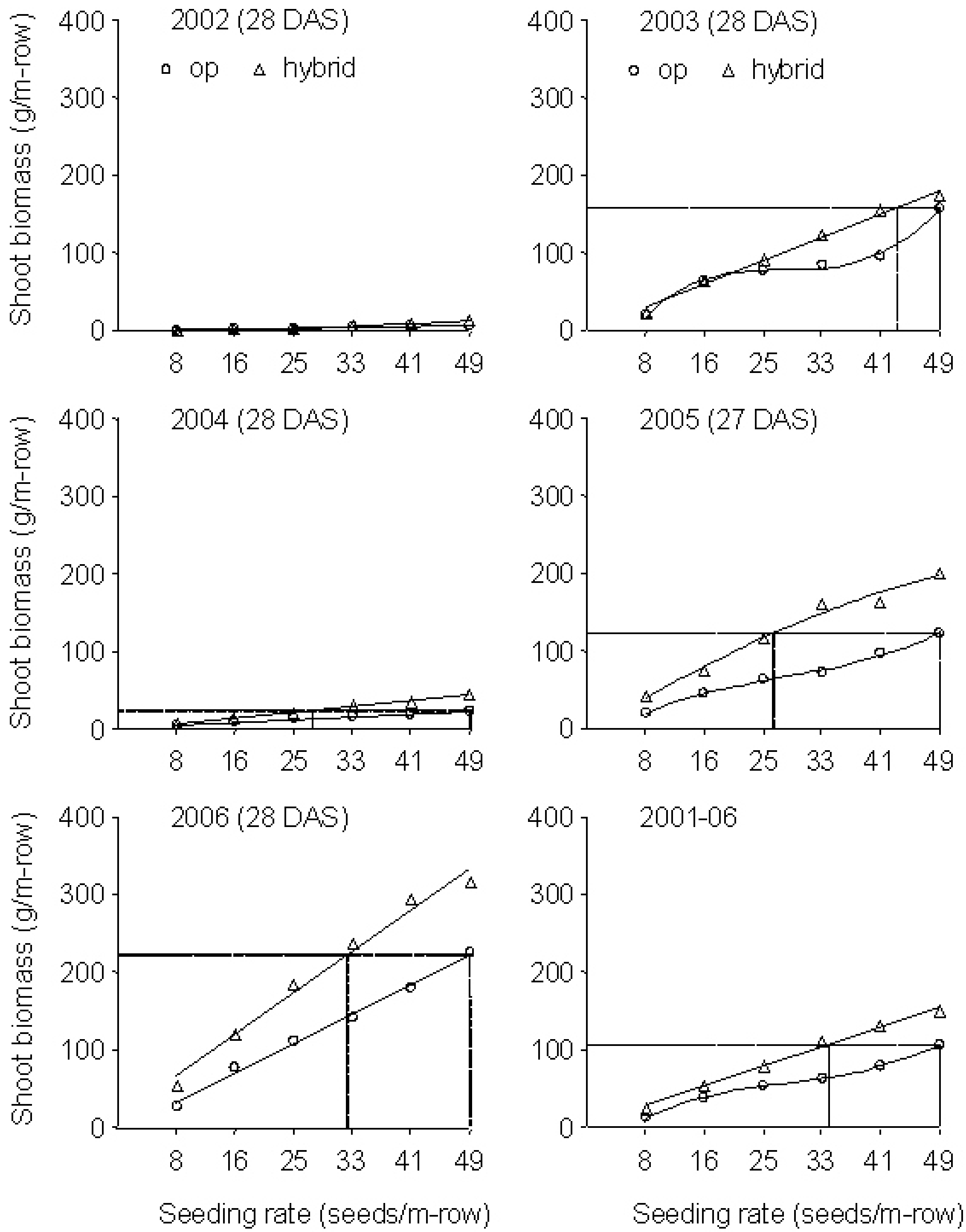

Fig. 11. Relationship between seeding rate and shoot biomass of open-pollinated (op) and hybrid Argentine canola seeded into conventional tillage (CT) in 2002-2006. Biomass was assessed 27-28 DAS.

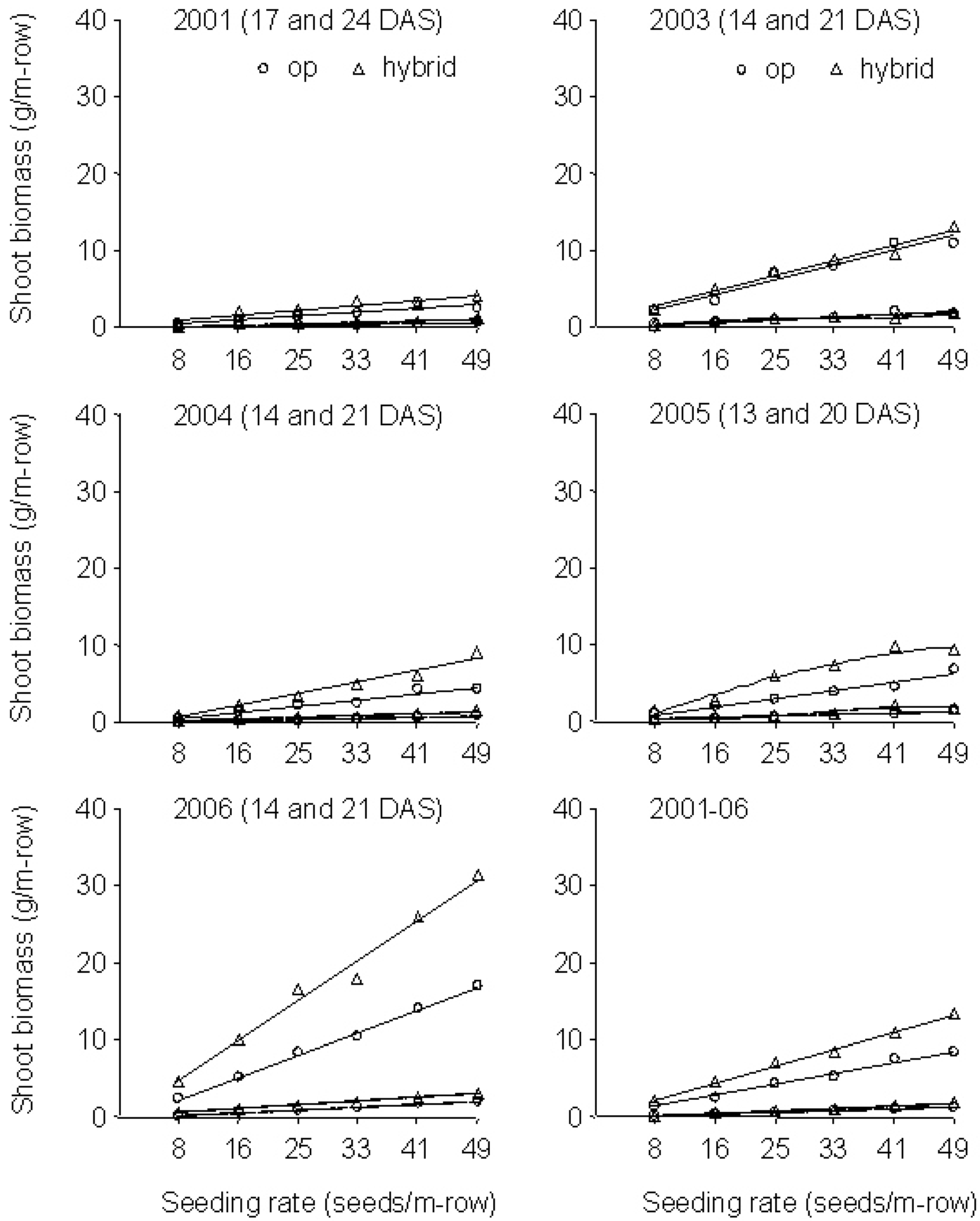

Fig. 12. Relationship between seeding rate and shoot biomass of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in early May in 2001-2006. Biomass was assessed 13-17 DAS (dotted lines) and 20-24 DAS (solid lines).

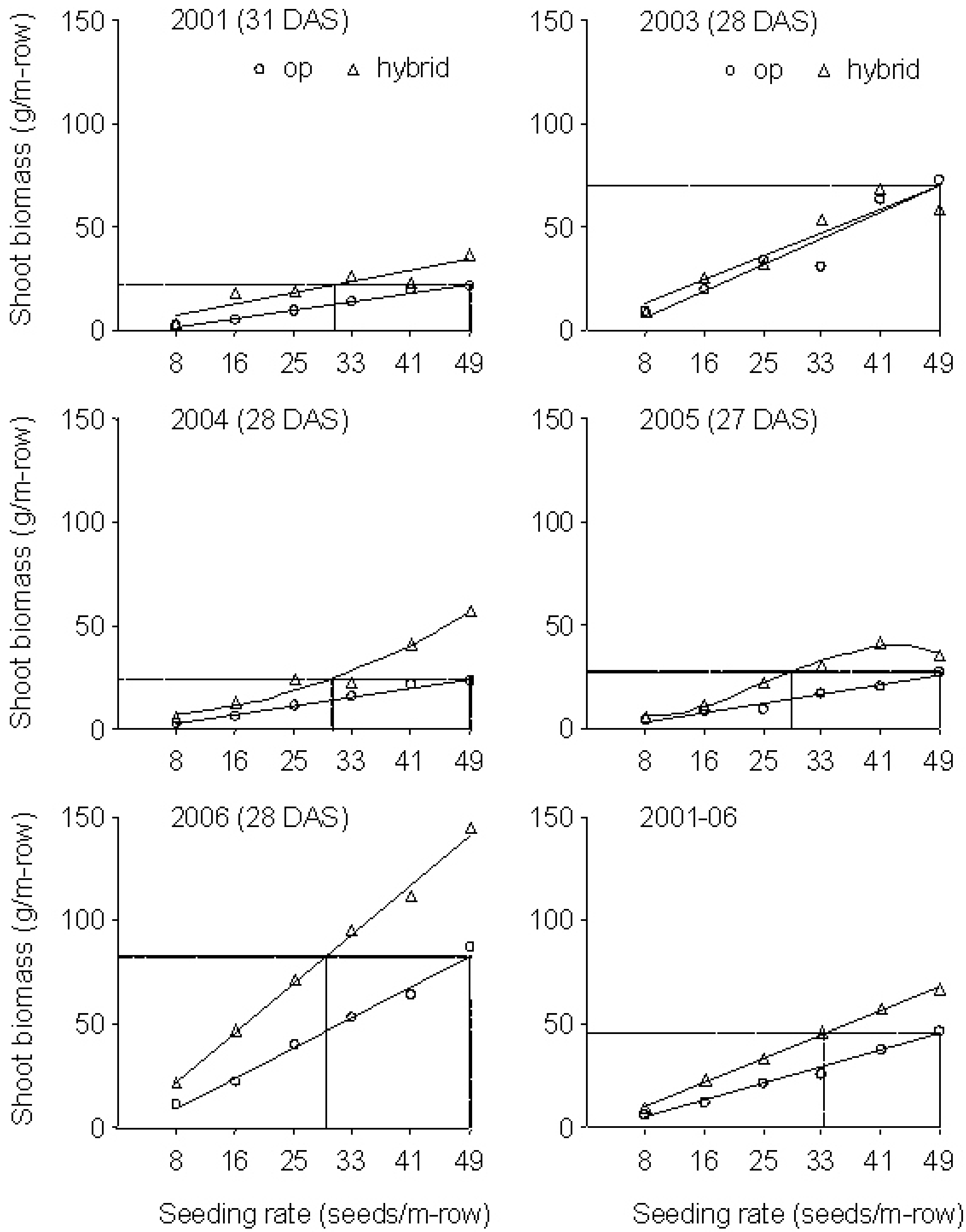

Fig. 13. Relationship between seeding rate and shoot biomass of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in early May in 2001-2006. Biomass was assessed 27-31 DAS.

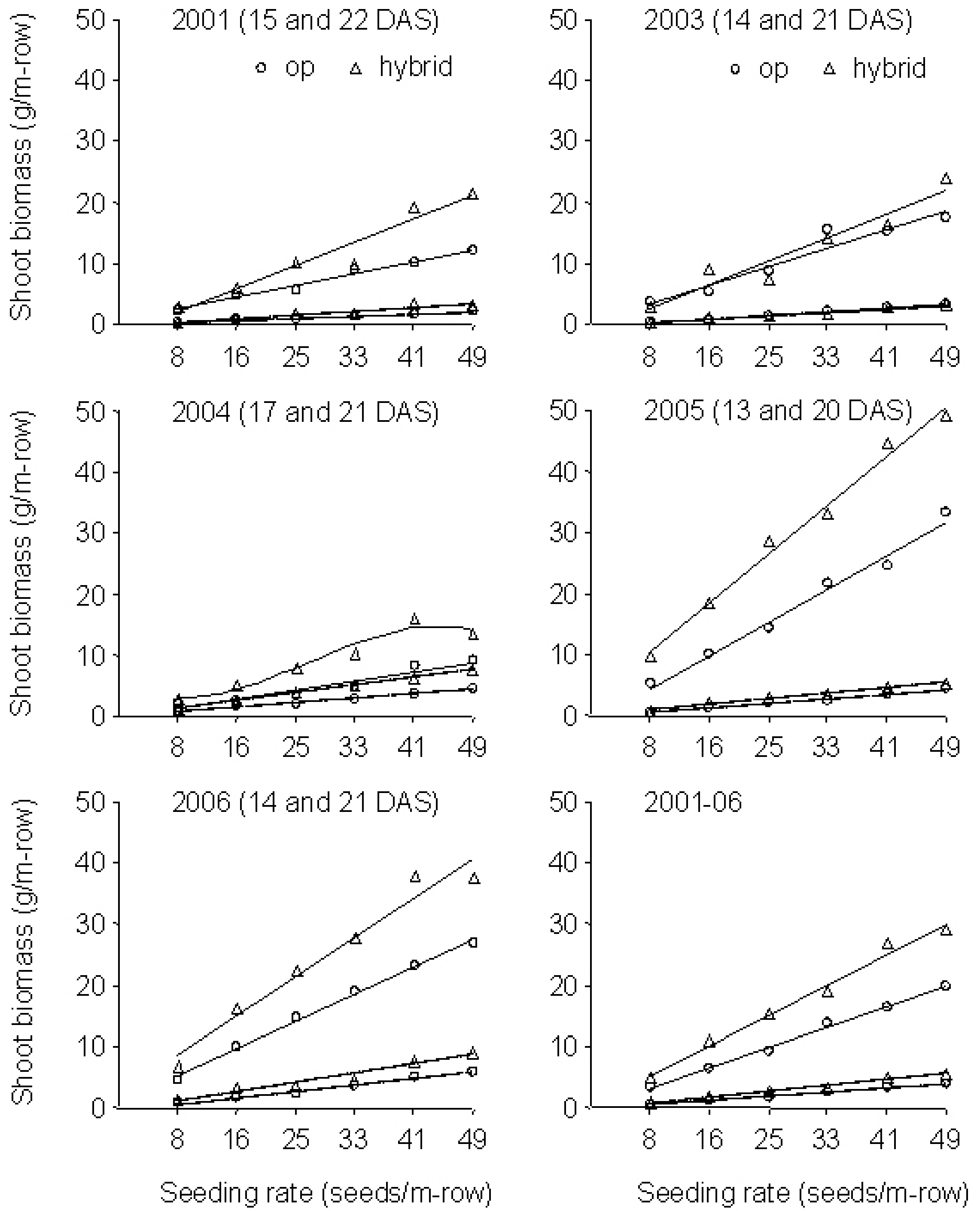

Fig. 14. Relationship between seeding rate and shoot biomass of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in late May in 2001-2006. Biomass was assessed 13-17DAS (dotted line) and 20-22 DAS (solid line).

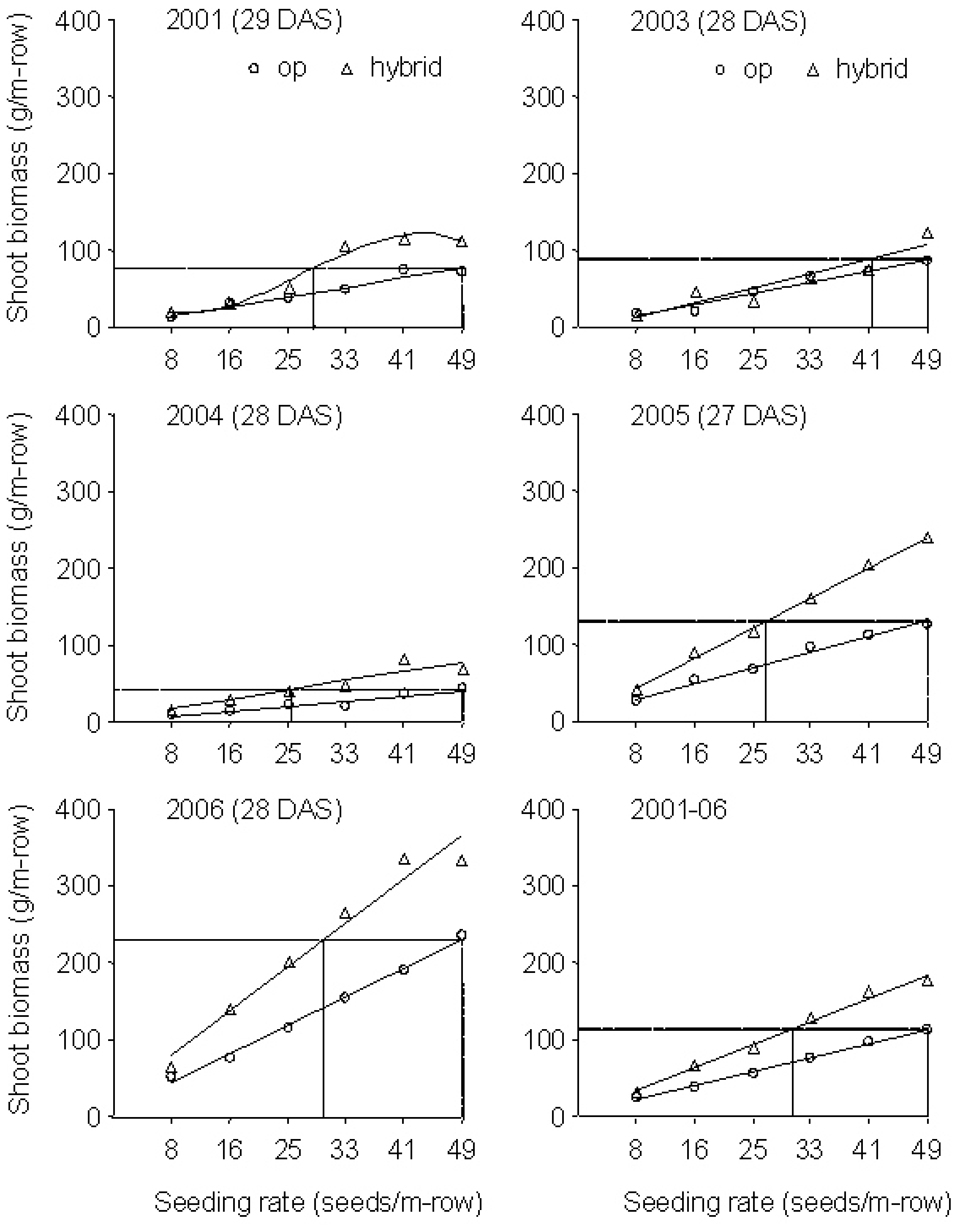

Fig. 15. Relationship between seeding rate and shoot biomass of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in late May in 2001-2006. Biomass was assessed 27-29 DAS.

Table 8. Seed yield of open-pollinated (op) and hybrid (h) Argentine canola seeded into conventional tillage (CT) and minimum tillage in early May (MTE) or late May (MTL) in 2001-2006. [1]

Year	Breeding type	Cultivar	Seed yield - CT		Seed yield - MTE		Seed yield - MTL	
			g/m^2	bu/acre	g/m^2	bu/acre	g/m^2	bu/acre
2001	op	SW Arrow	188.4a	33.6a	97.9a	17.5a	71.6a	12.8a
	h	InVigor 2663	238.9b	42.6b	136.7b	24.4b	96.2b	17.2b
2003	op	SP Banner	131.3a	23.4a	196.4a	35.0a	149.4a	26.7a
	h	InVigor 2663	129.2a	23.1a	218.9a	39.1a	160.8b	28.7b
2004	op	SP Banner	254.7a	45.4a	242.7a	43.3a	243.1a	43.4a
	h	InVigor 5020	312.1b	55.6b	309.5b	55.2b	291.7a	52.0a
2005	op	SP Banner	313.3a	55.9a	299.6a	53.5a	259.6a	46.3a
	h	InVigor 5020	381.5b	68.1b	341.6b	60.9a	301.9b	53.9b
2006	op	SP Banner	223.8a	39.9a	216.1a	38.6a	179.2a	32.0a
	h	InVigor 5020	302.0b	53.9b	273.1b	48.7b	222.8b	39.8b
all	op	Arrow/Banner	222.3	39.7	210.5	37.6	180.6	32.2
	h	InVigor	272.7	48.7	256.0	45.7	214.7	38.3

[1] For each year, means within columns followed by the same letter are not significantly different (ANOVA, $P \geq 0.05$). Means are an average of six seeding rates. Tests in CT conducted on SP Banner in 2002 not 2001.

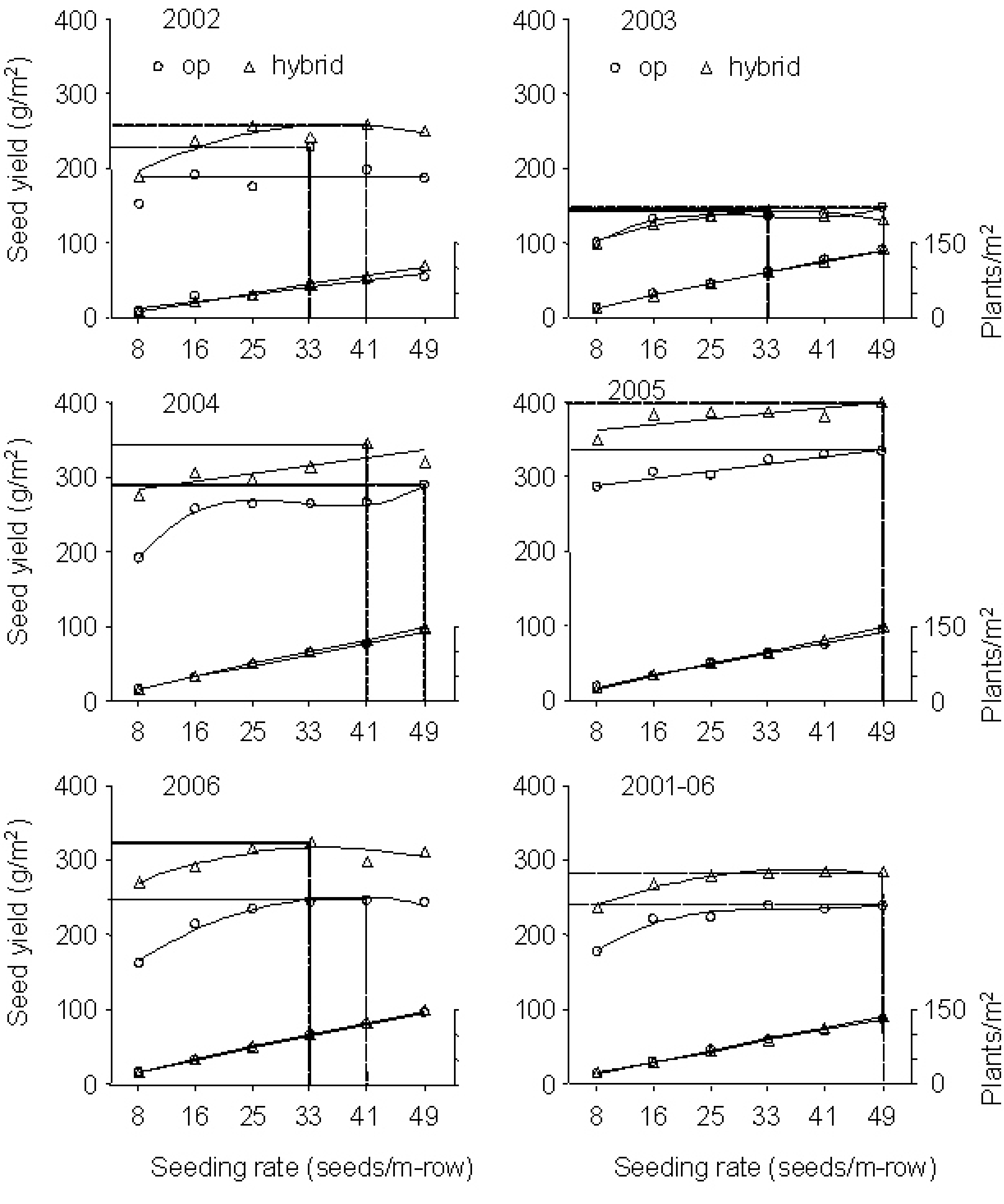

Fig. 16. Relationship between seeding rate and seed yield of open-pollinated (op) and hybrid Argentine canola seeded into conventional tillage (CT) in 2002-2006.

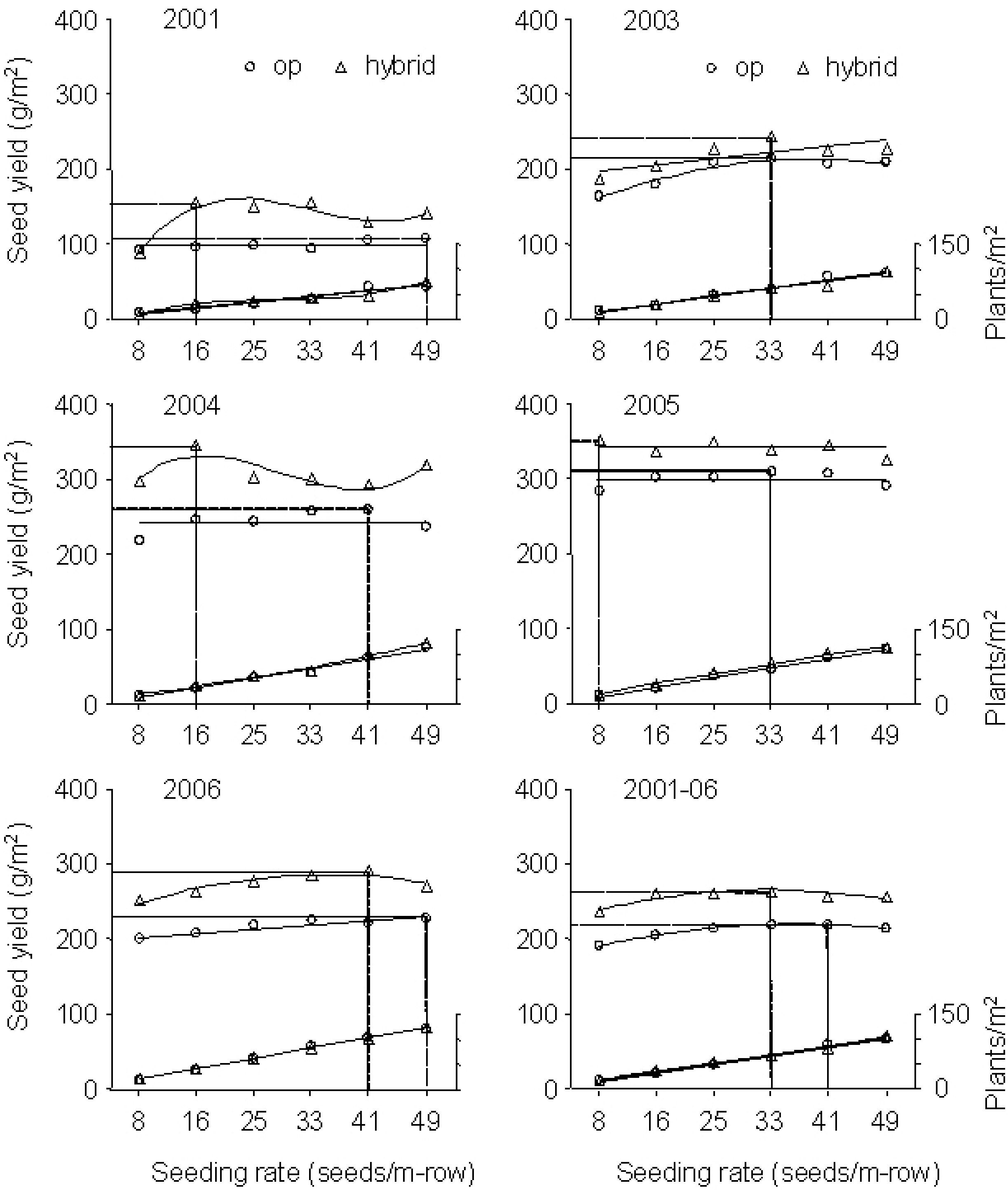

Fig. 17. Relationship between seeding rate and seed yield of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in early May in 2001-2006.

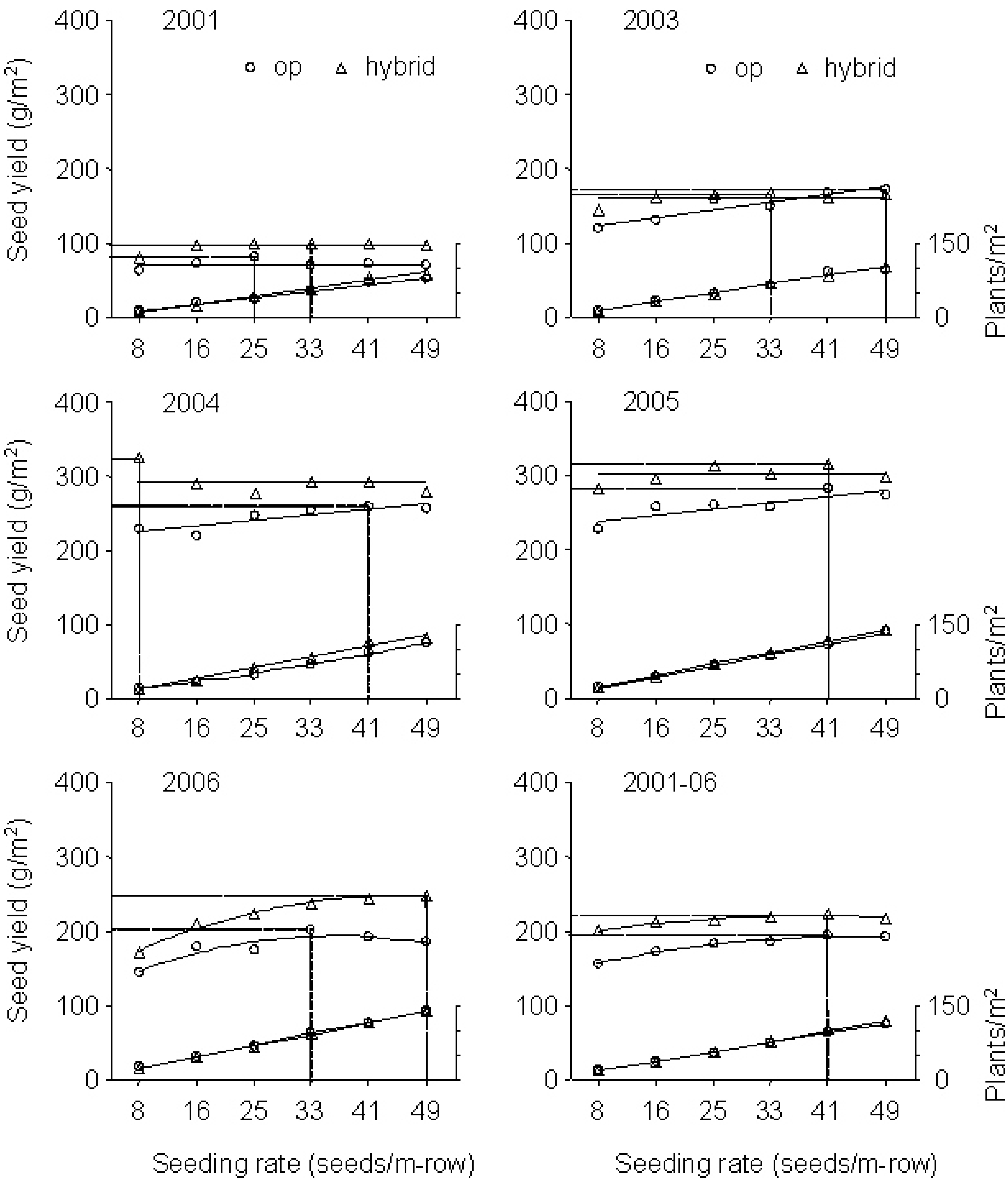

Fig. 18. Relationship between seeding rate and seed yield of open-pollinated (op) and hybrid Argentine canola seeded into minimum tillage (MT) in late May in 2001-2006.

Table 9. Relationship between seeding rate, plant densities, seed yield and economic returns of open-pollinated Argentine canola seeded in conventional tillage (CT) and minimum tillage (MT) in 2001-2006.

	Seeding rate				Seed yield		Gross return[2]			Net return[3]	
Tillage[1]	seeds/m-row	lb/acre	kg/ha	Plants/m^2	g/m^2	bu/acre	acre	ha	seed cost[2]	acre	ha
CT	8	<0.9	1.0	21	178	31.7	$237.80	$587.40	$3.60	$234.20	$578.50
	16	1.8	2.0	46	220	39.2	$294.00	$726.20	$7.20	$286.80	$708.40
	25	2.7	3.0	67	222	39.5	$296.30	$731.90	$10.80	$285.50	$705.20
	33	**3.6**	**4.0**	**89**	**239**	**42.5**	$318.80	$787.40	$14.40	**$304.40**	**$751.90**
	41	4.4	4.9	107	235	41.8	$313.50	$774.40	$17.60	$295.90	$730.90
	49	5.3	5.9	129	240	42.7	$320.30	$791.10	$21.20	$299.10	$738.80
MTE	8	<0.9	1.0	15	191	34.0	$255.00	$629.90	$3.60	$251.40	$621.00
	16	1.8	2.0	29	206	36.7	$275.30	$680.00	$7.20	$268.10	$662.20
	25	2.6	2.9	49	214	38.1	$285.80	$705.90	$10.40	$275.40	$680.20
	33	**3.5**	**3.9**	**63**	**219**	**39.0**	$292.50	$722.50	$14.00	**$278.50**	**$687.90**
	41	4.4	4.9	87	219	39.0	$292.50	$722.50	$17.60	$274.90	$679.00
	49	5.3	5.9	99	214	38.1	$285.80	$705.90	$21.20	$264.60	$653.60
MTL	8	<0.9	1.0	20	157	27.9	$209.30	$517.00	$3.60	$205.70	$508.10
	16	1.8	2.0	38	172	30.6	$229.50	$566.90	$7.20	$222.30	$549.10
	25	2.6	2.9	55	184	32.8	$246.00	$607.60	$10.40	$235.60	$581.90
	33	3.5	3.9	74	186	33.1	$248.30	$613.30	$14.00	$234.30	$578.70
	41	**4.4**	**4.9**	**96**	**194**	**34.5**	$258.80	$639.20	$17.60	**$241.20**	**$595.80**
	49	5.3	5.9	112	191	34.0	$255.00	$629.90	$21.20	$233.80	$577.50

[1] CT - seeded May 19 - May 30; MTE - seeded May 11 - May 16; MTL - seeded May 24 - June 2. Seed weights averaged 3.71g in CT and 3.65g in MT.
[2] Calculations based on a canola price of $7.50/bu and seed cost of $4.00/lb.
[3] Net return = gross return - seed cost

Table 10. Relationship between seeding rate, plant densities, seed yield and economic returns of hybrid Argentine canola seeded in conventional tillage (CT) and minimum tillage (MT) in 2001-2006.

	Seeding rate				Seed yield		Gross return[2]			Net return[3]	
Tillage[1]	seeds/m-row	lb/acre	kg/ha	Plants/m^2	g/m^2	bu/acre	acre	ha	seed cost[2]	acre	ha
CT	8	<1.1	1.2	22	237	42.2	$316.50	$781.80	$8.30	$308.20	$761.30
	16	2.2	2.5	45	269	47.9	$359.30	$887.50	$16.50	$342.80	$846.70
	25	**3.2**	**3.6**	**68**	**281**	**50.0**	$375.00	$926.30	$24.00	**$351.00**	**$867.00**
	33	4.3	4.8	90	282	50.2	$376.50	$930.00	$32.30	$344.20	$850.20
	41	5.4	6.0	112	285	50.7	$380.30	$939.30	$40.50	$339.80	$839.30
	49	6.5	7.3	138	284	50.6	$379.50	$937.40	$48.80	$330.70	$816.80
MTE	8	<1.1	1.2	17	236	42.0	$315.00	$778.10	$8.30	$306.70	$757.60
	16	**2.1**	**2.4**	**36**	**261**	**46.5**	$348.80	$861.50	$15.80	**$333.00**	**$822.50**
	25	3.2	3.6	53	262	46.6	$349.50	$863.30	$24.00	$325.50	$804.00
	33	4.3	4.8	67	264	47.0	$352.50	$870.70	$32.30	$320.20	$790.90
	41	5.4	6.0	83	257	45.7	$342.80	$846.70	$40.50	$302.30	$746.70
	49	6.4	7.2	106	257	45.7	$342.80	$846.70	$48.00	$294.80	$728.20
MTL	8	<1.1	1.2	20	201	35.8	$268.50	$663.20	$8.30	$260.20	$642.70
	16	**2.1**	**2.4**	**38**	**212**	**37.7**	$282.80	$698.50	$15.80	**$267.00**	**$659.50**
	25	3.2	3.6	58	215	38.3	$287.30	$709.60	$24.00	$263.30	$650.40
	33	4.3	4.8	79	220	39.2	$294.00	$726.20	$32.30	$261.70	$646.40
	41	5.4	6.0	103	223	39.7	$297.80	$735.60	$40.50	$257.30	$635.30
	49	6.4	7.2	118	217	38.6	$289.50	$715.10	$48.00	$241.50	$596.50

[1] CT - seeded May 19 - May 30; MTE - seeded May 11 - May 16; MTL - seeded May 24 - June 2. Seed weights averaged 4.50g in CT and 4.47g in MT.
[2] Calculations based on a canola price of $7.50/bu and seed cost of $7.50/lb
[3] Net return = gross return - seed cost