THE EFFECT OF CONVENTIONAL VERSUS ZERO TILLAGE,

WITH DIFFERENT AGRONOMIC PRACTICES,

ON INSECT PESTS OF CANOLA

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Principal Investigator: Dr. Lloyd Dosdall
Alberta Research Council
Postal Bag 4000
Vegreville Alberta

Joint Applicant: Mr. Michael Dolinski
Provincial Specialist, Entomology
Alberta Agriculture, Food and Rural Development
Agronomy Centre
Edmonton, Alberta

Summary

Infestations of root maggots (*Delia* spp.) (Diptera: Anthomyiidae) and flea beetles (*Phyllotreta* spp.) (Coleoptera: Chrysomelidae) were assessed for Polish (*Brassica rapa* L.) and Argentine (*Brassica napus* L.) canola grown under conventional and zero tillage regimes, with three different row spacings (10, 20, and 30 cm), and three seeding rates (5.0, 7.5, and 10.0 kg $\cdot$ ha^{-1}). The study was conducted at two sites in central Alberta: near Vegreville and approximately 35 km northwest of Westlock.

Two indices were used to assess degree of root maggot infestation: 1) the number of root maggot eggs laid per plant throughout the growing season, and 2) larval feeding damage caused to canola roots and assessed at the end of the season. Flea beetle damage was determined once weekly for two weeks when plants were in the seedling stage. For each treatment plot, estimates were made of percentages of cotyledon and leaf area eaten by flea beetles.

This study determined that root damage from feeding by larval root maggots was greater under zero tillage than under conventional tillage. Plants grown at higher densities (10.0 kg $\cdot$ ha^{-1}) had less root damage than plants grown at low (5.0 kg $\cdot$ ha^{-1}) densities, and canola plants grown at wider row spacings (30 cm) had less root damage than plants grown at narrower spacings (10 and 20 cm). Plants of *B. rapa* were significantly more susceptible to infestations by both root maggots and flea beetles than were plants of *B. napus*. Although row spacing and seeding rate had no significant effect on flea beetle damage, significantly greater damage was caused by flea beetles on plots subjected to conventional tillage compared with zero tillage.

Results of this study have enabled the formulation of several recommendations that can be made to canola growers in regions of Alberta that are routinely infested with high populations of root maggots and flea beetles. First, because *B. napus* is less susceptible to root maggot and flea beetle infestations than is *B. rapa*, canola growers should seed *B. napus* rather than *B. rapa*, provided it is possible to seed *B. napus* early enough in the growing season. Secondly, even though canola grown under zero tillage was subjected to

increased attack by root maggots than canola grown under conventional tillage, a yield advantage still occurred under the zero-till regimen. At Vegreville, this yield advantage for zero-till plots was only marginal compared with conventional-till plots, but at Westlock the yield advantage was substantial. Zero tillage is therefore an appropriate agronomic practice in areas infested by high populations of root maggots. Thirdly, row spacings of 30 cm resulted in less root maggot damage and improved yields compared with narrower row spacings of 10 or 20 cm. Increasing row spacing is an appropriate cultural control practice for root maggots in canola. Fourthly, increasing seeding rate to 10.0 $kg \cdot ha^{-1}$ rather than 5 $kg \cdot ha^{-1}$ resulted in decreased root maggot infestations and is also an appropriate cultural control practice for root maggots in canola. Finally, flea beetle infestations were particularly low in zero-till systems compared with conventional-till systems, and were not affected by changes in row spacing or seeding rate. Seed treatment with the insecticide lindane, used to reduce herbivory by flea beetles, is probably not necessary in Alberta when canola is grown under a zero-till regimen.

Introduction

In central Alberta, infestations of the root maggots, *Delia radicum* (L.) and *Delia floralis* (Fallén), are responsible for substantial economic losses in the production of canola (Griffiths 1986a, 1991); for example, in 1994 alone, root maggot damage to Alberta canola crops was estimated at $40 million (P. Thomas, pers. comm.). Plant damage occurs when larvae feed on root tissue, and injury is exacerbated when feeding channels are subsequently invaded by root rot fungi (Griffiths 1986a). This may result in host plant mortality (Liu and Butts 1982; Griffiths 1986a), or decreased crop yields estimated at 52% for *Brassica rapa* L. and 20% for *Brassica napus* L.(Griffiths 1991).

The flea beetles, *Phyllotreta cruciferae* (Goeze) and *Phyllotreta striolata* (Fabricius), are also major pests of canola in western Canada (Burgess 1977; Lamb and Turnock 1982). Adult beetles invade canola fields in spring from their overwintering sites in shelterbelts or wooded areas, and attack newly emerged seedlings by chewing pits in the cotyledons, leaves, and stems (Westdal and Romanow 1972; Burgess 1977). Attack by flea beetles reduces the leaf area available for photosynthesis and disrupts transpiration, which can lead to wilting and death of the seedlings especially under dry conditions. Although seedlings may recover from flea beetle attack, affected plants can show reduced biomass, delayed maturity, and stunting in their later developmental stages (Putnam 1977).

In recent years, canola producers have been encouraged to adopt minimum or zero tillage systems because they offer considerable potential for maintaining or improving soil productivity, particularly in regions where moisture is limiting (Lindwall 1989). The benefits of reduced tillage include less soil erosion, improved moisture conservation, increased soil organic matter, decreased human labour requirements, and improved crop yields (Stinner and House 1990; Jensen and Timmermans 1991). However, little research has been conducted on the impact of conventional versus zero tillage systems on populations of insect pests. For example, reduced tillage is associated with the accumulation of more organic crop residues on the soil surface than occurs with conventional tillage, and these residues may harbour the overwintering stages of some pest species, such as flea beetles. In addition, previous research by Dosdall et al. (1996a) found that emergence of root maggot adults from canola stubble was approximately 65% greater in zero-till plots compared with plots that had been tilled conventionally. Increased overwintering survival, and overwintering at closer proximity to the newly seeded crop, could cause increased pest populations and greater economic damage in the following year.

The objective of this study was to evaluate the impact of conventional versus zero tillage systems, used in conjunction with three different row spacings and three seeding rates, on infestations of root maggots (*Delia* spp.) and flea beetles (*Phyllotreta* spp.) in canola.

Methods and Materials

The experiments were randomized complete block designs with a split-plot feature and four replicates conducted during 1995 and 1996 at two sites in central Alberta: near Vegreville and near Westlock. Tillage treatment (conventional- and zero-till) was assigned to main plots with canola species (*B. rapa* and *B. napus*), row spacing (10, 20, and 30 cm), and seeding rate (5.0, 7.5, and 10.0 $kg \cdot ha^{-1}$) assigned to sub-plots. The seeding rates of 5.0, 7.5, and 10.0 $kg \cdot ha^{-1}$ corresponded approximately to the recommended rate, 1.5, and 2.0 times the recommended rate, respectively (Thomas 1990). Under both conventional and zero tillage, 18 plots of canola – nine of *B. rapa* cv. Horizon and nine of *B. napus* cv. Delta – were established which comprised:

1) *B. rapa*, seeded at 5.0 $kg \cdot ha^{-1}$, with a 10 cm row spacing;
2) *B. rapa*, seeded at 5.0 $kg \cdot ha^{-1}$, with a 20 cm row spacing;
3) *B. rapa*, seeded at 5.0 $kg \cdot ha^{-1}$, with a 30 cm row spacing;

4) *B. rapa*, seeded at 7.5 $kg \cdot ha^{-1}$, with a 10 cm row spacing;
5) *B. rapa*, seeded at 7.5 $kg \cdot ha^{-1}$, with a 20 cm row spacing;
6) *B. rapa*, seeded at 7.5 $kg \cdot ha^{-1}$, with a 30 cm row spacing;

7) *B. rapa*, seeded at 10.0 $kg \cdot ha^{-1}$, with a 10 cm row spacing;
8) *B. rapa*, seeded at 10.0 $kg \cdot ha^{-1}$, with a 20 cm row spacing;

9) *B. rapa*, seeded at 10.0 $kg \cdot ha^{-1}$, with a 30 cm row spacing;

10) *B. napus*, seeded at 5.0 $kg \cdot ha^{-1}$, with a 10 cm row spacing;
11) *B. napus*, seeded at 5.0 $kg \cdot ha^{-1}$, with a 20 cm row spacing;
12) *B. napus*, seeded at 5.0 $kg \cdot ha^{-1}$, with a 30 cm row spacing;

13) *B. napus*, seeded at 7.5 $kg \cdot ha^{-1}$, with a 10 cm row spacing;
14) *B. napus*, seeded at 7.5 $kg \cdot ha^{-1}$, with a 20 cm row spacing;
15) *B. napus*, seeded at 7.5 $kg \cdot ha^{-1}$, with a 30 cm row spacing;

16) *B. napus*, seeded at 10.0 $kg \cdot ha^{-1}$, with a 10 cm row spacing;
17) *B. napus*, seeded at 10.0 $kg \cdot ha^{-1}$, with a 20 cm row spacing; and
18) *B. napus*, seeded at 10.0 $kg \cdot ha^{-1}$, with a 30 cm row spacing.

Each sub-plot measured 6 m by 2 m, and seeding was performed in mid to late May. Soil was fertilized according to the soil test recommendations for canola production. The canola seed was treated with a fungicide to reduce infestation by seedling diseases, but no lindane (flea beetle insecticide) treatment was applied to the seed. Plots having conventional tillage were cultivated with tandem discs and mounted tine harrows so the soil was worked to a depth of approximately 15 cm. For both conventional- and zero-till plots, seeding was performed with a coulter double disc no-till drill. Zero-till plots were situated on stubble that was seeded to a cereal crop during the previous year.

Once per week for approximately six weeks during the peak period of egg-laying by root maggot females, 100 plants (25 from each of four replicate sub-plots) for each treatment were evaluated for susceptibility to oviposition. Each plant was examined visually and the numbers of eggs laid at the base, the lower leaf axils, and in the soil in a 1-cm-radius around the plant stalk were determined according to the method of Dosdall et al. (1994).

Flea beetle damage was assessed twice while plants were in the seedling stage: approximately 10 and 17 days after seeding. On each assessment date, two rows per treatment were rated on a scale from 0 to 10 where 0 = no damage and 10 = 91-100% of the leaf or cotyledon area damaged by flea beetle attack.

Plots were harvested at the end of the season using a Hege® plot combine to determine seed yields per plot. After harvest, 100 plants (25 from each replicate sub-plot) for each treatment were dug out, washed, and scored for degree of root maggot damage using the semi-quantitative rating scale of Dosdall et al. (1994) where 0 = no root damage, 1 = less than 10% of the root surface with root maggot feeding channels, 2 = 11-25%, 3 = 26-50%, 4 = 51-75%, and 5 = 76-100% of the taproot surface area damaged.

Data were subjected logarithmic transformation, $\log_{10}(x + 1)$, to stabilize variances among the means. Data were then subjected to analysis of variance and Student-Newman-Keuls multiple comparisons (SAS Institute Inc. 1990) to determine significance of differences in mean eggs laid per plant, and root damage and seed yield at the end of the season for both species of canola seeded on plots subjected to different tillage regimes and grown at varying row spacings and plant densities.

Results

At the Westlock site, both field seasons were characterized by normal rainfall levels, with 27.9 and 18.7 cm received between seeding and harvest in 1995 and 1996, respectively. Such cool, moist conditions are conducive to producing comparatively high root maggot populations (Griffiths 1986b); however, flea beetle populations were quite low at Westlock in both years and little leaf and cotyledon damage was observed even though no lindane (insecticide) was used in the seed dressing. At Vegreville, drought occurred during the 1995 field season with only 3.28 cm of precipitation received between seeding and harvest, and most of this occurred in early July. Emergence of canola seedlings was very patchy after seeding, and rain approximately six weeks later caused germination of canola seed that had been dormant. Because of the poor plant establishment due to the drought, and the secondary germination of canola seedlings that occurred after rain was received in July, the plots were not harvested to determine seed yield. In 1996, precipitation levels were normal at Vegreville, with 22.9 cm received between seeding and harvest. Plots could then be harvested at the end of the season.

In both 1995 and 1996, root maggot egg populations at Vegreville were significantly greater on plants of *B. rapa* compared with *B. napus* ($P < 0.05$) (Figs. 1, 2). In 1995, significantly more root maggot eggs were laid on plants of both canola species grown in zero tillage compared with those grown in conventional tillage ($P < 0.05$) (Fig. 1). In 1996, this relationship was observed for plants of *B. rapa*, but not for *B. napus* (Fig. 2). Fewest eggs were generally laid on plants seeded at the widest row spacing (30 cm) compared with narrower spacings (10 and 20 cm). This relationship was particularly evident in 1995 for plots of *B. rapa* grown in a zero-till regimen where egg populations declined significantly with an increase in row spacing ($P < 0.05$) (Fig. 1). In addition, mean eggs per plant tended to decline with an increase in seeding rate, although this was more apparent for plots subjected to zero tillage than conventional tillage (Figs. 1, 2).

In both 1995 and 1996, root maggot egg populations at Westlock were relatively low, and significantly more eggs were laid on plants of *B. rapa* relative to *B. napus* ($P < 0.05$) (Figs. 3, 4). In 1995, no statistically significant differences in mean eggs laid per plant were observed for plots of either *B. napus* or *B. rapa* subjected to conventional tillage versus zero tillage ($P > 0.05$). In 1996, significantly more eggs were laid on *B. rapa* plants grown in zero tillage than in conventional tillage ($P < 0.05$); however, root maggot eggs laid on plants of *B. napus* were not significantly affected by tillage method ($P > 0.05$). In both 1995 and 1996, no statistically significant differences were observed in mean numbers of root maggot eggs for plants sown at different row spacings or seeding rates ($P > 0.05$).

At Vegreville in both years, mean root damage ratings of plants of both *B. napus* and *B. rapa* were significantly greater for plants grown in the zero-till regimen than for plants grown in conventional tillage ($P < 0.05$) (Figs. 5, 6). Plants of *B. rapa* were damaged to a significantly greater degree than plants of *B. napus* in both years ($P < 0.05$). Least root damage often occurred to plants grown at the widest row spacing (Fig. 7). Mean root damage values usually declined significantly with an increase in seeding rate; the order from greatest to least root damage was often $5.0\ kg \cdot ha^{-1} > 7.5\ kg \cdot ha^{-1} > 10.0\ kg \cdot ha^{-1}$ (Fig. 8). The only exceptions where root damage did not decline significantly with an increase in seeding rate occurred in 1995 for plots of *B. rapa* and *B. napus* grown in the zero-till plots (Fig. 8).

At Westlock, mean root damage ratings were significantly greater for plants of *B. rapa* than for *B. napus* in both 1995 and 1996 ($P < 0.05$) (Figs. 9, 10). In 1995, mean root damage ratings of plants of *B. napus* plants were significantly greater for plants grown in the zero-till regime than for plants grown in conventional tillage ($P < 0.05$); however, no statistically significant differences were observed among these tillage regimes for plants of *B. rapa* ($P > 0.05$) (Fig. 9). In 1996, significantly greater mean root damage ratings were found for both canola species grown in zero tillage than in conventional tillage ($P < 0.05$) (Fig. 10). Least root damage usually occurred to plants grown at the widest row spacings (Fig. 11). In 1995, the effect of row spacing was consistent where damage to plants sown at 30 cm row spacings was significantly less than for plants grown at 10 cm spacings ($P < 0.05$) (Fig. 11). In 1996, row spacing of plants of *B. napus* did not significantly affect root maggot infestation levels ($P > 0.05$); however, for plants of *B. rapa* grown in conventional tillage, significantly greater damage was observed for plants grown at the most narrow spacing (10 cm) compared with the wider spacings of 20 or 30 cm ($P < 0.05$) (Fig. 11). In both years, mean root damage ratings were significantly affected by seeding rate with the exception of plants of *B. rapa* grown in zero tillage (Fig. 12); mean root damage values declined with an increase in seeding rate: the order from greatest to least root damage was 5.0 kg per ha > 7.5 kg per ha > 10.0 kg per ha.

At both Vegreville and Westlock, plants of *B. rapa* were significantly more susceptible to flea beetle infestation than *B. napus* in both years of the study ($P < 0.05$). Row spacing and seeding rate had no significant effect on flea beetle damage ($P > 0.05$). Tillage regime, however, did have a significant impact on flea beetle populations. Significantly greater damage was caused by these pests on plots tilled using conventional methods than on plots subjected to zero tillage ($P < 0.05$).

At Vegreville, seed yield of *B. napus* significantly exceeded that for *B. rapa* for plots under both conventional and zero tillage treatments ($P < 0.05$) (Fig. 13). Yield for both canola species was slightly greater for the zero-till than for the conventional-till plots, but this difference was not significant statistically ($P > 0.05$). For plots subjected to both conventional and zero tillage, significant increases in yield occurred at 20 and 30 cm row spacings compared with 10 cm spacings ($P < 0.05$) (Fig. 14). No statistically significant differences were observed for seed yields in relation to plant density ($P > 0.05$) (Fig. 14).

At Westlock, in both years of the study, seed yield of *B. napus* significantly exceeded that for *B. rapa* for plots under both conventional and zero tillage treatments ($P < 0.05$), and yield for both canola species was significantly greater for the zero-till plots than for the conventional-till plots ($P < 0.05$) (Figs. 15, 16). Increases in seed yield with increased row spacings were consistent in both years, and were statistically significant in 1995 for *B. napus* grown in zero tillage and in 1996 for both *B. napus* and *B. rapa* grown in conventional tillage (Fig. 17). Differences in seed yield in relation to seeding rate were not significant statistically with the exception of *B. rapa* plants grown in conventional tillage during 1995 (Fig. 18).

Discussion

Previous research has established that cultivation can have a significant impact on populations of insects which spend a portion of their life cycles in the soil, and on the subsequent crop losses they cause (Stinner and House 1990; Dent 1991). Stinner and House (1990) evaluated 45 studies which described the impact of tillage or the lack of tillage on invertebrate pests from widely differing regions of the world. In 28% of species studied, crop damage increased with less tillage; in the majority of species (43%), damage decreased with a decrease in tillage. Tillage had no significant influence on crop damage for 29% of species evaluated. This study determined that cultivation prior to seeding had different effects on two important insect pests of canola. With zero tillage, feeding damage by root maggots was greater than with conventional tillage; however, herbivory from flea beetles was greater with conventional than with zero tillage.

In general, increases in host plant density cause reductions in insect pest populations (A'Brook 1968; Farrell 1976; Coaker 1987), but there are exceptions (Mayse 1978; Troxclair and Boethel 1984). Several reasons have been proposed to explain lower insect numbers in dense plantings. The presence of excess vegetation has been considered to act as a deterrent to oviposition (Delobel 1981), and dense plantings may induce changes in the microenvironment favored by the pest (Coaker 1987). Some flying insects appear to rely on spacing contrasts between bare earth and vegetative cover as cues for landing responses; if the landing stimulus is greater over widely spaced plants, increases in plant density can deter landing and cause overall reductions in pest populations (A'Brook 1968).

In this study, the effects of increasing canola plant density on root maggot infestations were in general agreement with those determined previously by Dosdall and Dolinski (1995) and Dosdall et al. (1995a). Canola plants grown at higher densities develop smaller basal stems than those grown at lower densities, and this causes them to be less attractive to ovipositing root maggot females (Dosdall et al. 1995b, 1996b). The reduced root maggot infestations at higher plant densities generally results in greater seed yields (Dosdall and Dolinski 1995). A similar relationship was recorded by Lunginbill and McNeal (1958) for wheat stem sawfly, *Cephus cinctus* Norton on wheat. Planting wheat at high densities decreased stem diameter, stem moisture content, and plant height. *Cephus cinctus* prefers larger, more succulent plants for oviposition, and damage to wheat decreased as plant density increased. However, it should be noted that no evidence was found in the present study to indicate that increasing plant density had any effect on flea beetle infestations.

The effect of altering row spacing has not been evaluated previously for the cultural control of insect pests of canola. This study determined that widening row spacing to 30 cm rather than 10 or 20 cm resulted in decreased root maggot infestations; however, row spacing did not appear to affect flea beetle populations. The reason for reduced root maggot damage at wider row spacings is probably related to basal stem diameter. Dosdall et al. (1995b, 1996b) determined that root maggot females selected plants with larger basal stems for oviposition. When plant density is standardized over several different row spacings, as was done in this study, there are more plants per row at wider row spacings than at narrower row spacings. With more canola plants per row, those plants develop smaller basal stem diameters as a result of increased intraspecific plant competition, and hence will be less attractive to ovipositing females. With fewer canola plants per row, plants develop larger basal stems, which are more attractive to ovipositing female flies.

It is important to note that even though root maggot infestations on zero-till canola exceeded infestations on canola grown in plots tilled using conventional methods, seed yield from zero-till plots was still greater than for conventional-till plots (Table 1). There are two possible explanations for the increased yield on zero-till plots compared with plots tilled conventionally: 1) flea beetle infestations were greater on canola grown in a conventional-tillage system than in zero tillage, and this could have caused the reduced yields for those plots, and 2) the improved soil moisture and organic matter contents of zero-till plots, compared with conventional-till plots, enabled plants to compensate for increased root maggot pressure. The first explanation is unlikely. Even though flea beetle infestations were significantly greater on conventional than on zero-till plots, no seedling mortality was observed from flea beetle attack, and at the true leaf (rosette) stage, plants from the two tillage regimens showed no apparent developmental differences. Alternatively, it has been shown that improved soil moisture conditions, especially early in the season, can enable canola plants to compensate for root maggot attack. Dosdall and Dolinski (1995) and Dosdall et al. (1996b) determined that canola seeded early in the season was more susceptible to root maggot attack than canola seeded later; however, seed yield was compromised in late plantings. This was explained by the more favourable soil moisture conditions early in the season that enabled plants to compensate for root maggot attack, and this is quite similar to the improved soil moisture levels that occur in zero-till versus conventional-till systems. It is therefore most likely that canola grown in zero-till systems can take advantage of improved soil moisture and organic matter contents to enable plants to compensate for increased root maggot pressure. A zero-till system for canola is therefore an appropriate agronomic practice in areas infested by high populations of root maggots.

The yield improvement on zero-till plots compared with conventional-till plots was only marginal at Vegreville, but at Westlock the yield increases were substantial. These data are summarised in Table 1 and indicate that the yield improvements for both *B. napus* and *B. rapa* were greater at the Westlock site (mean yield increase for *B. napus* in 1995 and 1996 = 6.2 bushels per acre; mean yield increase for *B. rapa* in 1995 and 1996 = 3.0 bushels per acre) than at Vegreville (mean yield increase for *B. napus* = 0.4 bushels per acre; mean yield increase for *B. rapa* = 0.2 bushels per acre). It is probable that these yield differences between sites resulted from the severe drought at Vegreville during 1995 which produced depleted soil moisture levels that extended into the 1996 season. Even though rainfall was adequate in Vegreville during 1996, soil moisture levels may still not have recovered sufficiently to permit canola plants in zero-till plots to compensate as fully for increased pressure from root maggot infestation.

Important advantages of utilising a zero-till system for canola production are the reduced requirements of human labour, fuel, and equipment. This study has shown that in spite of greater susceptibility of zero-till canola plants to root maggot infestation, improved gross returns can still be achieved. Even if one assumes that input costs for zero-till and conventional-till systems are equal, economic benefit can be achieved with zero tillage. For example, at Vegreville in 1996 the mean yield improvements for *B. napus* and *B. rapa* were 0.4 and 0.2 bushels per acre, respectively, with a zero-till system over a conventional-till system. With a crop value of $10 per bushel for canola, the improvement in gross return is $4 and 2 per acre for zero tillage over conventional tillage. Should normal levels of precipitation resume in future years, resulting in restoration of soil moisture content in Vegreville, economic returns should be even greater with zero tillage. Drought has not occurred at Westlock for several years, and here the mean yield improvements for *B. napus* and *B. rapa* in zero tillage over conventional tillage were 7.1 and 2.5 bushels per acre in 1995 and 5.4 and 3.4 bushels per acre in 1996. Assuming canola prices of $10 per bushel, this would result in gross returns of $71 (*B. napus*) and $25 (*B. rapa*) per acre for zero tillage over conventional tillage in 1995 and $54 (*B. napus*) and $34 (*B. rapa*) in 1996. Clearly, the economic benefits of adopting a zero-tillage system for canola production are substantial, and the increased infestations of root maggots in these systems can be ameliorated if growers adopt higher seeding rates and wider row spacings.

Conclusions

Results of this study have determined that with a zero-till regimen, plants of both *B. rapa* and *B. napus* were damaged by feeding of larval root maggots to a significantly greater degree than plants grown in a conventional-till system. In addition, this study determined that increasing row spacing resulted in a corresponding reduction in root maggot infestations, and that flea beetle infestations were significantly greater with conventional tillage than with zero tillage. Further, the study corroborated previous evidence that *B. rapa* is more susceptible to infestation by root maggots than is *B. napus*, and that root maggot infestations can be reduced by increasing seeding rates.

In spite of the increase in root maggot infestations with zero tillage than with conventional tillage, it is important to note that when the entire Vegreville and Westlock yield data set is considered, yield of canola grown in zero tillage substantially exceeded yield for plants grown with conventional tillage. It is evident, therefore, that the increased soil moisture levels that are characteristic of zero-till systems can help canola compensate for increased root maggot feeding pressure.

The major recommendations for canola producers that have arisen from this research are:

1. Argentine canola (*B. napus*) is less susceptible to root maggot and flea beetle infestation than is Polish canola (*B. rapa*). Canola growers in regions of Alberta which are infested annually with high population densities of root maggots and flea beetles, should seed *B. napus* rather than *B. rapa* if producers can seed *B. napus* early enough in the growing season.

2. Even though canola grown in zero tillage was subjected to increased attack by root maggots than canola grown in conventional tillage, improved yield still occurred with zero-till systems. Zero tillage is therefore an appropriate agronomic practice in areas infested with high populations of root maggots.

3. Increasing row spacing to 30 cm resulted in comparatively less root maggot damage than narrower row spacings of 10 or 20 cm. Increasing row spacing is an appropriate cultural control practice for root maggots in canola.

4. Increasing seeding rate to 10 $kg \cdot ha^{-1}$ rather than 5 $kg \cdot ha^{-1}$ resulted in decreased root maggot infestations and is therefore an appropriate cultural control practice for root maggots in canola.

5. Flea beetle infestations were particularly low in zero-till systems compared with conventional-till systems, and are not affected by changes in row spacing or seeding rate. Seed treatment with the insecticide lindane, to reduce herbivory by flea beetles, is probably not necessary when canola is grown in zero-till systems.

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Table 1. Yield of canola, converted to bushels per acre, for plots at Vegreville (1996) and Westlock (1995 and 1996) subjected to conventional and zero-tillage regimes. Yield at Vegreville was not determined in 1995 because of drought. Means in a row followed by the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

			Yield (bu/acre)	
Site	Year	Species	Conventional Tillage	Zero Tillage
Vegreville	1996	*B. napus*	39.81 a	40.25 a
		B. rapa	29.02 a	29.19 a
Westlock	1995	*B. napus*	35.10 a	42.18 b
		B. rapa	27.52 a	30.05 b
	1996	*B. napus*	34.56 a	39.92 b
		B. rapa	26.66 a	30.06 b

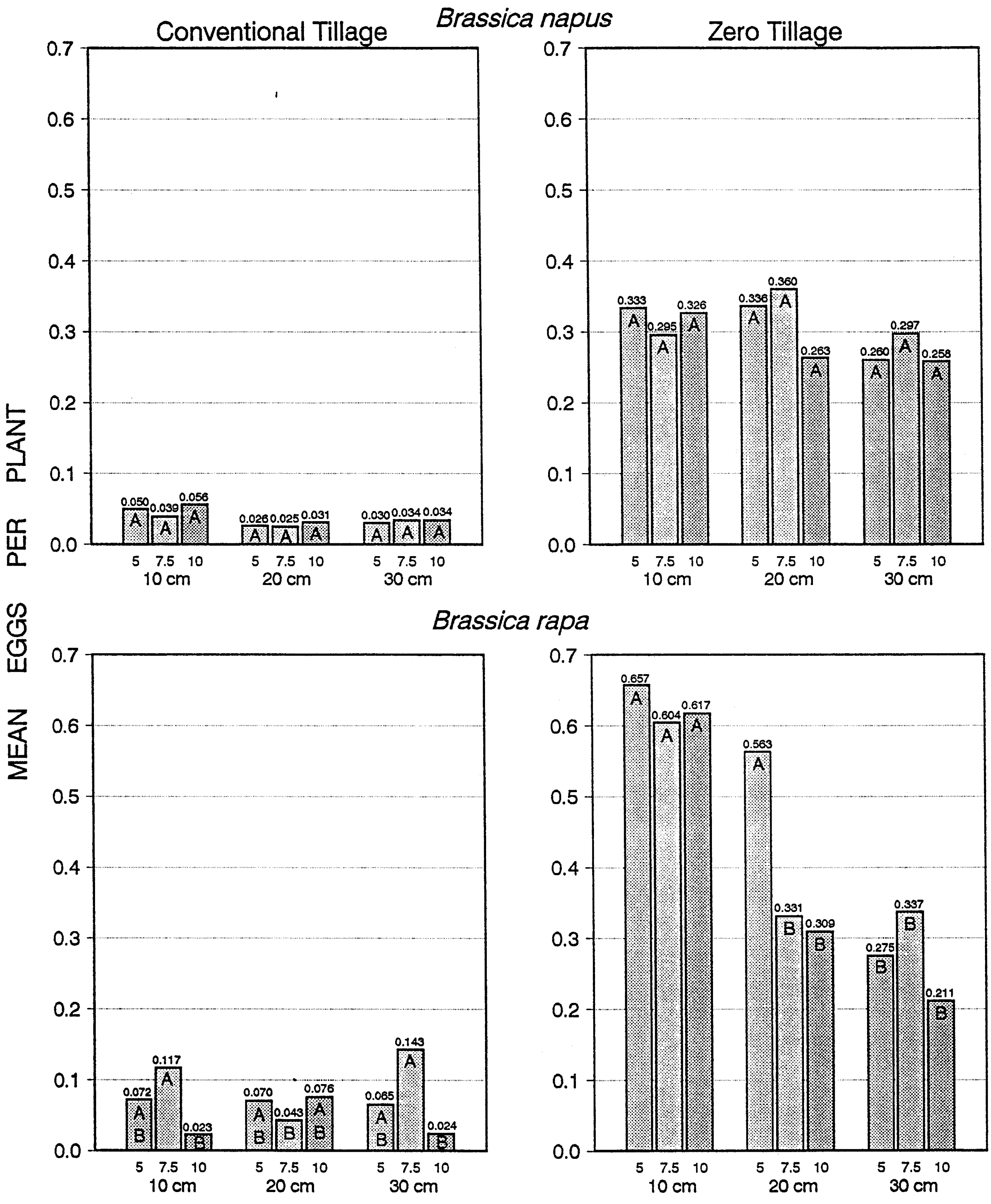

Fig. 1. Mean numbers of eggs per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Vegreville site in 1995. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

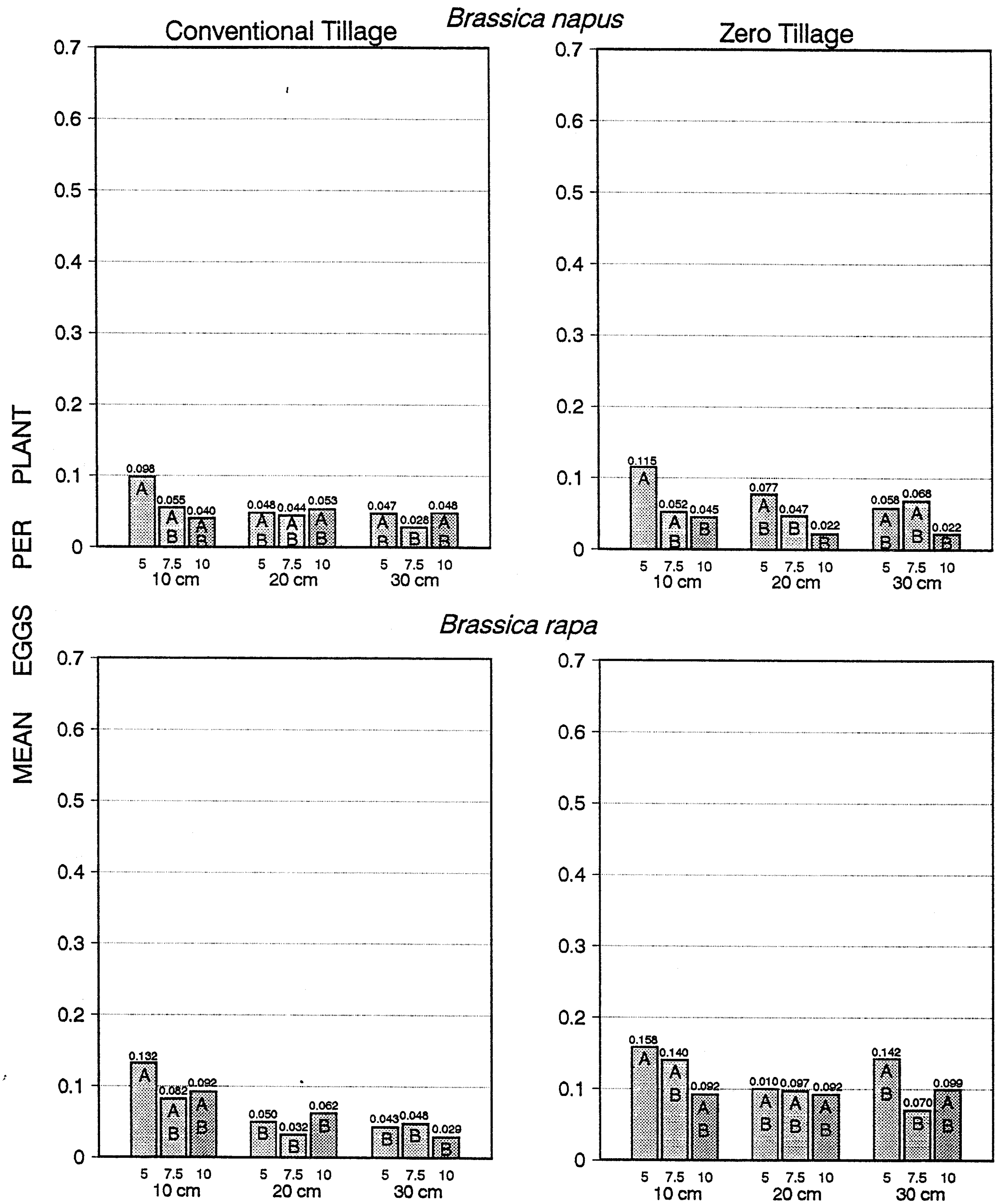

Fig. 2. Mean numbers of eggs per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Vegreville site in 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

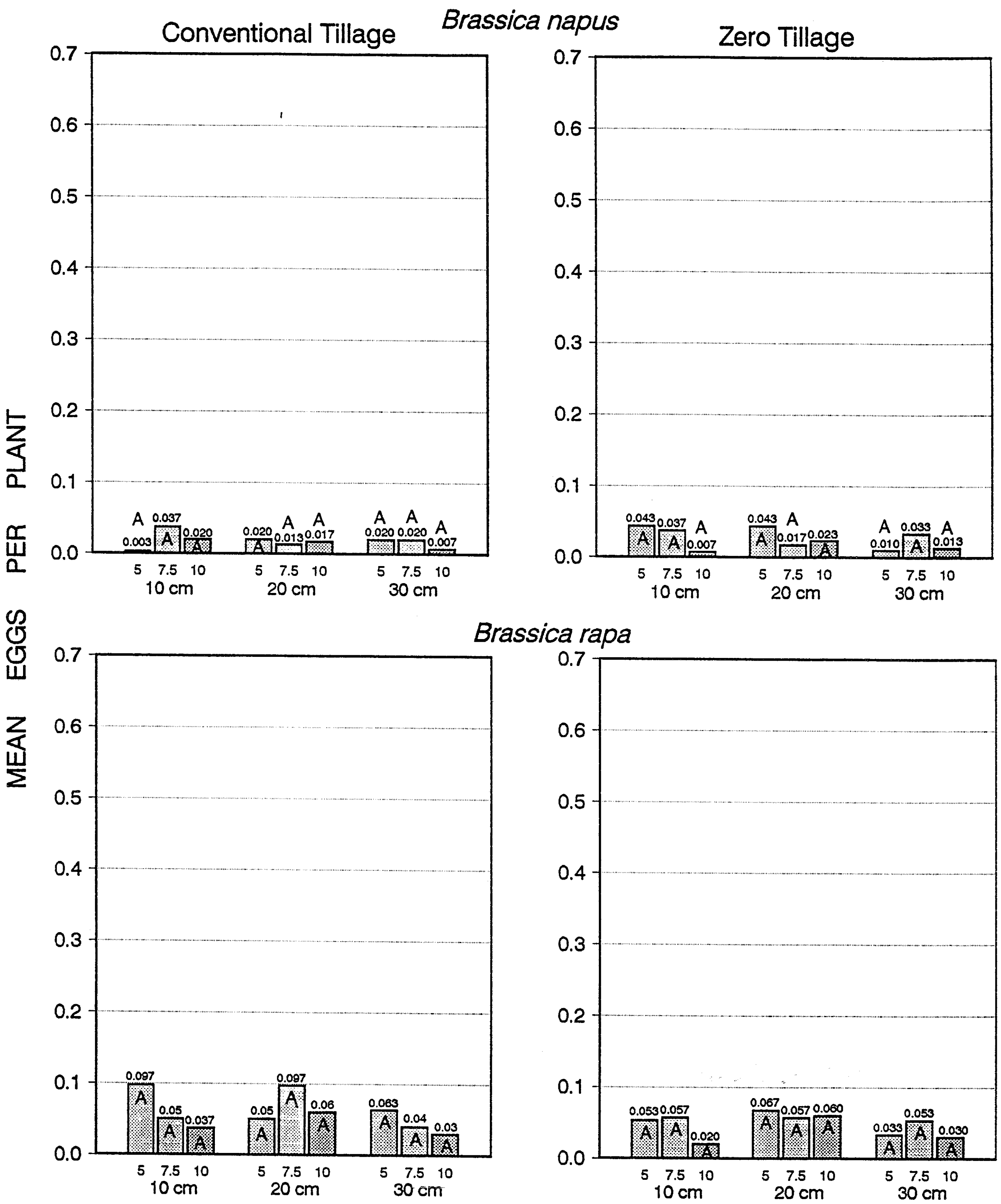

Fig. 3. Mean numbers of eggs per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1995. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

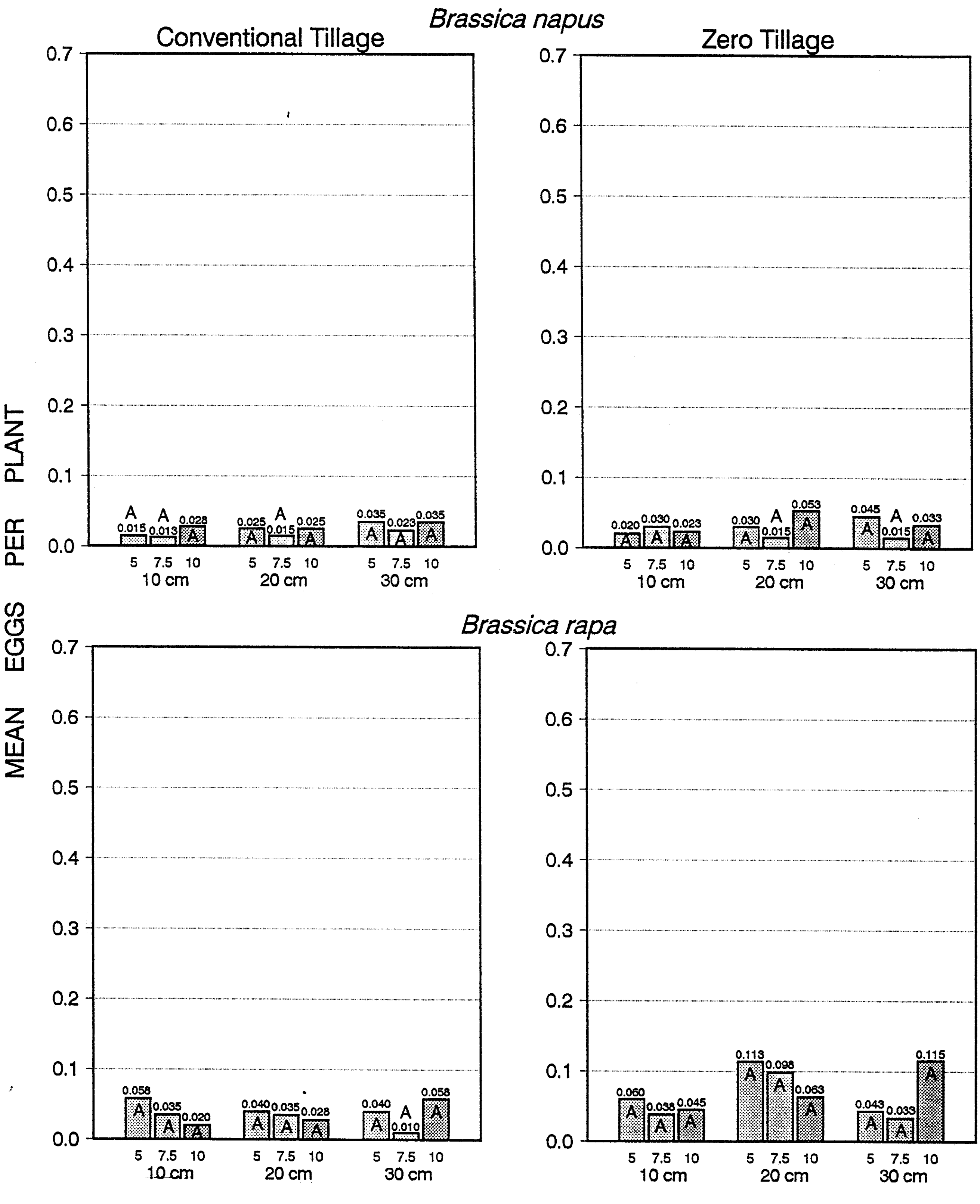

Fig. 4. Mean numbers of eggs per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

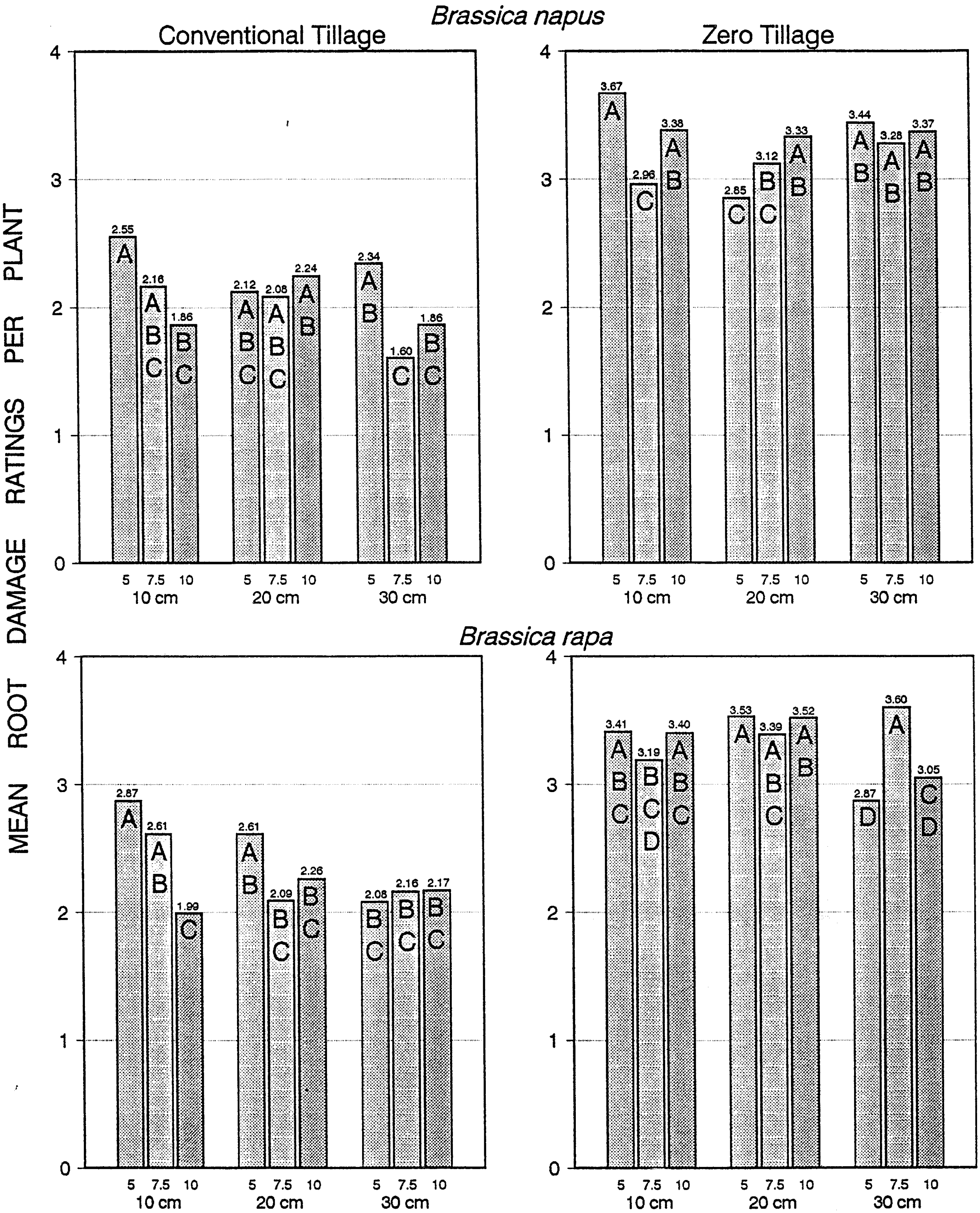

Fig. 5. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Vegreville site in 1995. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

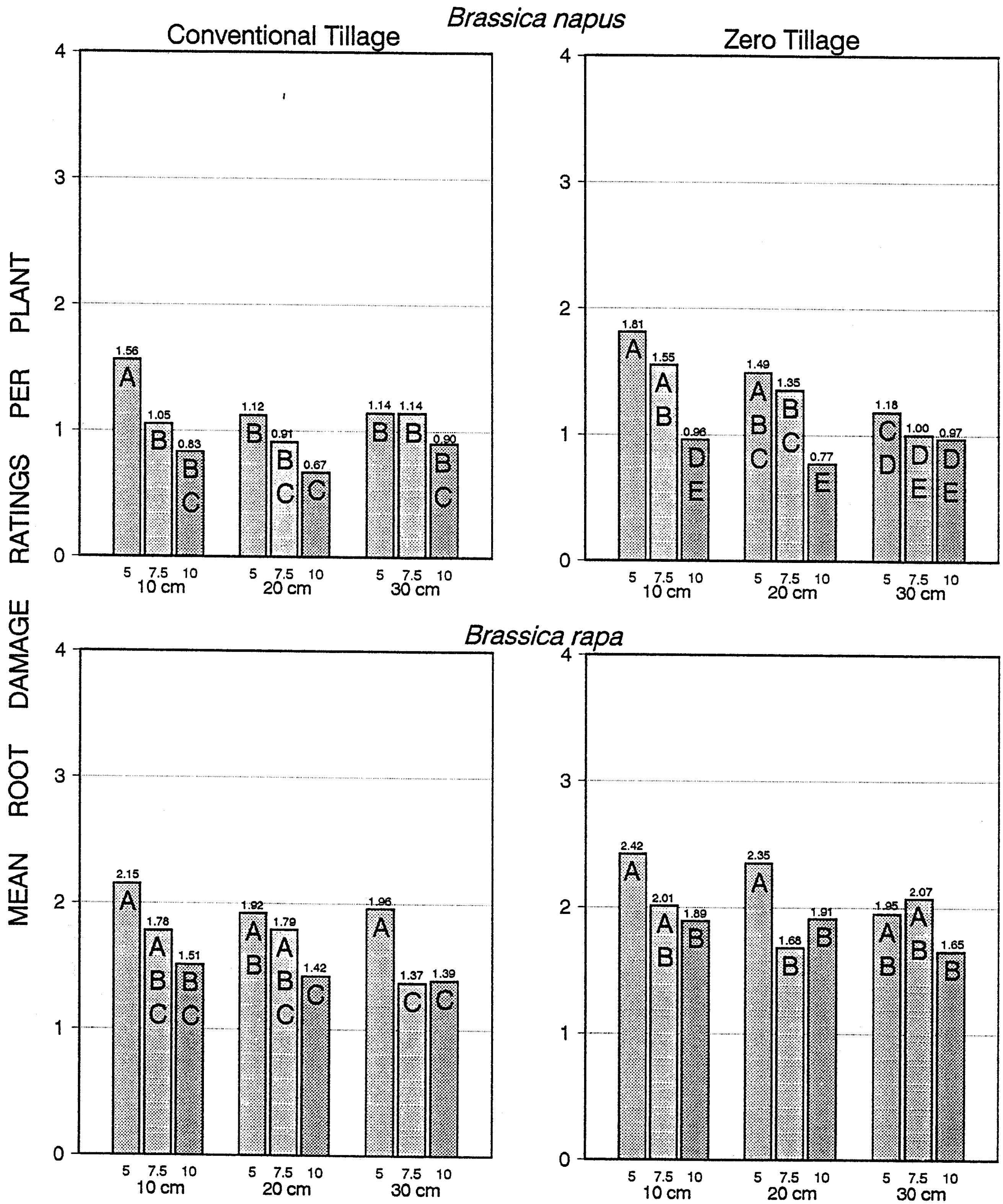

Fig. 6. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Vegreville site in 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

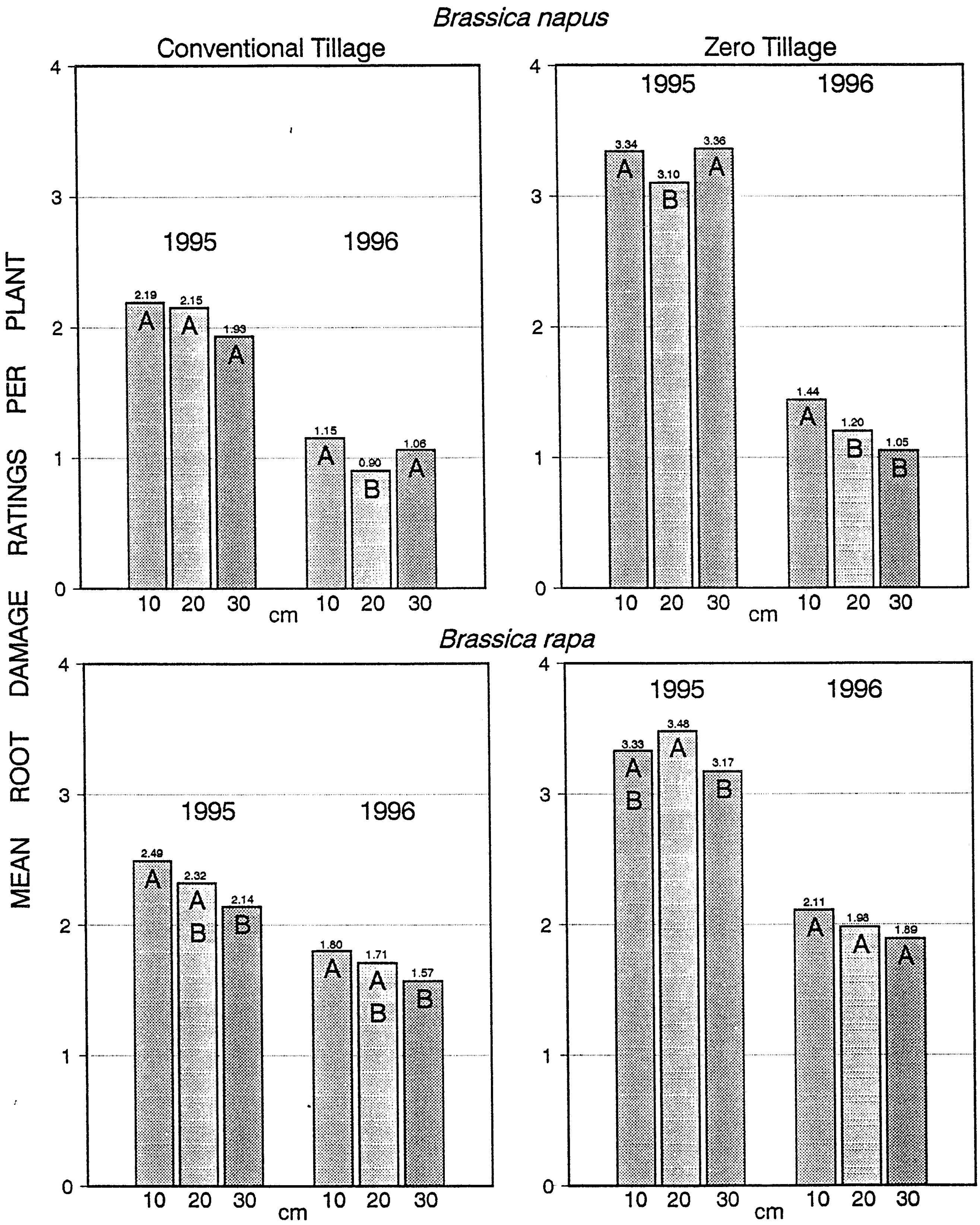

Fig. 7. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) at the Vegreville site in 1995 and 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species, tillage regime, and year having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

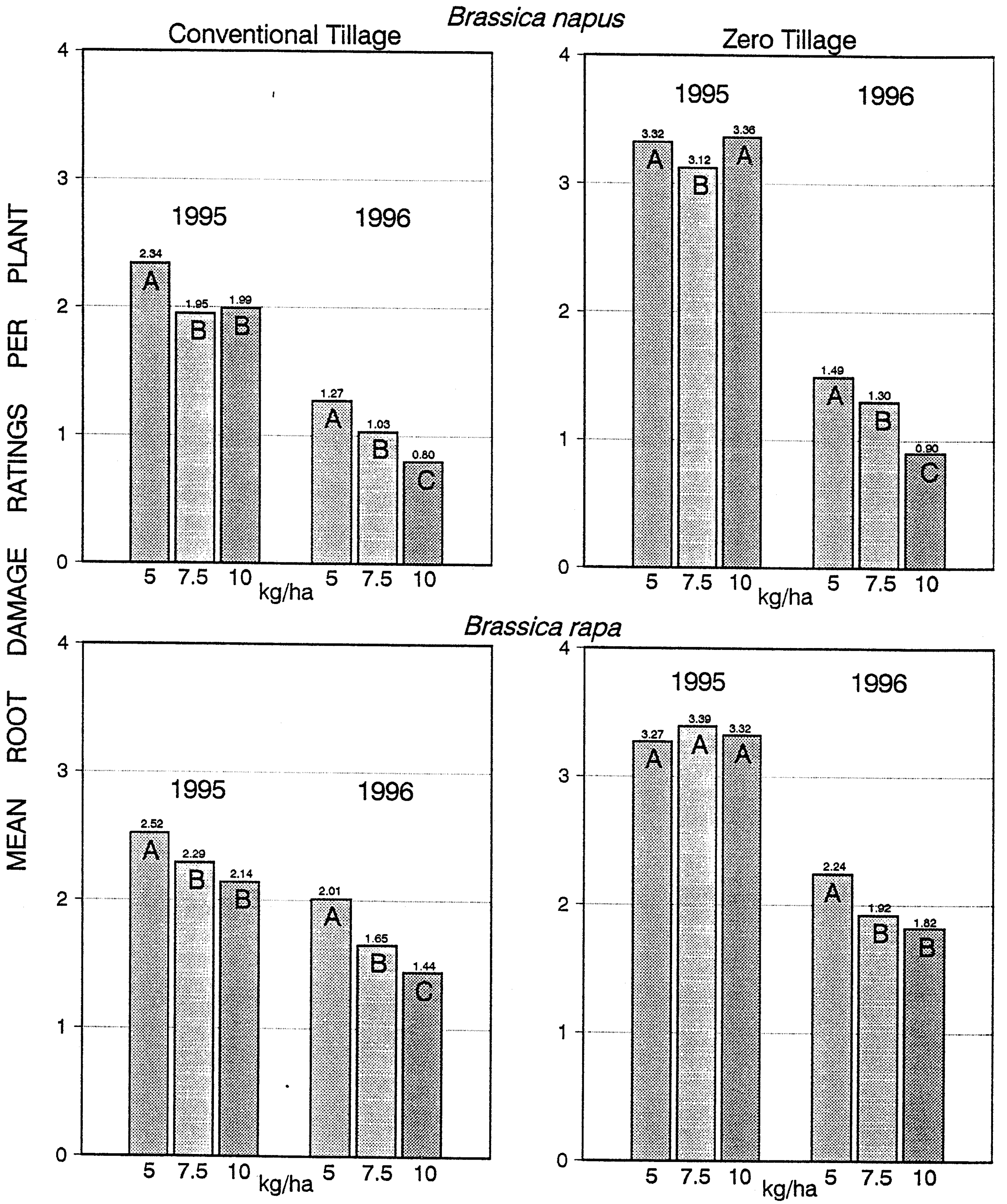

Fig. 8. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Vegreville site in 1995 and 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species, tillage regime, and year having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

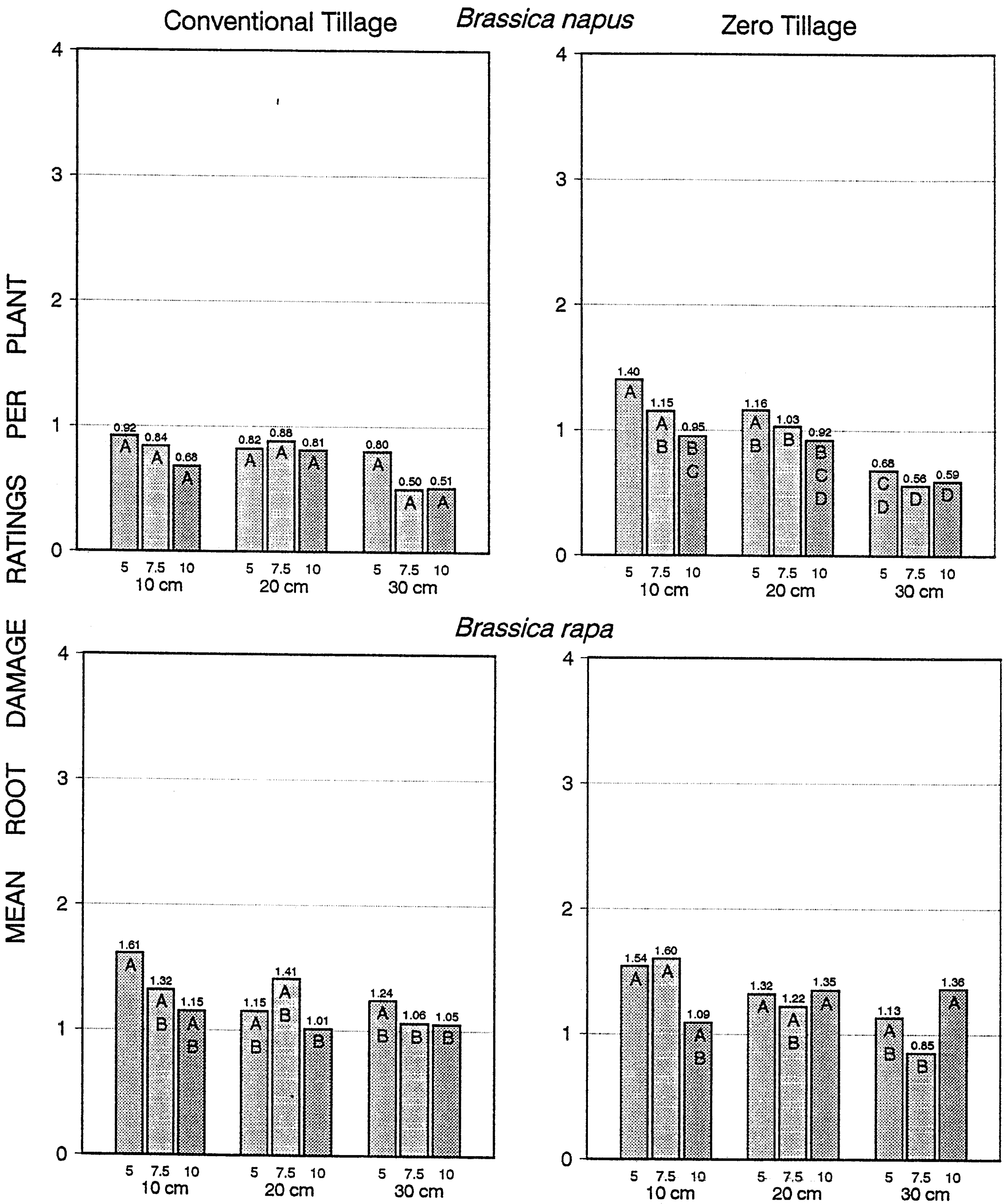

Fig. 9. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1995. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

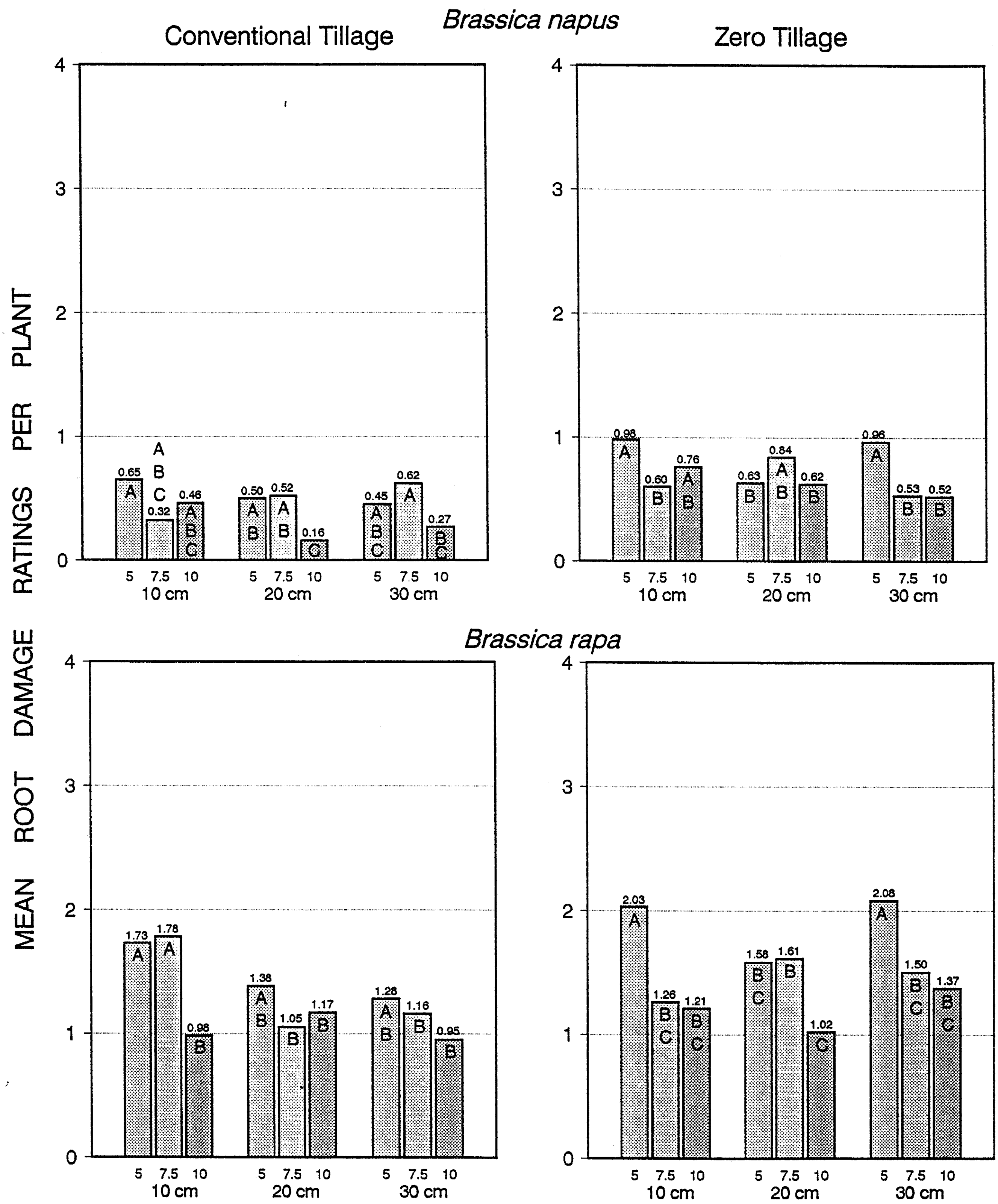

Fig. 10. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

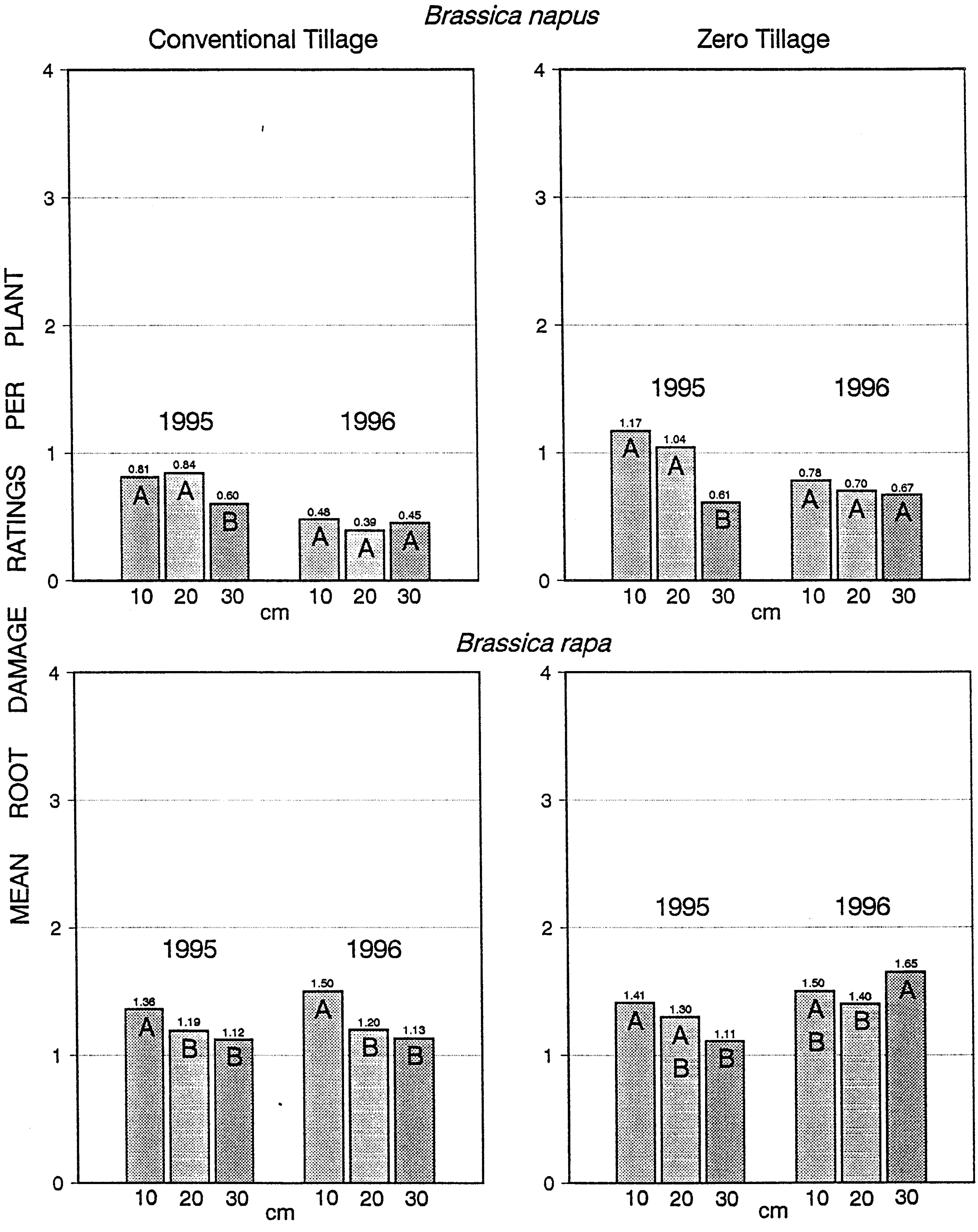

Fig. 11. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) at the Westlock site in 1995 and 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species, tillage regime, and year having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

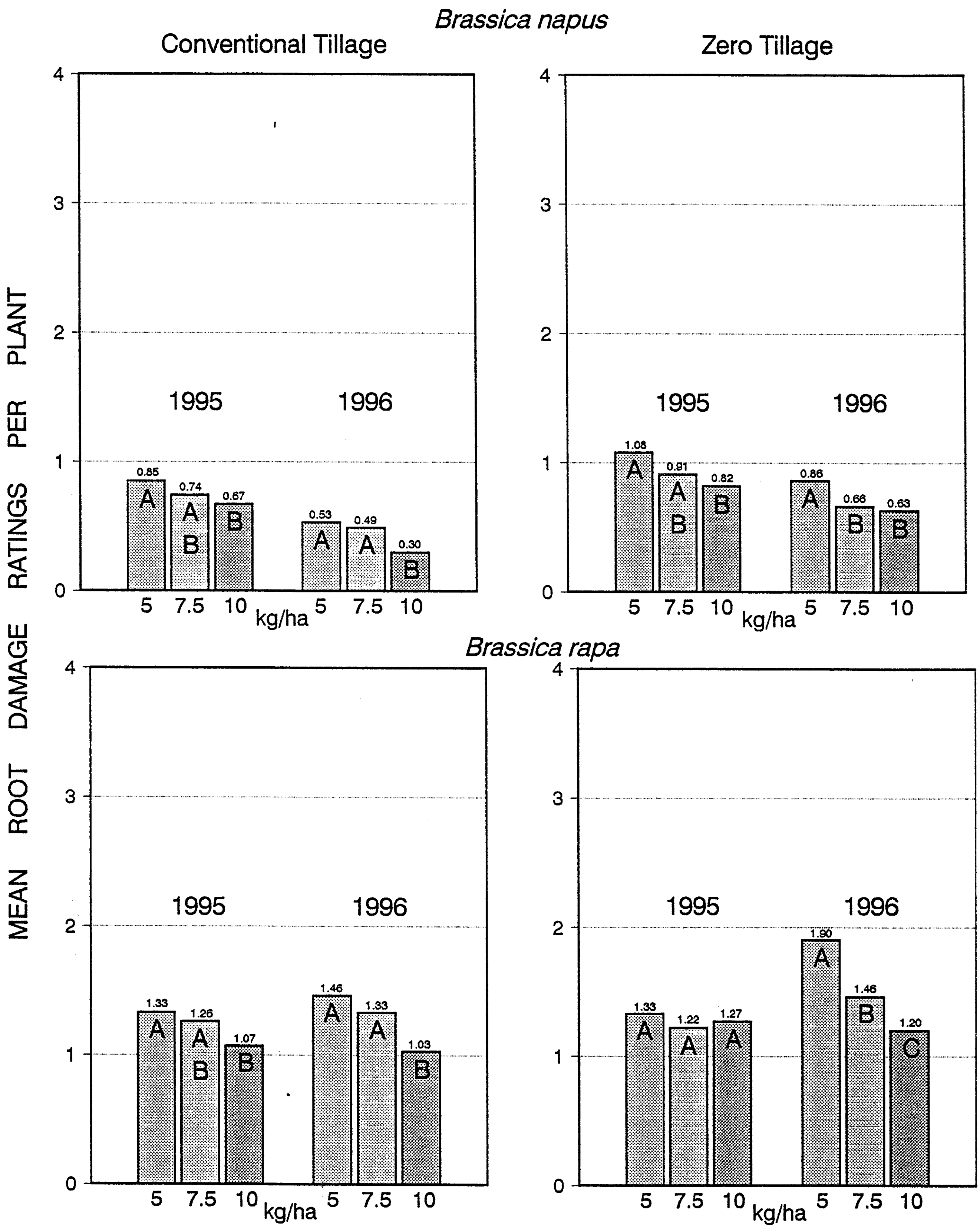

Fig. 12. Mean root damage ratings per plant for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1995 and 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species, tillage regime, and year having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

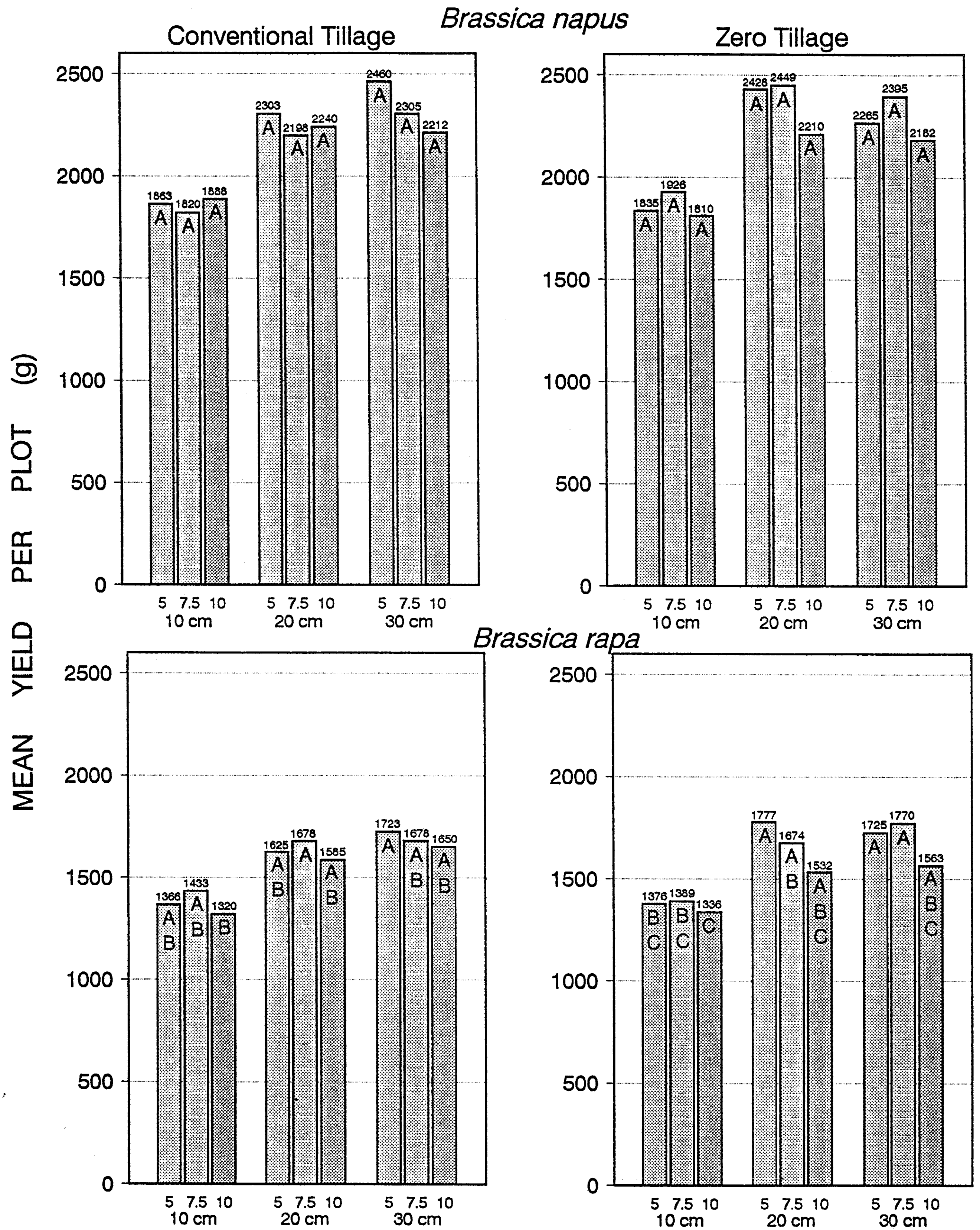

Fig. 13. Mean seed yields per plot for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Vegreville site in 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species, tillage regime, and year having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

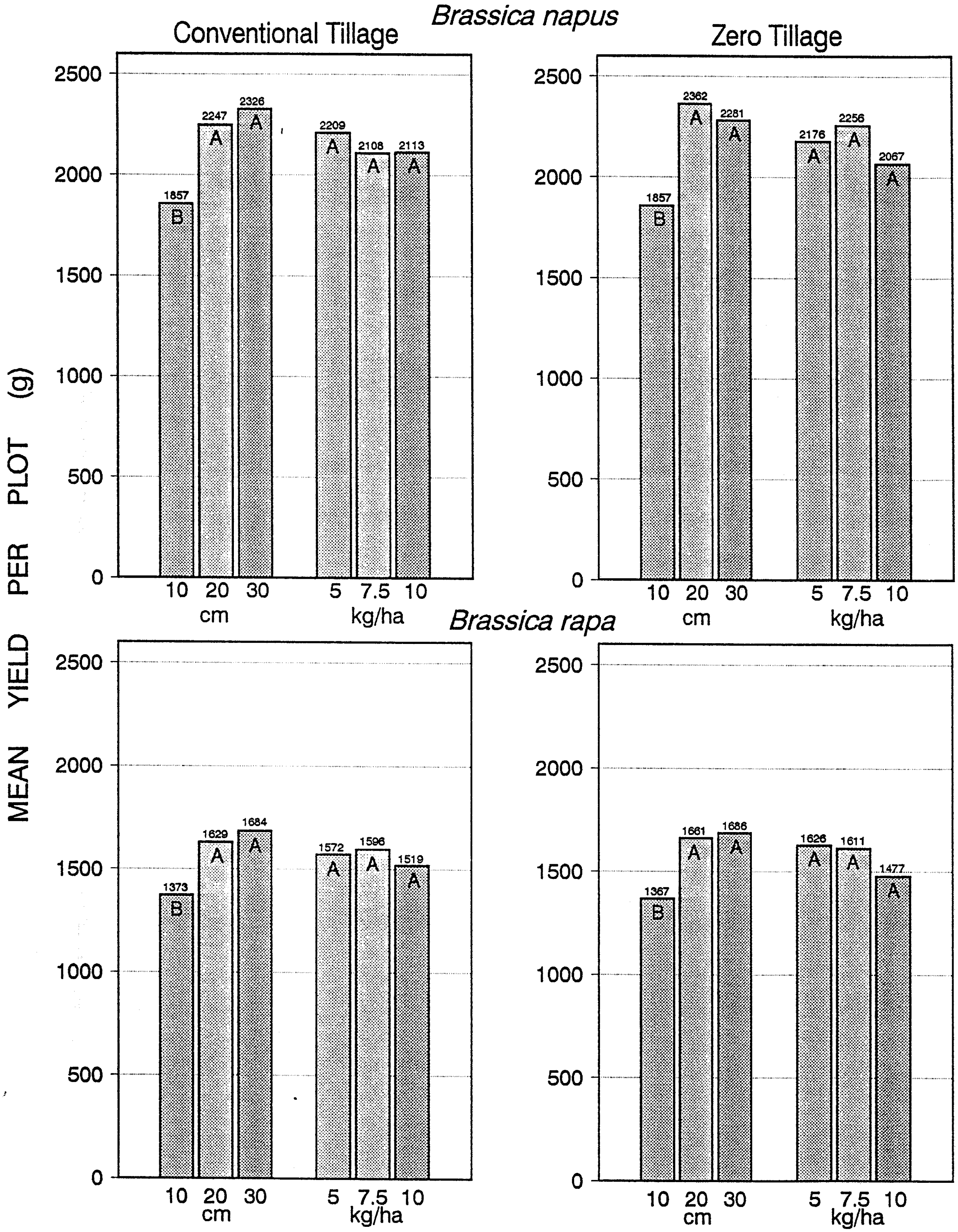

Fig. 14. Mean seed yields per plot for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Vegreville site in 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species, tillage regime, and year having the same letter indicate no significant difference using analysis of variance and Student-Newman-Keuls multiple comparisons.

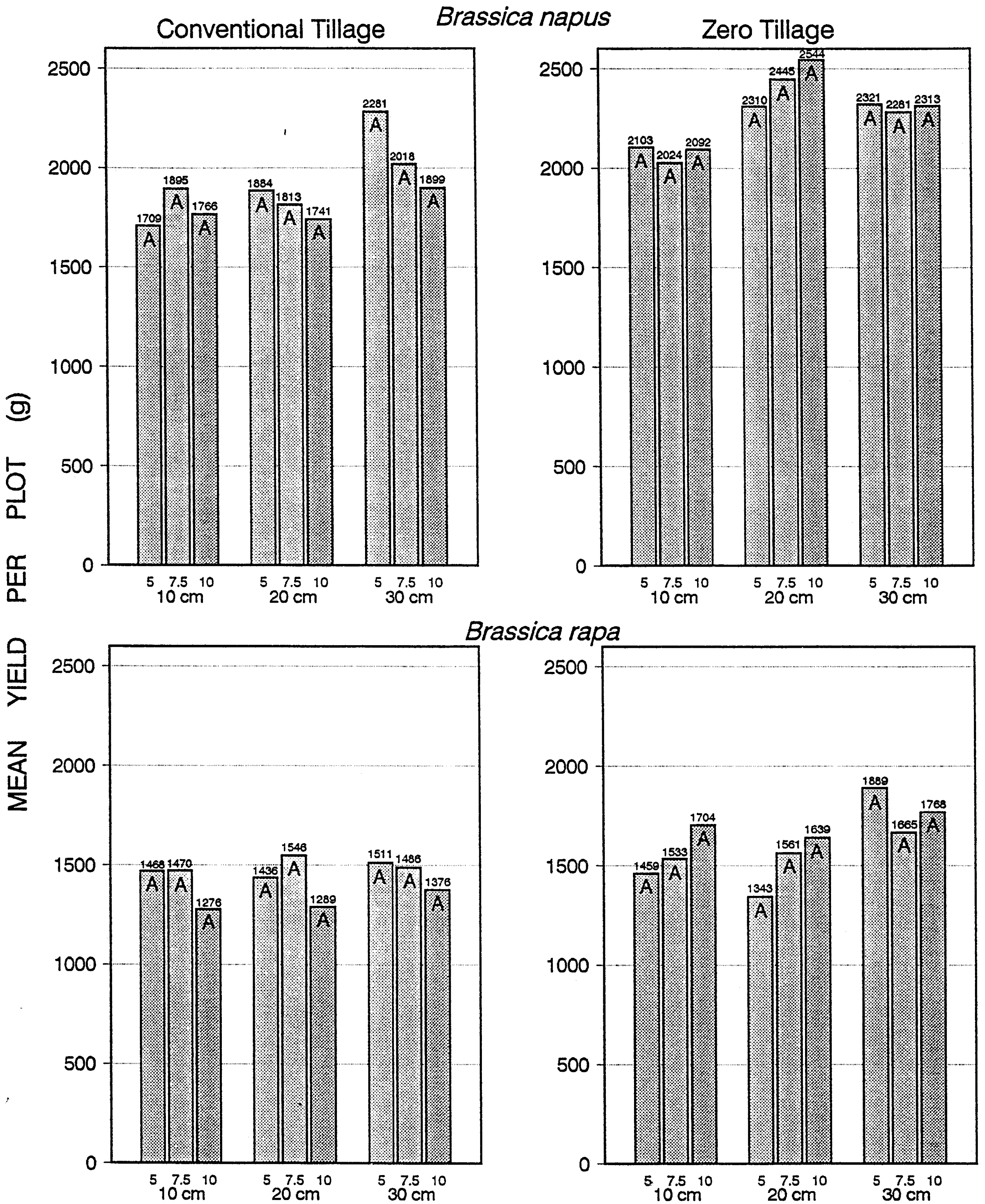

Fig. 15. Mean seed yields per plot for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1995. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman Keuls multiple comparisons.

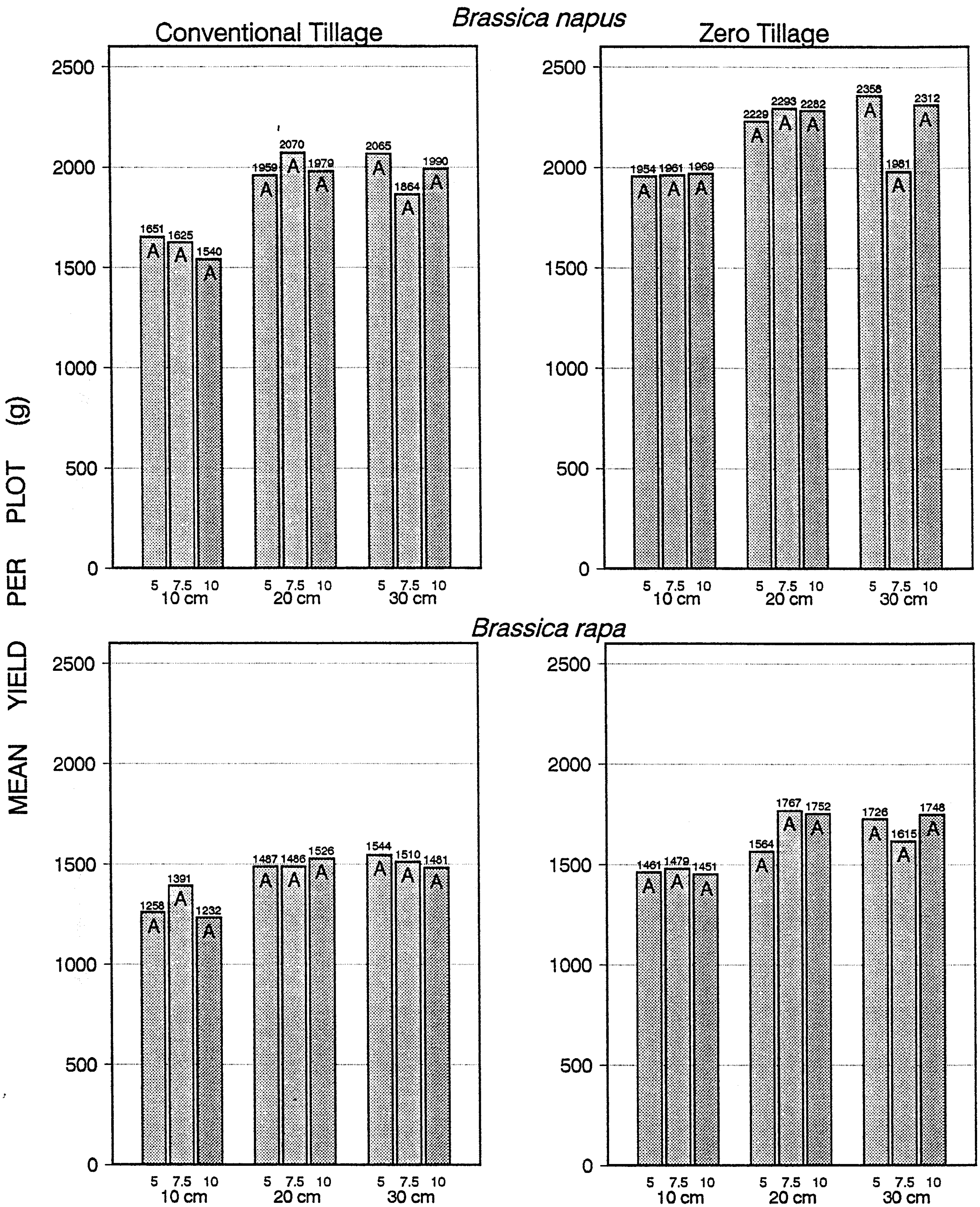

Fig.16. Mean seed yields per plot for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) and at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman Keuls multiple comparisons.

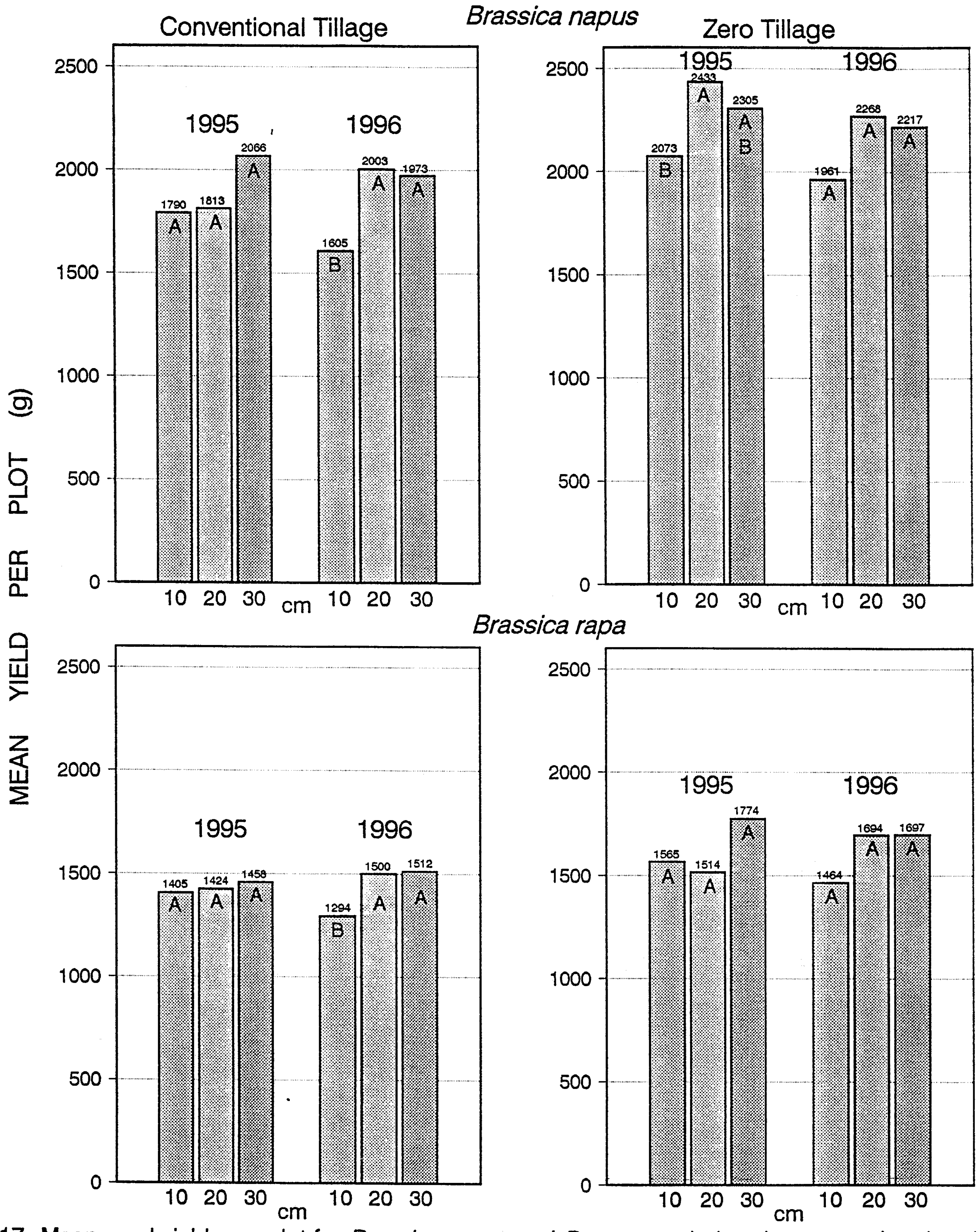

Fig. 17. Mean seed yields per plot for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different row spacings (10, 20, and 30 cm) at the Westlock site in 1995 and 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman Keuls multiple comparisons.

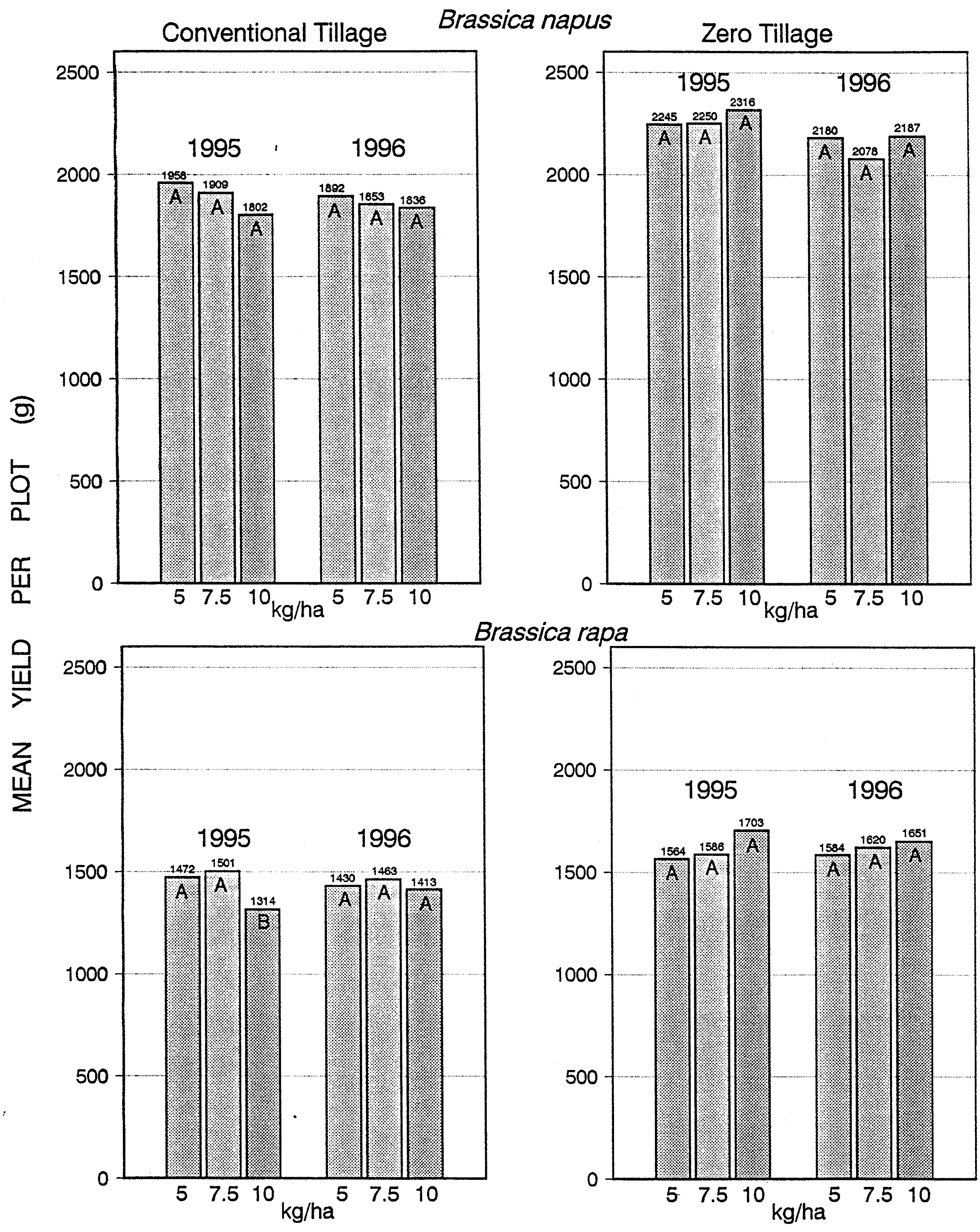

Fig. 18. Mean seed yields per plot for *Brassica napus* and *B. rapa* seeded under conventional and zero tillage regimes at different seeding rates (5.0, 7.5, and 10.0 kg/ha) at the Westlock site in 1995 and 1996. Letters on histograms indicate significance of differences between treatments: means within each canola species and tillage regime having the same letter indicate no significant difference using analysis of variance and Student-Newman Keuls multiple comparisons.