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Effect of Annual Medic Smother Plants on Weed Control and Yield in Corn

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ABSTRACT

Utilization of spring-seeded smother plants for weed control could reduce the impact of corn (*Zea mays* L.) production on environmental quality. Research was conducted to determine whether currently available medic cultivars are adapted for use as smother plants in corn. In field experiments at Becker and Rosemount, MN, in 1992 *Medicago scutellata* (L.) Mill. cultivars 'Sava' and 'Kelson' were seeded over corn at 0, 85, 260, or 775 seeds m^{-2}. In 1993 Sava and Kelson, plus 'Santiago' (*M. polymorpha* L.) and 'George' (*M. lupulina* L.), were seeded over corn at 260 seeds m^{-2} with N fertilization rates of 0, 84 (56 at Rosemount), or 168 kg ha^{-1}. Land equivalent ratios for corn and medic intercrops grown in 1992 were not greater than one, indicating that corn and medics competed strongly for resources. Medics seeded with corn at a high enough rate to consistently suppress weeds (260 seeds m^{-2}) reduced weed dry wt. 14 wk after corn emergence by 69% at Becker and by 41% at Rosemount compared to corn grown without a smother crop. The same seeding rate reduced corn grain yield in weed free plots by 21% at Becker and 15% at Rosemount, compared to monoculture yields. In 1993, medic smother plants reduced weed dry wt. more when grown in the 0 kg ha^{-1} N plots than when grown in the 168 kg ha^{-1} N plots. Corn yield losses, however, were less severe in the 168 kg ha^{-1} N treatments than the 0 N treatments.

Abbreviations: LER, land equivalent ratio.

Smother plants are specialized cover or mulch species selected to suppress weeds without reducing main crop yield (De Haan et al., 1994). Incorporation of spring-seeded smother plants into corn production systems in the Upper Midwest, USA, could substantially reduce the impact of agricultural production on environmental quality. Smother plants have the potential to suppress weed growth (De Haan et al., 1994), increase soil water infiltration (Bruce et al., 1992), decrease soil erosion (Cripps and Bates, 1993), contribute N to the main crop (Corak et al., 1991; Decker et al., 1994; Maskina et al., 1993), and reduce economic risk (Hanson et al., 1993). Weeds in corn are typically controlled by a combination of tillage and herbicide inputs. Tillage reduces soil surface residue and increases the risk of soil erosion, while herbicides can contaminate water resources. A smother plant capable of effectively suppressing weedy plant species would give producers a much needed alternative weed control method.

Previous research investigating the possibility of biological weed control through plant interference has focussed on the use of winter annual or perennial plant species sown in the fall and suppressed or killed with a herbicide application or mechanical disturbance in the spring (Curran et al., 1994; Eadie et al., 1992; Eberlein et al., 1992; Echtenkamp and Moomaw, 1989; Enache and Ilnicki, 1990; Fisher and Burrill, 1993; Grubinger and Minotti, 1990; Hoffman et al., 1993; Johnson et al., 1993; Kumwenda et al., 1993; Mohler, 1991; Teasdale, 1993; Tollenaar et al., 1993). Species evaluated include alfalfa (*Medicago sativa* L.), Austrian winter pea [*Pisum sativum* L. subsp. *sativum* var. *arvense* (L.) Poir], barley (*Hordeum vulgare* L.), chewings fescue (*Festuca rubra* L.), crimson clover (*Trifolium incarnatum* L.), hairy vetch (*Vicia villosa* Roth), ladino clover (*Trifolium repens* L.), subterranean clover (*Trifolium subterraneum* L.), white clover (*Trifolium repens* L.), winter rye (*Secale cereale* L.), and wheat (*Triticum aestivum* L.). Hairy vetch, ladino clover, subterranean clover, and white clover show promise in the Central USA, but none of these species is consistently winterhardy in the Upper Midwest, USA, and spring growth of these species can deplete soil water resources. In addition, all of the species investigated, except subterranean clover, require chemical or mechanical suppression to limit their competitive effects on corn.

Spring-seeded annual smother plants are an alternative method for integrating cover crop species into corn production systems, and they may be better adapted to use in the Upper Midwest, USA, than winter annual or perennial plant species. Nitrogen and biomass accumulation would be lower with spring-seeded species than with winter annuals or perennials seeded in the fall (Stute and Posner, 1993), and erosion control in early spring would be less effective, but weed suppression could be comparable (De Haan et al., 1994), and sod suppression would not be necessary.

The feasibility of short-term spring-seeded smother plants is supported by plant competition research. Studies indicate that the presence of weeds for the first 2 to 8 wk after corn emergence may not be detrimental to crop yield, depending on the weed species present, the weed population density, the soil fertility and moisture availability, and the corn cultivar used (Bunting et al., 1964; Hall et al., 1992; Knake and Slife, 1969; Nieto et al., 1968; Thomas and Allison, 1975; Zimdahl, 1988). A spring-seeded smother plant may be able to be grown with corn for a similar period of time without reducing crop yield. Previous research also indicates that weeds emerging 3 to 6 wk after corn do not reduce corn yield (Hall et al., 1992; Knake and Slife, 1965; Thomas and Allison, 1975). Smother plant suppression of weeds for the first 4 wk of the growing season may therefore prevent weeds from competing effectively with corn.

Annual *Medicago spp.* (annual medics) such as *M. polymorpha* and *M. scutellata* are native to regions surrounding the Mediterranean Sea, where they grow as winter annuals. In the mid 1800's annual medics were introduced into the USA as forage crops and they have become naturalized in parts of the South and Southwest. For the past 50 years, however, annual medics have been virtually ignored by agricultural researchers and producers in the USA. Annual medics were also introduced into Australia where they have become an important crop, with several cultivars released for forage use.

Annual medics have the potential to perform well when grown as spring-seeded smother plants in corn. They have a wide range of growth habits, and many have good forage quality, prolific seed production, and resistance to insect pests. In addition, research by Welty et al. (1988) indicates that annual medics can substantially increase soil NO_3-N content.

Annual medics have not been evaluated as smother crops in any agronomic system in the USA. The goal of this research was to evaluate the performance of several annual medic cultivars when used as smother plants in corn and determine: 1) the degree of resource competition between corn and annual medics, 2) the effects of annual medic cultivar and seeding rate on weed dry wt. and corn development, and 3) the influence of N fertilization on the competitive interactions among corn, annual medics, and weeds.

MATERIALS AND METHODS

General Methods

Field experiments were conducted during 1992 and 1993 at the Becker, MN, Sand Plains Agricultural Experimental Station and at the Rosemount, MN, Agricultural Experiment Station. Soil at Becker was a Hubbard loamy sand (sandy, mixed, Udorothentic Haploboroll) and soil at Rosemount was a Waukegan silt loam (fine-silty, mixed, mesic, Typic Hapludoll). Soil pH was 6.1 and 6.6 for Becker, and 6.5 and 6.8 for Rosemount in 1992 and 1993, respectively. Soil organic matter averaged 1.7% at Becker and 2.2% at Rosemount.

The experimental site at Becker was mold-board plowed in the spring and then field cultivated before planting. The Rosemount site was chisel plowed in the fall and field cultivated in the spring. Corn was seeded in 76-cm-wide rows using a four-row corn planter. Medics were over-seeded 0.5 to 1 cm deep in 15-cm-wide rows using a shoe-type planter with press wheels. Annual medic seeds were inoculated before planting with medic-specific inoculum (LiphaTech, Inc., Milwaukee, WI).

Weeds in weed-free plots were controlled by a preplant incorporated application of Eradicaine [EPTC (S-ethyl dipropylthiocarbamate) + R-25788 plant protectant (N,N-diallyl-2,2-dichloracetamide)] herbicide at 3.75 kg a.i. ha^{-1}. Eradicaine controlled most annual grass and broadleaf weeds and was not phytotoxic to annual medics. Weed-free plots were hand weeded as needed. Stand pipe irrigation was used at Becker to maintain soil moisture for optimum crop growth.

The experimental design at each location was a randomized complete block with a split-split-plot restriction on randomization and three replications. Main plot treatments were weedy or weed free. Data were analyzed by analysis of variance and multiple regression procedures. Analysis was done by site because of the large environmental differences between Becker and Rosemount. Full versus reduced model F tests were used to determine if regression lines were different (Weisberg, 1985).

1992 Experiments

Soil fertility at Becker was adjusted by broadcasting 31 kg ha^{-1} N, 39 kg ha^{-1} P, and 192 kg ha^{-1} K during the first week of April. At planting, 14 kg ha^{-1} N, 18 kg ha^{-1} P, and 54 kg ha^{-1} K were banded 10 cm to the side of the corn row. At Rosemount 140 kg ha^{-1} N was applied as anhydrous ammonia in the spring before corn planting. Hybrid field corn ('Pioneer 3751') was planted 13 May at Becker at 75,800 seeds ha^{-1}, and at Rosemount 'Dekalb 421' field corn was planted 12 May at 64,200 seeds ha^{-1}. *Medicago scutellata* annual medic cultivars with determinate ('Sava') and indeterminate ('Kelson') growth habits were seeded over corn within 12 h of corn planting.

The most common weed species at Becker were common ragweed (*Ambrosia artemisiifolia* L.), common lambsquarter (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), and yellow foxtail (*Setaria lutescens* (Weigel) Hubb.). Velvetleaf (*Abutilon theophrasti* Medic.) was the dominant weed species at Rosemount, although common lambsquarters, redroot pigweed, yellow foxtail, and giant foxtail (*Setaria faberii* Herrm.) were also present.

The main plots were 30.5 m long and 16 corn rows wide. Subplots were with or without corn and were 15.25 m long and 16 corn rows wide. Sub-subplots were 7.62 m long and four corn rows wide. Sub-subplot treatment combinations were a two by four factorial of Sava or Kelson annual medic seeded at 0, 85, 260, or 775 seeds m^{-2}.

Dry wt. 14 wk after corn emergence was taken from a 0.7 m^2 area for corn, a 0.6 m^2 area for medic, and a 1.0 m^2 area for weeds. Corn was hand harvested from 4.6 m of the center two corn rows of each sub-subplot during the second week of October, and fresh wt. was recorded. A subsample of 5 ears from each sub-subplot was weighed, dried for 4 days at 60 °C, then weighed, shelled, and reweighed. Corn grain yield was calculated based on 15.5% moisture content. Corn stover was harvested from the same plot area as the grain, and fresh wts. were recorded in the field. A subsample of three to five plants was dried at 60 °C for 4 days and used to calculate sub-subplot stover moisture at harvest, and stover dry wt.

Land equivalent ratios (LERs) for the corn and medic intercrop were calculated using the equation: $\text{LER} = (Y_{ab}/Y_{aa}) + (Y_{ba}/Y_{bb})$ where Y_{aa} and Y_{bb} are monocrop biomass of the component crops *a* (corn) and *b* (medic) 14 wk postemergence, and Y_{ab} is the intercrop biomass of crop *a* and Y_{ba} is the intercrop biomass of crop *b*. The two quantities in parenthesis in the LER equation are the relative yields for corn and medics, respectively. Corn mean monocrop biomass was calculated for each replicate at each location and used as the estimate for monocrop yield (Vandermeer, 1989). Medic biomass from the highest yielding seeding rate of medics grown in monoculture was used to estimate monocrop medic biomass. Means were obtained for each cultivar and location combination.

Responses of weed dry weight 14 wk after corn emergence and corn grain yield (averaged across annual medic cultivars) to annual medic seeding rate were estimated using the hyperbolic model of Cousins (1991): $Y_{mf}\left[1 - \frac{Id}{(1 + Id/(}\right.$ where *Y* is actual weed weight or corn grain yield, *d* is annual medic seeding rate, and Y_{mf}, *I*, and *C* are estimated parameters denoting, respectively, annual medic free weed weight or corn grain yield, yield loss (in weed weight or corn grain) per unit annual medic seeding density as *d* approaches 0, and maximum yield loss as *d* approaches infinity.

1993 Experiments

Soil fertility at Becker was adjusted with broadcast applications of 64 kg ha^{-1} P and 208 kg ha^{-1} K during the second week of April. Commercial fertilizer was not applied at Rosemount before seeding. Hybrid field corn (Pioneer 3751) was planted 5 May at Becker at 75,800 seeds ha^{-1}, and at Rosemount 14 May at 64,200 seeds ha^{-1}. Sava, Kelson, and 'Santiago' (a relatively prostrate *M. polymorpha* L. cultivar with indeterminate growth), were planted over corn immediately after corn seeding at Becker and Rosemount. 'George' black medic (*M. lupulina* L.) was also seeded at Rosemount. The seeding rate for all medic cultivars was constant at 260 seeds m^{-2}.

Predominant weeds at Becker were wild buckwheat (*Polygonum convolvulus* L.), common ragweed, common lambsquarter, yellow foxtail, green foxtail (*Setaria viridis* (L.) Beauv.), smooth crabgrass (*Digitaria ischaemum* (Schreb.) Muhl.), and redroot pigweed. At Rosemount the most abundant weeds were common lambsquarters, redroot pigweed, ladysthumb (*Polygonum persicaria* L.), velvetleaf, and yellow foxtail.

Main plots were 22.9 m long and 16 and 20 corn rows wide respectively at Becker and Rosemount. Subplot dimensions were 7.6 m long by 16 and 20 corn rows wide respectively at Becker and Rosemount. Subplot treatments at Becker were applications of 0, 84 (medium), and 168 (high) kg ha^{-1} N broadcast in split applications as ammonium nitrate. Thirty four kg ha^{-1} N was applied to medium and high N subplots on 4 May; 34 kg ha^{-1} and 100 kg ha^{-1} were applied to medium and high N subplots respectively on 26 May; and 16 and 34 kg ha^{-1} N was applied to medium and high N subplots respectively on 31 June. At Rosemount, subplot treatments were 0, 56, and 168 kg ha^{-1} N broadcast after corn planting on 14 May as ammonium nitrate. Sub-subplots at both sites were 7.6 m long and 4 corn rows wide. Sub-subplot treatments at Becker were no medic, Kelson, Sava, or Santiago. Rosemount sub-subplot treatments were no medic, Kelson, Sava, Santiago, or George.

Dry wt. 14 wk after corn emergence was obtained from a 0.5 m^2 area of each sub-subplot for corn, and a 0.3 m^2 area of each sub-subplot for medic and weeds. Corn ears and stover were hand harvested from 4.6 m of the center two corn rows of each sub-subplot at physiological maturity on 23 September at Becker, and on 4 October at Rosemount. Fresh wt. of corn ears and stover was recorded in the field, and subsamples were taken from each sub-subplot, dried for 4 d at 60 °C, and used to determine ear moisture at harvest, corn grain yield at 15.5% moisture, and stover dry wt. as described for the 1992 experiments.

RESULTS AND DISCUSSION

1992 Experiments

Land Equivalent Ratio. Relative yields of corn and medic 14 wk after corn emergence were much more sensitive to changes in medic seeding rate at Becker than at Rosemount. The large changes in relative yields at Becker (Fig. 1a) were probably caused by low soil N availability due to sandy soil and the relatively low rate of N fertilizer applied. The Rosemount site (Fig. 1b) was representative of high nutrient status soils on which corn is often grown in the Midwest. High soil fertility at this site favored corn growth, and changes in medic seeding rate affected corn and medic relative yields much less than at Becker. At both locations increases in medic biomass at higher medic seeding rates were offset by decreases in corn biomass. As a result, LERs were not significantly ($p<0.05$) greater than 1 at Becker or Rosemount at any medic seeding rate.

An ideal smother plant would not compete with the main crop for resources, and the resulting main crop/smother plant intercrop should be characterized by LERs consistently greater than 1. The fact that LERs were not greater than 1 in the corn and medic intercropping system indicates that corn and medics were competing for resources, or that some other interference mechanism was involved.

Weed Control. Weed dry wt. 14 wk after corn emergence was strongly influenced by corn and annual medic interference (Fig. 2). Corn interference reduced weed dry wt. at 14 wk by more than 50% when compared to weeds grown without corn or medics at Becker and

Rosemount (weedy checks are medic plots at the 0 seeds m^{-2} medic seeding rate in Fig. 2). There were no differences in weed suppression between Sava and Kelson annual medic cultivars at either location, so results were averaged for the two cultivars. Annual medics alone seeded at the intermediate rate (258 seeds m^{-2}) reduced weed dry wt., compared to dry wt. of weeds grown without corn or medics, by 80% at Becker but by only 20% at Rosemount. Much of the difference between locations was due to weed species, as most of the weeds at Becker were small seeded annual broadleaf species whereas velvetleaf was the dominant weed species at Rosemount. Soil N availability may also have been a factor in the different levels of weed dry wt. suppression by annual medics at each site, as one would expect the legume smother crop to be more competitive with non-legume weeds on the sandy soil at Becker with a low rate of applied N than on the loam soil at Rosemount that received a higher rate of applied N.

Differences in weed species and soil nutrients between locations also affected the relative competitive ability of corn and annual medics with weeds. At Becker, annual medics grown without corn and seeded at 258 and 774 seeds m^{-2} were able to suppress weed growth more effectively than corn grown without medics. However, at Rosemount corn grown without medics reduced weed biomass more than medics grown without corn at all seeding rates.

The response of weed dry wt. to medic seeding rate when medics were seeded with or without corn at Becker differed in *y* intercept, but not in slope, as suggested by the parameter estimates in Table 1, and as determined by full versus reduced model F tests. This was also the case at Rosemount. The response of weed dry wt. to medic seeding rate, averaged over corn presence or absence, was different in both *y* intercept and slope between locations, however. This difference in slope was indicative of the ability of annual medics to suppress the small seeded weeds present at Becker, but not the velvetleaf at Rosemount. Based on the fitted lines, annual medic smother plants seeded with corn at a rate just high enough to consistently suppress weeds (260 seeds m^{-2}) reduced weed biomass at Becker by 69% and at Rosemount by 41% compared to corn with no medic smother crop.

Corn Grain Yield. Corn grain yield in weed-free plots at Becker and Rosemount declined with increasing annual medic seeding rate while yields in weedy plots were relatively low but remained constant as annual medic seeding rate increased (Fig. 3). The response of corn grain yield to annual medic presence was not different at Becker or Rosemount, except for intercept, as suggested by the parameter estimates (Table 1) and as determined by full versus reduced model F tests. Based on the fitted lines, weed presence in plots without medics reduced corn grain yield 33% at Becker and 25% at Rosemount compared to monoculture corn yields. Although annual medic smother plants reduced weed biomass in the weedy treatments (Fig. 2) the decrease in weed biomass did not result in an increase in corn grain yield at the end of the growing season. This indicates that the annual medic smother plants and the weeds they displaced at Becker and Rosemount had similar competitive effects on corn. Medic smother plants seeded at even the highest density, however, did not reduce corn yield more than weeds, suggesting that under conditions of very heavy weed pressure the annual medic smother crop could be less competitive with corn than weeds. The fitted lines indicate that an annual medic seeding rate of 260 seeds m^{-2} (high enough to effectively reduce weed dry wt.) reduced corn grain yield in weed-free plots by 21% at Becker and 15% at Rosemount compared to monoculture corn yields.

1993 Experiments

Corn and Medic Dry Weight. Corn dry wt. from weed-free plots sampled 14 wk after emergence at Becker was reduced by medic presence at all levels of N fertilization (Fig. 4a). Corn dry wt. did not differ with annual medic cultivar, and the regression line fit to data from all three cultivars gave the best prediction of corn dry wt. response to annual medic presence for a range of N fertilizer rates. The response of corn dry wt. to N fertilizer application in plots without medics was linear, while the response in plots that contained an annual medic smother crop was curvilinear. The curvilinear response in plots with annual medics suggests that annual medics were effective competitors for N and that a N fertilization rate high enough to meet the demands of both medics and corn was necessary to diminish the competitive effects of medics on corn. These data suggest that at some high level of N fertilization it may be possible to overcome the corn dry wt. reduction caused by annual medics. From an environmental and economic perspective this may not be feasible. However, N in this study was broadcast on the soil surface making it equally available to corn, medics, and weeds. Precision application of N to a location in the soil profile favoring corn uptake rather than weed or medic uptake could reduce the N fertilizer requirement compared to broadcast applications.

In weed-free plots at Rosemount the response of corn dry wt. to N rate when grown with Santiago, Kelson, and Sava smother crops was linear (Fig. 4b), but corn dry wt. at even the highest N rate was reduced by annual medic interference, compared to corn grown without annual medics. Increasing the rate of N fertilization in plots without medics did not affect corn dry wt., indicating that residual N was sufficient for monoculture corn growth. George annual medic reduced corn dry wt. at the zero N level, but did not reduce corn dry wt. compared to corn grown without medics when 56 or 168 kg ha^{-1} N were applied. These results indicate that George may have had a lower N requirement than Santiago, Kelson, or Sava, or that it did not compete successfully with corn for available soil N.

Medic dry wt. at 14 wk responded much differently than corn dry wt. to increasing levels of N fertilization. In weedy and weed-free plots at Becker, dry wt. generally decreased curvilinearly, and an increase in N fertilization from 0 to 84 kg ha^{-1} decreased medic dry wt. more than an increase from 84 to 168 kg ha^{-1} (Fig. 5). High rates of N fertilization favored corn and weed growth and removed the competitive advantage the leguminous medics had at low soil N levels. Averaged across weedy and weed-free treatments, Kelson dry wt. was greater than the dry wt. of Santiago or Sava at all N fertilizer rates.

The response of annual medic dry wt. at 14 wk to N rate at Rosemount was not as well defined as at Becker. The response was different in weedy (Fig. 6a) than in weed-free (Fig. 6b) plots for each annual medic species, but the trend was toward lower annual medic dry wt. in plots that received higher rates of applied N. Sava and Kelson produced more dry wt. than George and Santiago at all N rates in weedy plots, but in weed-free plots with 168 kg ha^{-1} of applied N Santiago dry wt. yields were equivalent to those of Sava and Kelson. This suggests that Santiago did not fix atmospheric N_2 as efficiently as Sava and Kelson, but that it could utilize applied N. When Santiago was grown in weedy plots, weeds competed with the medic for the applied N, and Santiago dry wt. did not increase with higher levels of applied N. Sava and Kelson dry wts. with 0 kg ha^{-1} of applied N were much higher in weed-free plots than weedy plots, indicating that weeds were competitive with these annual medics even at low rates of applied N, presumably due to high residual soil N levels that allowed for vigorous growth of non-N fixing species. George produced less dry wt. than the other medic species at all treatment combinations, perhaps accounting for the fact that it did not reduce corn dry wt. at 14 wk as much as the other medic cultivars.

Weed Control. Weed dry wt. at 14 wk at Becker was reduced 76% by an annual medic smother crop averaged over all rates of applied N and all annual medic cultivars. Weed dry wt. increased along with the level of applied N in treatments with corn alone and in treatments with corn plus an annual medic smother crop (Fig. 7a). Annual medic cultivars were similar ($p<0.05$) in their ability to suppress weed dry wt.

At Rosemount, weed dry wt. at 14 wk in corn plots without an annual medic smother crop was approximately 50% lower than at Becker (Fig. 7b). Although weed dry wt. in medic-free corn plots increased with higher levels of applied N, the weed wts. at any N rate were not different from the over-all mean due to variability in natural weed populations. Weed dry wt. in corn intercropped with Kelson, Santiago, and George annual medics increased with increasing levels of applied N. The response between the three cultivars was not different, based on reduced versus full model F tests. Based on the difference between mean weed dry wt. averaged for all N rates in corn without medics and the predicted average weed dry wt. production for Kelson, Santiago, and George, annual medic smother plants reduced weed dry wt. at the 0 kg ha^{-1} N rate by 87% and at the 168 kg ha^{-1} N rate by 53%. In contrast, Sava reduced weed dry wt. at all levels of N fertilization by 92%. At Becker Sava was also the most effective at reducing weed dry wt. at high levels of applied N. Sava was probably the most weed competitive of the annual medic cultivars evaluated. George, however, even though it produced less biomass than other medic cultivars and was less competitive with corn, was as effective in reducing weed biomass as Kelson and Santiago.

Corn Grain Yield. Corn grain yield at Becker in weed-free plots was linearly related to the rate of applied N in plots without annual medic smother plants, but the response was curvilinear in plots with annual medics (Fig. 8a). The corn grain yield response to applied N is similar to the response of corn dry wt. at 14 wk, except the curvilinear response of corn grain yield in plots with annual medics has shifted up to overlap the no-medic yields. Corn intercropped with annual medics was apparently able to grow rapidly late in the season and compensate for dry wt. reductions earlier in the year. The compensatory corn growth may have been facilitated by N transfer from the senescing annual medics to corn. Full versus reduced model F tests indicate that separate regression lines are not warranted for annual medic cultivars, but analysis of variance indicates that at the 84 kg ha^{-1} N rate yield of corn grown with Santiago was lower than corn yield in the other treatments, and at the 168 kg ha^{-1} N rate corn yields from monoculture corn and the Santiago intercrop were lower than the yield of corn intercropped with Kelson or Sava.

In weedy plots at Becker, corn grain yield averaged for N rate and annual medic treatments was 2.3 Mg ha^{-1} (54%) lower than yield in weed-free plots (Fig. 8b), because of the intense weed pressure at this location. Yields of corn grown with Sava were greater than the yields of corn grown in monoculture at all rates of N fertilization. Sava generally was more effective in suppressing weed growth than the other annual medics, and this may have been partially responsible for the high corn grain yields obtained when it was used as a smother crop. Sava also senesced earlier than Kelson or Santiago, and N release from Sava biomass may have occurred earlier in the growing season than release from the other medic cultivars. Early release may have been important in allowing corn to take up the N before it was too mature to benefit from N inputs. Kelson also increased corn grain yields over the no medic treatment, but only at the medium and high levels of applied N. Corn grain yield in plots with Santiago or no medic smother crop had a curvilinear response to N fertilization. Presumably weeds were competing with corn for N and immobilized a large portion of the applied N at the 84 kg ha^{-1} N rate, thereby reducing corn grain yield. This data indicates that at high levels of weed infestation the annual medic cultivars evaluated can reduce corn grain yield loss due to weed competition.

At Rosemount, analysis of variance indicated that weed presence did not reduce corn grain yield so data were averaged over weed treatments. The response of corn grain yield to Sava, Kelson, and Santiago was not different over N fertilization rates, as determined by a full versus reduced model F test. Based on the predicted averages, Sava, Kelson, and Santiago reduced corn grain yield, compared to corn grown in monoculture, by 39, 49 and 22% respectively when N was applied at 0, 56 and 168 kg ha^{-1} (Fig. 9). Nitrogen fertilization of 168 kg ha^{-1} reduced the competitive effects of Sava, Kelson, and Santiago annual medic smother plants on corn grain yield, but did not eliminate them. Corn grown with George annual medic yielded better than corn grown with Sava, Kelson, or Santiago at all N fertilizer rates. Yields of corn grown with George were lower than yields from corn grown without medics at the 56 kg ha^{-1} N rate, but equivalent at the other N rates.

CONCLUSIONS

These results indicate that the annual medic smother plants evaluated interfered with corn growth, and that they competed with corn for resources. When Kelson, Sava, or Santiago annual medics were seeded with corn as smother plants at a rate high enough to effectively suppress weed growth they reduced corn grain yield in most environments by approximately 20% compared to monoculture corn yields, even at high levels of applied N. Kelson, Sava, and Santiago were selected for performance as forage legumes in Australia; they grow too large and tall and do not senesce early enough in the growing season to be ideal smother plant species for the Upper Midwest, USA.

The leguminous annual medic smother plants evaluated were most effective in suppressing weeds at low levels of applied N, indicating that a legume smother plant grown with a N_2 fixing main crop species could provide very effective weed suppression. Precision fertilizer placement may permit a similar system to work with non-legume main crops.

Results from these experiments indicate that the response of corn and weeds to annual medic smother crops varies considerably from one location to another. This response indicates that it may be difficult to develop a smother plant that performs well under a wide range of soil types, fertility levels, and weed species.

Development of successful annual medic smother plants will require additional research to identify annual medic genotypes that are less competitive with corn than the Australian forage cultivars, but provide more early season ground cover than George. Individual plants of George were not as vigorous as those of the other medic cultivars early in the season, and the upright growth habit of the cultivar produced relatively open stands at the seeding rates investigated. Competition between corn and annual medic smother plants could be reduced by selecting annual medic genotypes characterized by small individual plant size, prostrate growth habit, and a short life cycle length.

Research investigating the influence of soil type, precipitation, weed species, and soil nutrient status on medic smother plant performance will be necessary to identify the environments in which annual medic smother plants can be successfully integrated into cropping systems.

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FIGURE CAPTIONS

Fig. 1. Land equivalent ratio and relative yields of corn and medic from weed-free plots at Becker (a) and Rosemount (b) in 1992 based on dry wt. 14 wk after corn emergence, as affected by medic seeding rate. Symbols indicate means ($n=6$) averaged over Sava and Kelson annual medic cultivars. Regression equations are based on individual observations.

Fig. 2. Weed dry wt. 14 wk after corn emergence at Becker and Rosemount in 1992 as influenced by corn and medic interference, and fitted lines from Table 1. Symbols indicate means ($n=6$) averaged over Sava and Kelson annual medic cultivars.

Fig. 3. Corn grain yield at Becker and Rosemount in 1992 as influenced by weed and medic interference, and fitted lines from Table 1. Symbols indicate means ($n=6$) averaged over Sava and Kelson annual medic cultivars.

Fig. 4. Corn dry wt. 14 wk after emergence in weed-free plots at Becker (a) and Rosemount (b) in 1993 as influenced by medic presence and N fertilizer application. Symbols indicate means ($n=3$). Regressions (on individual observations): (a) No medics, $y = 323 + 5.00 (X)$, $R^2 = 0.89$, $p = 0.0001$; Kelson, Santiago, and Sava combined, $y = 261 + 0.0246 (X^2)$, $R^2 = 0.83$, $p < 0.0001$; (b) No medic, mean = 1393; George, $y = 961 + 85.51 (X^{0.33})$, $R^2 = 0.88$, $p = 0.0001$; Santiago and Kelson, $y = 412 + 4.25 (X)$, $R^2 = 0.75$, $p < 0.0001$; Sava, $y = 536 + 2.299 (X)$, $R^2 = 0.86$, $p = 0.0002$.

Fig. 5. Medic dry wt. 14 wk after corn emergence at Becker in 1993 as influenced by weed presence and N fertilizer application. Symbols indicate means ($n=3$). Error bars indicate LSD at 0.05 for comparing means within a N rate.

Fig. 6. Medic dry wt. 14 wk after corn emergence at Rosemount in 1993 as influenced by N fertilizer application in weed free (a) and weedy (b) plots. Symbols indicate means ($n=3$). Error bars indicate LSD at 0.05 for comparing means within a N rate.

Fig. 7. Weed dry wt. 14 wk after corn emergence at Becker (a) and Rosemount (b) in 1993 as influenced by N fertilization and annual medic interference. Symbols indicate means ($n=3$). Regressions (on individual observations): (a) No medic, $y = 116 + 31.55\ (X^{0.33})$, $R^2 = 0.30$, $p = 0.07$; Sava, Kelson, and Santiago, $y = 13.4 + 0.469\ (X)$, $R^2 = 0.35$, $p = 0.0007$; (b) No medic, mean = 145.4; Kelson, Santiago, and George, $y = 19.4 + 0.291\ (X)$, $R^2 = 0.23$, $p = 0.006$; Sava, mean = 11.2.

Fig. 8. Corn grain yield from weed-free (a) and weedy (b) plots at Becker in 1993 as influenced by N fertilization and annual medic interference. Symbols indicate means ($n=3$). Regressions (on individual observations): (a) No medic, $y = 2091 + 26.03\ (X)$, $R^2 = 0.88$, $p = 0.0001$; Kelson, Santiago, and Sava, $y = 2168 + 0.1884\ (X^2)$, $R^2 = 0.85$, $p > 0.0001$; (b) Sava, $y = 1786 + 13.98\ (X)$, $R^2 = 0.53$, $p = 0.156$; Kelson, $y = 252 + 20.78\ (X)$, $R^2 = 0.90$, $p = 0.0001$; No medic and Santiago, $y = 561 + 0.084\ (X^2)$, $R^2 = 0.74$, $p < 0.0001$.

Fig. 9. Corn grain yield from weedy and weed-free plots at Rosemount in 1993 as influenced by N fertilization and annual medic interference. Symbols indicate means (n=6). Regressions (on individual observations): No medic, $y = 5527 + 248.3\ (X^{0.5})$, $R^2 = 0.75$, $p < 0.0001$; George, $y = 5398 + 17.87\ (X)$, $R^2 = 0.71$, $p < 0.0001$; Sava, Kelson, and Santiago, $y = 3380 + 0.121\ (X^2)$, $R^2 = 0.76$, $p < 0.0001$.

Table 1. Observed medic-free weed dry wt. and corn grain yield in 1992†, and the parameter estimates used in the nonlinear equations to generate the fitted lines for weed dry wt. and corn grain yield (Figs. 2 and 3)‡.

Variable	Location and treatment	Medic-free yield	Parameter estimates§		
			Y_{mf}	I	C
		g m^{-2}			
Weed wt at 14 wk	Becker, medic	439	439 (37)	0.0119 (0.0047)	1.055 (0.123)
	Becker, corn +medic	207	199 (20)	0.0186 (0.0128)	0.800 (0.109)
	Rosmt, medic	798	806 (80)	0.0013 (0.0021)	0.411 (0.330)
	Rosmt, corn + medic	335	341 (56)	0.0034 (0.0043)	0.740 (0.393)
		Mg ha^{-1}			
Corn grain yield	Becker, weed-free	6.309	6.302 (0.410)	0.0047 (0.0066)	0.2589 (0.0923)
	Becker, weedy	4.146¶	—	—	—
	Rosmt, weed-free	10.941	11.095 (0.393)	0.0011 (0.0008)	0.3273 (0.1132)
	Rosmt, weedy	8.372#	—	—	—

†Averaged across Sava and Kelson annual medic cultivars.

‡Standard errors of the parameter estimates are in parenthesis.

§Y_{mf} is the medic-free yield of weeds or corn grain, I is the yield loss per unit of annual medic seeding density as density approaches 0, and C is the yield loss as seeding rate approaches infinity, based on the model by Cousins (1991).

¶Mean corn grain yield over all medic seeding rates was 4.233 Mg ha^{-1}.

#Mean corn grain yield over all medic seeding rates was 8.273 Mg ha^{-1}.

Fig.1

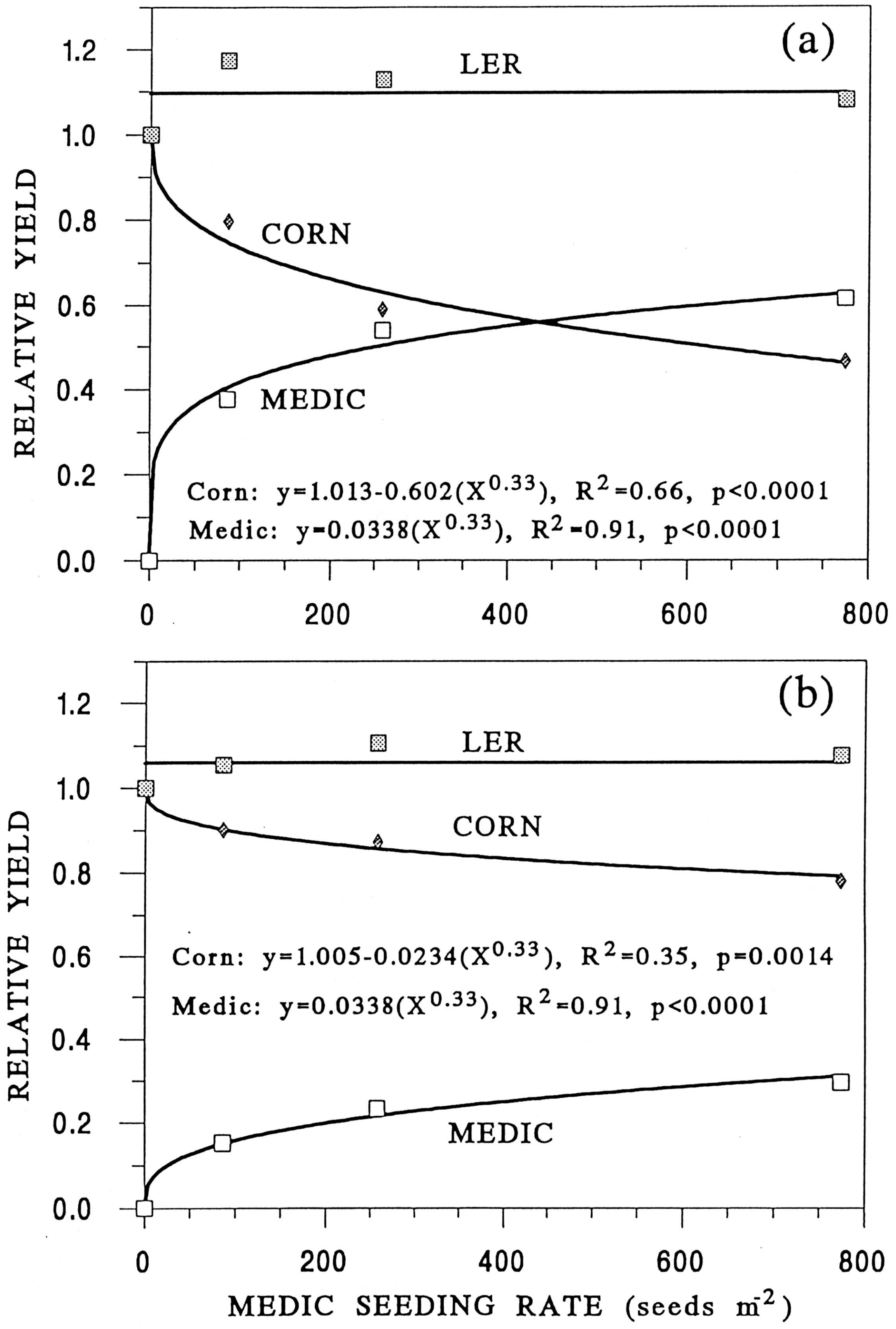

(a)
LER
CORN
MEDIC
Corn: y=1.013-0.602(X^0.33), R^2=0.66, p<0.0001
Medic: y=0.0338(X^0.33), R^2=0.91, p<0.0001
RELATIVE YIELD
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
200
400
600
800
(b)
LER
CORN
Corn: y=1.005-0.0234(X^0.33), R^2=0.35, p=0.0014
Medic: y=0.0338(X^0.33), R^2=0.91, p<0.0001
MEDIC
RELATIVE YIELD
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
200
400
600
800
MEDIC SEEDING RATE (seeds m^-2)

Fig. 2

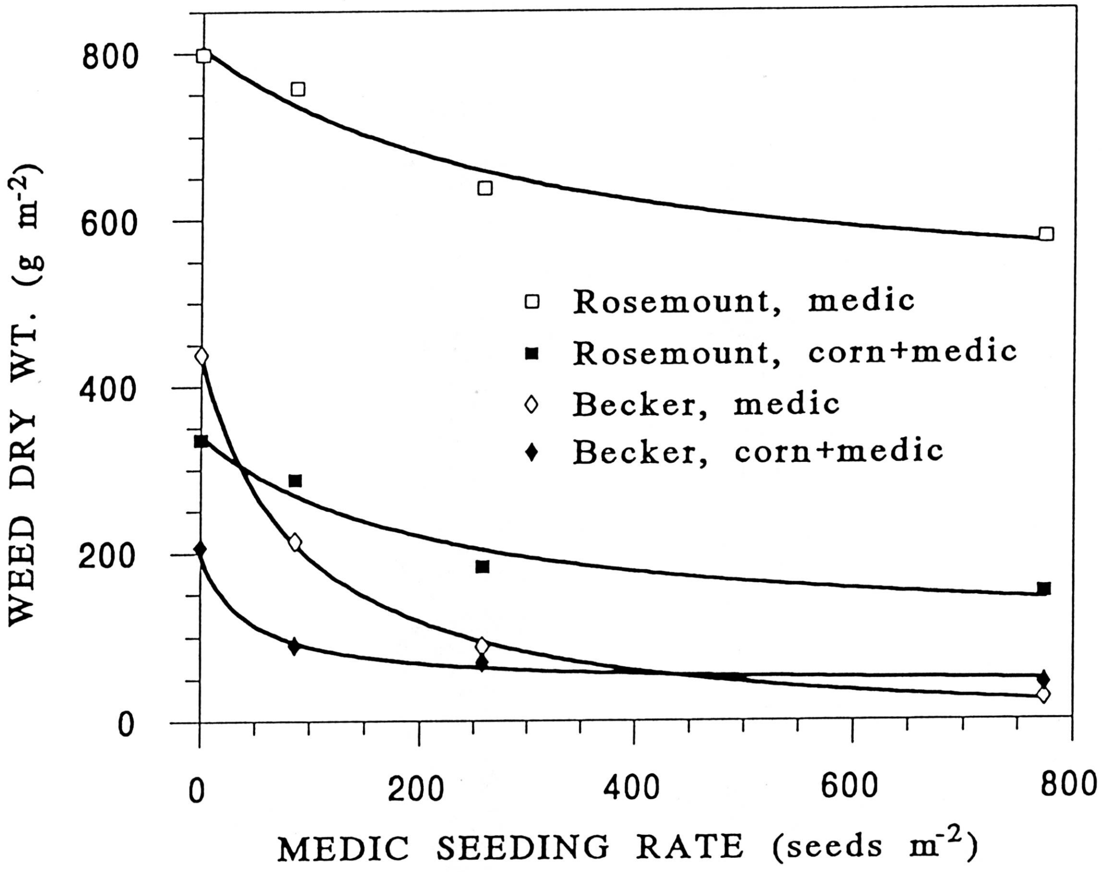

WEED DRY WT. (g m-2)
800
600
400
200
0
0
200
400
600
800
MEDIC SEEDING RATE (seeds m-2)
□ Rosemount, medic
■ Rosemount, corn+medic
◇ Becker, medic
◆ Becker, corn+medic

Fig. 3

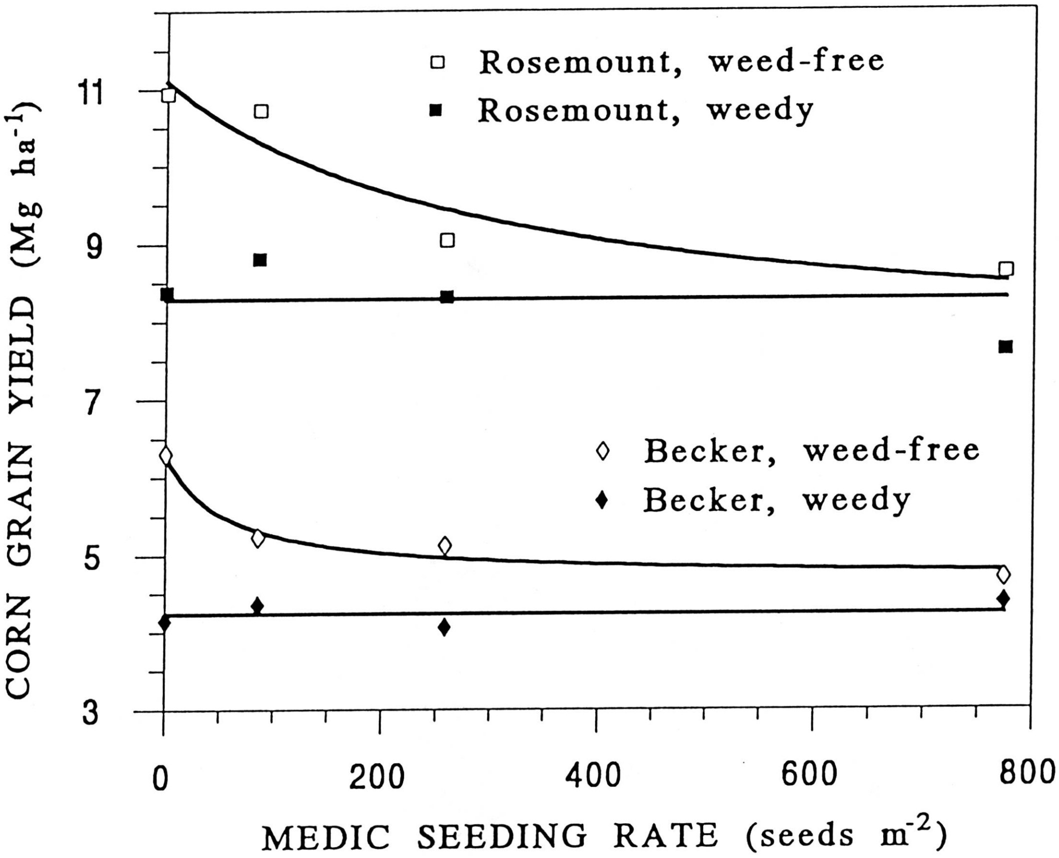
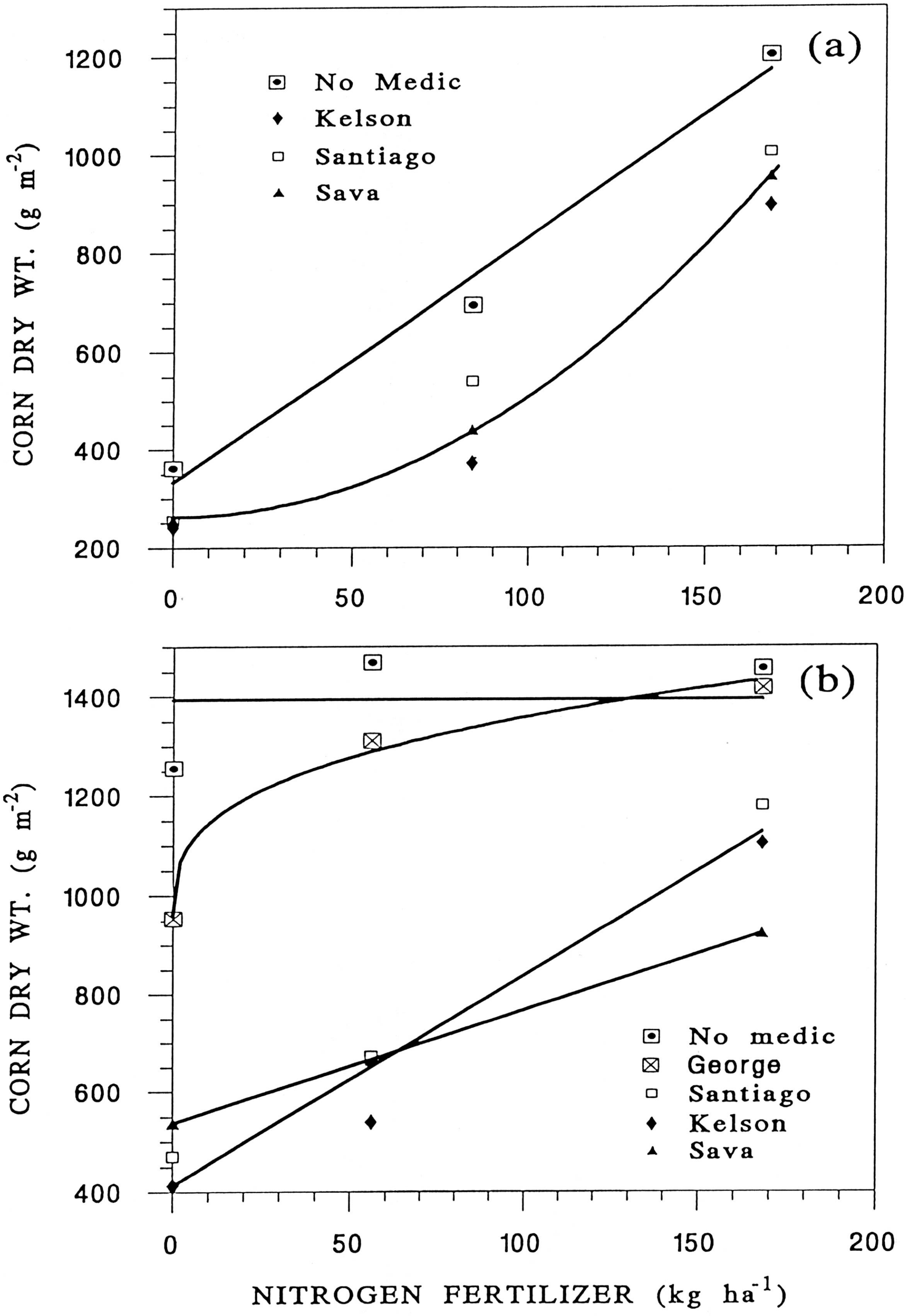
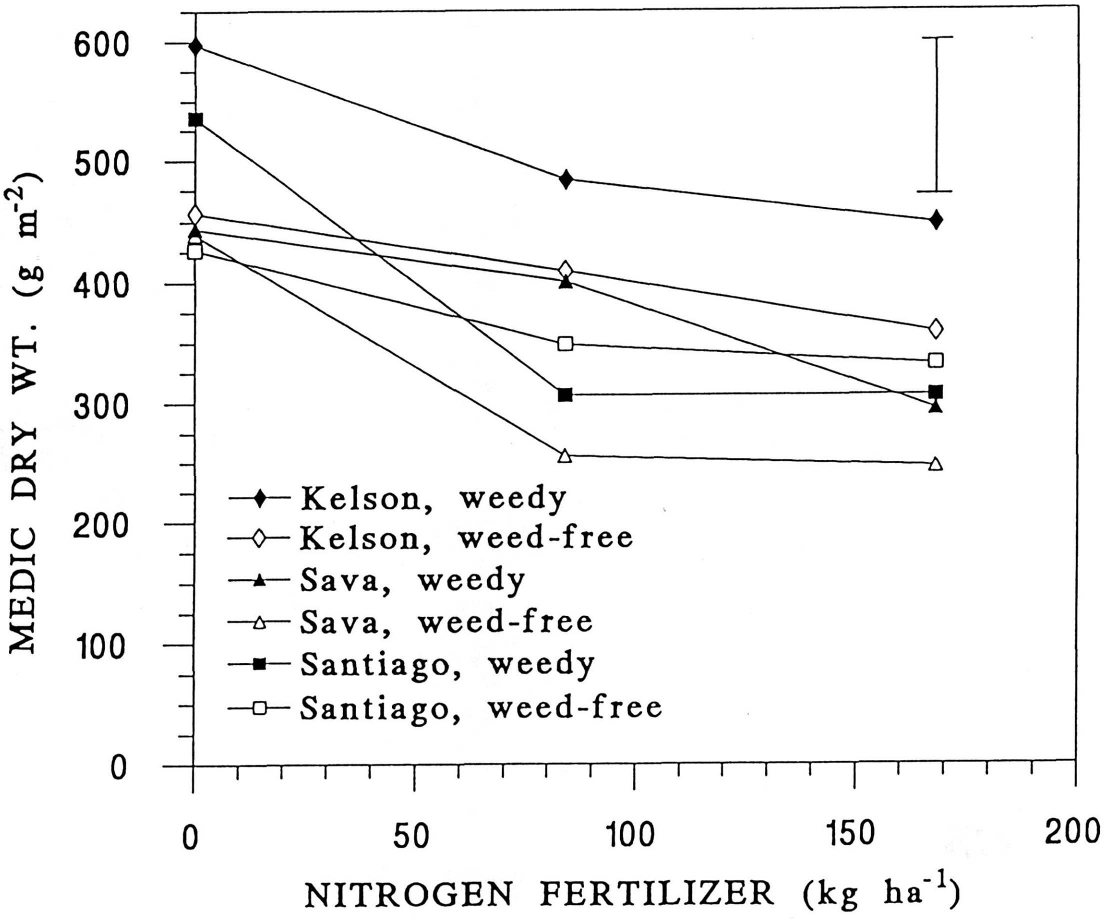

□ Rosemount, weed-free
■ Rosemount, weedy
◊ Becker, weed-free
♦ Becker, weedy
CORN GRAIN YIELD (Mg ha⁻¹)
3
5
7
9
11
0
200
400
600
800
MEDIC SEEDING RATE (seeds m⁻²)

Fig. 4



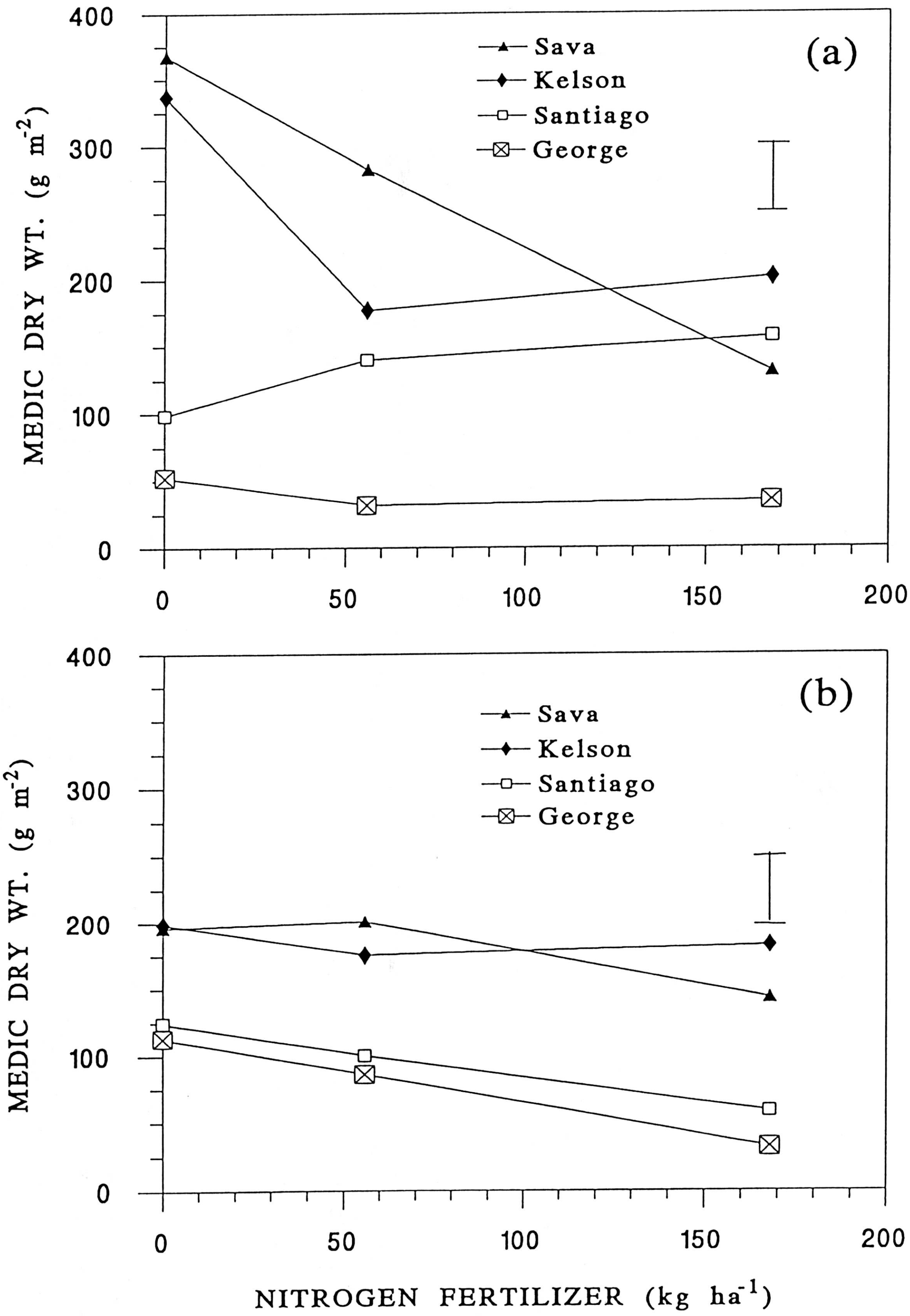
(a)
No Medic
Kelson
Santiago
Sava
CORN DRY WT. ($g\ m^{-2}$)
200
400
600
800
1000
1200
0
50
100
150
200
(b)
No medic
George
Santiago
Kelson
Sava
CORN DRY WT. ($g\ m^{-2}$)
400
600
800
1000
1200
1400
0
50
100
150
200
NITROGEN FERTILIZER ($kg\ ha^{-1}$)

Fig. 5



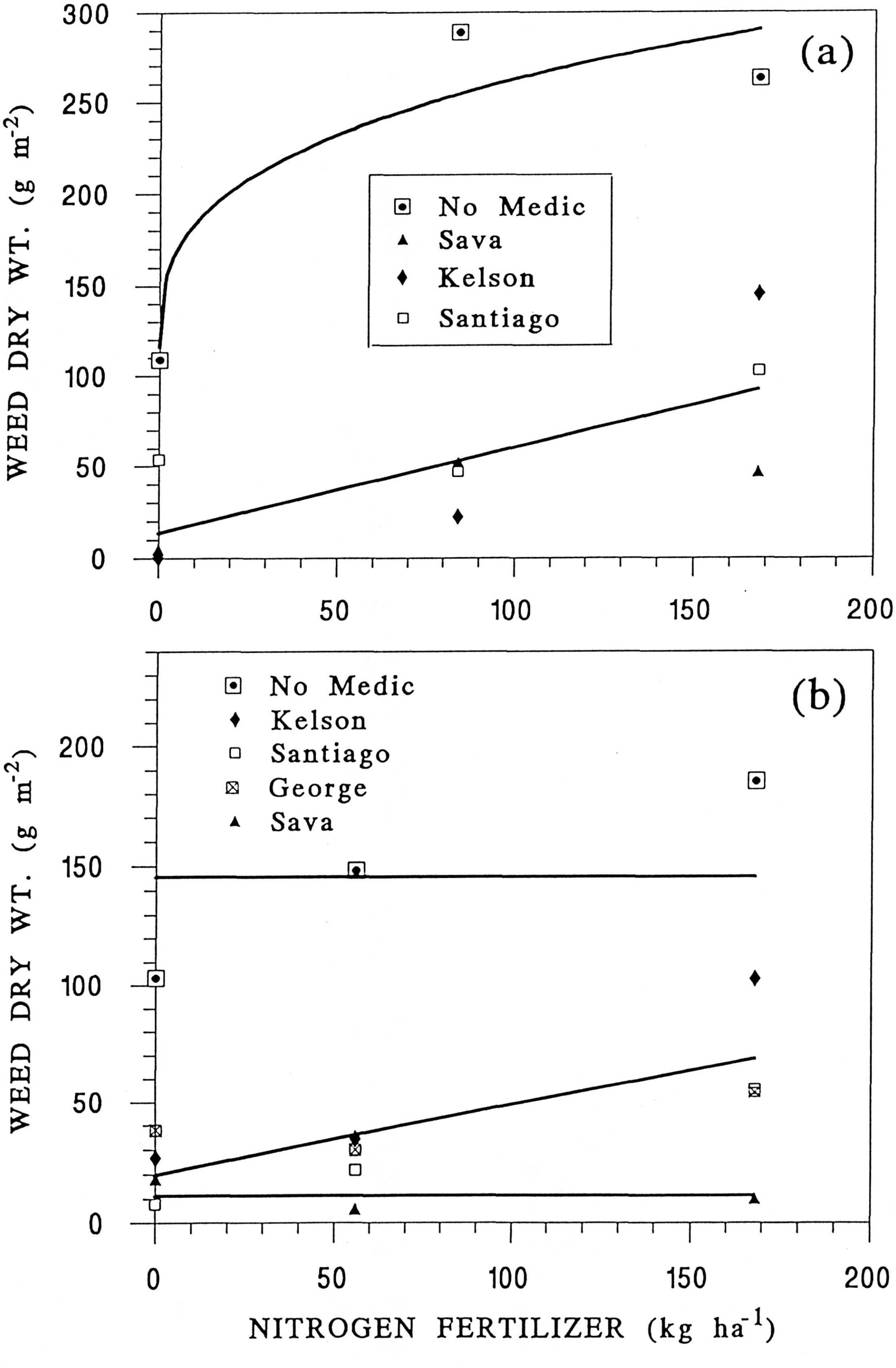
600
500
400
300
200
100
0
MEDIC DRY WT. (g m-2)
0
50
100
150
200
NITROGEN FERTILIZER (kg ha-1)
Kelson, weedy
Kelson, weed-free
Sava, weedy
Sava, weed-free
Santiago, weedy
Santiago, weed-free

Fig. 6



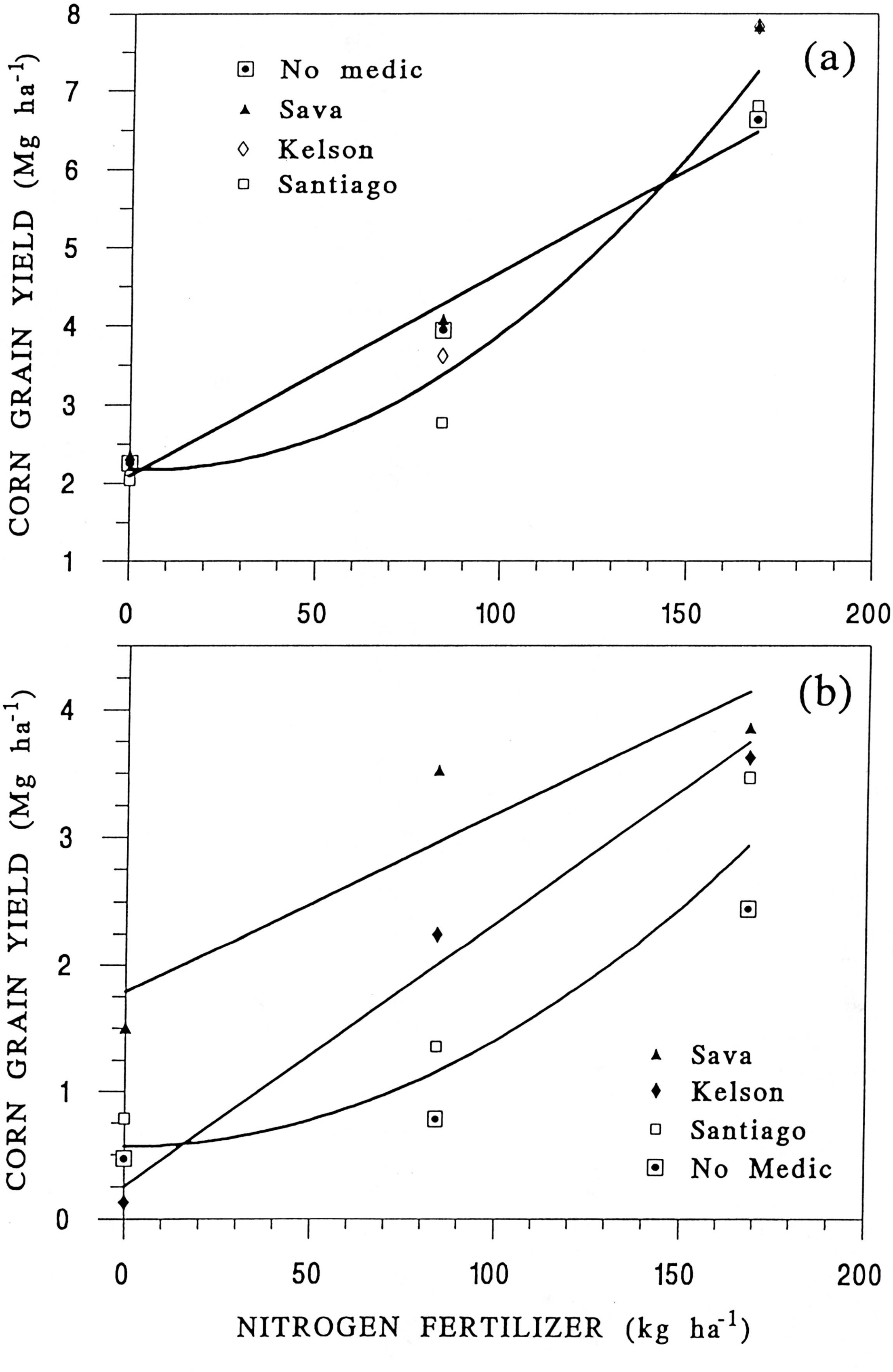
(a)
Sava
Kelson
Santiago
George
MEDIC DRY WT. ($g\ m^{-2}$)
400
300
200
100
0
0
50
100
150
200
(b)
Sava
Kelson
Santiago
George
MEDIC DRY WT. ($g\ m^{-2}$)
400
300
200
100
0
0
50
100
150
200
NITROGEN FERTILIZER ($kg\ ha^{-1}$)

Fig. 7



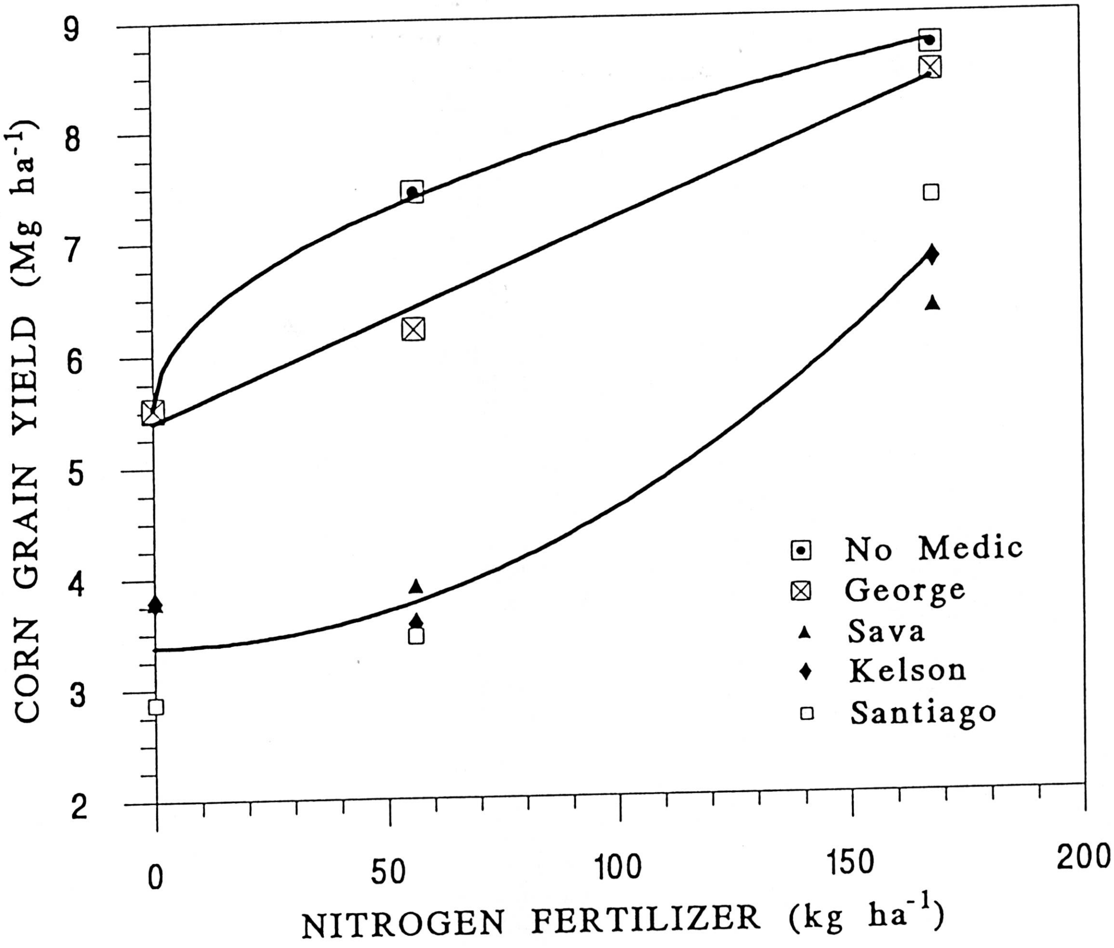
300
250
200
150
100
50
0
WEED DRY WT. (g m^{-2})
0
50
100
150
200
(a)
⊡ No Medic
▲ Sava
♦ Kelson
□ Santiago
200
150
100
50
0
WEED DRY WT. (g m^{-2})
(b)
⊡ No Medic
♦ Kelson
□ Santiago
⊠ George
▲ Sava
0
50
100
150
200
NITROGEN FERTILIZER (kg ha^{-1})

Fig. 3



(a)
No medic
Sava
Kelson
Santiago
CORN GRAIN YIELD (Mg ha^{-1})
1
2
3
4
5
6
7
8
0
50
100
150
200
(b)
Sava
Kelson
Santiago
No Medic
CORN GRAIN YIELD (Mg ha^{-1})
0
1
2
3
4
0
50
100
150
200
NITROGEN FERTILIZER (kg ha^{-1})

Fig. 9


CORN GRAIN YIELD (Mg ha^{-1})
9
8
7
6
5
4
3
2
0
50
100
150
200
NITROGEN FERTILIZER (kg ha^{-1})
⊡ No Medic
⊠ George
▲ Sava
♦ Kelson
□ Santiago