EFFECTS OF FERTILITY, SEEDING RATE, AND WEED CONTROL ON ALFALFA (*Medicago sativa*) FORAGE PRODUCTION IN AN ESTABLISHED STAND

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INTRODUCTION

This thesis is a manuscript to be submitted for publication in Weed Science, the Journal of the Weed Science Society of America.

EFFECTS OF FERTILITY, SEEDING RATE, AND WEED CONTROL ON ALFALFA (*Medicago sativa*) FORAGE PRODUCTION IN AN ESTABLISHED STAND

Abstract. Alfalfa was seeded at rates of 4.5, 9.0, 13.4, and 22.4 kg ha^{-1} in September of 1980. A field experiment was conducted on this area during two growing seasons (1988 and 1989) to evaluate the effects of fertility, seeding rate, and weed control on alfalfa forage production. Fertility levels in 1988 were adequate and low and in 1989 were adequate, intermediate, and low. In both years the adequate fertility level was 100% sufficient in P and K and the low fertility level had soil index values of 12 for P and less than 170 for K, while the intermediate fertility level in 1989 had soil index values of 56 for P and 198 for K. The weed control variables were either a herbicide mixture of terbacil (0.56 kg ha^{-1}) and oryzalin (1.68 kg ha^{-1}) or no herbicide. The data collected in 1988 and 1989 consisted of alfalfa stem density, weed plant density, alfalfa and weed heights, light intensity measurements, and alfalfa and weed dry matter production. In both years, the adequate fertility level increased alfalfa heights, weed dry matter production, and alfalfa dry matter production and

decreased light intensity at the soil surface. There was a reduced alfalfa stem density associated with the 4.5 kg ha^{-1} seeding rate and this resulted in decreased alfalfa production. Also associated with the 4.5 kg ha^{-1} seeding rate was an increased light penetration at the time of large crabgrass germination and an increase in production of weed dry matter. The herbicide treatment controlled weeds and this resulted in significant increases in alfalfa stem density, alfalfa stem heights, and alfalfa dry matter production.

Nomenclature: terbacil, 5-chloro-3-(1,1-dimethylethyl)-6-methyl-2,4(1H,3H)-pyrimidinedione; oryzalin, 4-(dipropylamino)-3,5-dinitrobenzenesulfonamide; alfalfa, *Medicago sativa* L. 'Riley'; large crabgrass, *Digitaria sanguinalis* (L.)Scop. #[1] DIGSA.

Additional index words. Dry matter production, fertility level, seeding rate, weed control, weed plant density, alfalfa stem density, light intensity measurements, terbacil, oryzalin, cool season grasses, DIGSA.

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[1]Letters following this symbol are a WSSA-approved computer code from the Composite List of Weeds, Weed Sci. 32, Suppl. 2. Available from WSSA, 3019 West Clark St., Champaign, IL 61820.

INTRODUCTION

Weed management is an important part of alfalfa production when alfalfa plant populations decrease in older alfalfa stands. Winter annual grasses and broadleaf weeds germinate and grow in the fall and winter when the alfalfa is dormant and then compete with first harvest growth of alfalfa. This weed growth decreases the amount of water, nutrients, light, and space that would be available to alfalfa. Summer annual grasses and broadleaf weeds germinate during May and June and compete directly with alfalfa for the remainder of the summer.

When weeds are harvested with alfalfa, the quality of the harvested forage, using protein content as the indicator, declines (3, 4, 6, 9, 19, 20). Herbicides have been selectively used to control weeds in alfalfa (2, 4, 6, 7, 8, 13, 16, 19, 20), and alfalfa yields are usually increased when weeds are controlled (4, 6, 8, 9, 20). However, there are also reports that alfalfa yields were not increased or in some cases actually reduced when herbicides were used to control weeds (4, 8, 13, 16, 19).

Kapusta and Strieker (6) reported increased alfalfa and protein yields associated with effective downy brome (Bromus tectorum L. # BROTE) control at first harvest with a significant yield increase of alfalfa at second harvest attributed to downy brome control. Cosgrove and Barrett (4) found that increases in alfalfa yield and forage protein content associated with weed control in established stands of alfalfa were dependent on stand density and the degree of weed infestation. They found that in thin stands of alfalfa with severe weed infestation, controlling weeds actually decreased the total first harvest forage yield, but the forage quality was increased since the weeds were removed. In dense stands of alfalfa with light weed infestation, there was little benefit from use of herbicides for weed control. However, in dense stands of alfalfa with severe weed infestation, there was potential for increased alfalfa yields and protein content (quality) from the use of herbicides (4).

Swan (16) found that repeated applications with most herbicides on alfalfa did not significantly reduce alfalfa yields, but some yield reductions were noted with simazine [6-chloro-N,N'-diethyl-1,3,5-triazine-2,4-diamine] (0.45 kg ha^{-1}), terbacil (0.45 kg ha^{-1}), and secbumeton [N-ethyl-6-methoxy-N'(1-methylpropyl)-1,3,5-triazine-2,4-diamine] (2.70 kg ha^{-1}).

Adequate fertility is another vital component of alfalfa management. Stein and Westerman (14) reported that total yields averaged over application rates for P source and application method combinations resulted in an average yield increase of 213% and 313% over unfertilized plots in 1981 and 1982, respectively. Rehm (11) found a curvilinear response from the use of P and S applied to irrigated alfalfa grown in a sandy soil in northeastern Nebraska. Fertilization with P increased alfalfa yield all 4 years of the study while S increased alfalfa yield 3 of the 4 years.

Stivers and Ohlrogge (15) reported significant increases in alfalfa yield with the addition of P and K. They also noted a significant decrease in stand longevity with insufficient levels of potash. Attoe and Truog (1), reported significant increases in alfalfa yields with P and K fertilizers and winter survival of alfalfa was usually much better with higher levels of K. Wang et al. (18) also related winter survival and stand longevity to adequate levels of lime and available P and K.

Gerwig and Ahlgren (5) found no significant increase in alfalfa yield with the addition of P to a soil with adequate P and deficient in soil K. However, the addition of K showed significantly higher alfalfa yields with an increase in yield with each increment of K applied up to 224 kg ha^{-1}.

Both weed control and fertility can influence the amount of light that is available for alfalfa. Walker et al. (17) stated the area, vertical distribution, and display of the foliage of the crop and weeds determine the ability of the crop to intercept photosynthetically active radiation and, ultimately, to produce an economic yield. Rhykerd et al. (12) found that light treatments and length of growth periods have a pronounced effect on the proportion of alfalfa leaf to stem ratio. The effect, in general, was an increased leaf/stem ratio of alfalfa at lower light intensities and decreases at higher light intensities. When comparing the leaf/stem ratios to a 30-day and a 45-day growth period, the leaf/stem ratios were lower under almost every light treatment at the end of the 45-day growth period except at the highest light intensity where the ratios were approximately equal. Therefore, it appears the proportion of leaves to stems decreases with senescence. This may have also been due to the plants changing from a vegetative to a reproductive stage during the last 15 days of growth with the 45-day growth period.

Pritchett and Nelson (10) found more reduction in alfalfa and bromegrass root growth than in top growth as a result of shading. This would undoubtedly reduce a plant's ability to extract water and nutrients from a soil. There was also a reduction in the dry weight of both plants as light intensity reduced, and alfalfa nodulation decreased as light intensity decreased but resumed upon removal of shading.

Herbicide and fertilization applications may be extremely useful for forage quality, forage production, and stand longevity in established stands of alfalfa. However, important management decisions still need to be made on which herbicides or fertilizer to use and the timing of both applications. Also competition for light has been studied and is a major factor that can affect a crop, especially in weed/crop interactions. A good understanding of weed/crop interactions subjected to various fertility levels, herbicide treatments, and seeding rates could enhance the ability to make good management decisions for alfalfa production. Therefore, the objectives of this research were to evaluate the effects of different fertility levels on growth and top dry matter production of alfalfa and annual weeds at various alfalfa stand densities, to measure the light penetration and canopy cover of alfalfa and weeds at ground level at the various alfalfa stand densities and fertility levels, and to compare growth and top dry matter production of alfalfa with and without weed interference.

MATERIALS AND METHODS

This study was conducted on an area that was planted to 'Riley' alfalfa in September of 1980. The experimental design was a split-plot design with three main plots and eight subplots with a factorial arrangement of four alfalfa seeding rates with and without weeds. Subplot dimensions were 1.8 by 6.1 m with 3 m borders between the three main plots and with a 1.8 m alley between the four replications. Alfalfa was planted at 4.5, 9.0, 13.4, and 22.4 kg ha^{-1} on a Farnum silt loam (fine-loamy, mixed, thermic Pachic Argiustolls) with a 1.6 m Brillion[2] seeder. At initiation

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[2]Brillion Iron Works, Brillion, WI 54110.

of the study and just prior to alfalfa planting, cheat (Bromus secalinus L. # BROSE) was broadcast by hand in the weed treatment plots at a rate of 16.8 kg ha^{-1}. Prior to alfalfa establishment, the area was fertilized according to the Oklahoma State University soil test recommendations for alfalfa establishment and the fertilizer was incorporated with a tandem disk.

The effects of alfalfa seeding rate, weeds, and time of first cutting on first year forage production for this experimental area were reported by Pike and Stritzke (9). After the first-cutting harvest variable of main plots in 1981, yields were determined when alfalfa was in 10 to 25% bloom. This resulted in 4 to 5 forage yield estimates per year from 1981 through 1987. There were no effects of treatments on alfalfa production in 1982 and 1983 (unpublished data). In February of 1984, the entire experimental area was broadcast fertilized with 112 kg ha^{-1} of P_2O_5 and 112 kg ha^{-1} of K_2O to bring the soil test indices up to the 100% sufficiency level. Weeds were beginning to invade the weed-free subplots in 1984, so a herbicide treatment of terbacil (0.56 kg ha^{-1}) plus oryzalin (1.68 kg ha^{-1}) was also initiated in 1984 and applied each year in March to all weed-free subplots using a hand-held CO_2 backpack sprayer.

In 1988, the soil in the experimental area was tested and three fertility levels (adequate, intermediate, and low) were identified and assigned to main plots. The soil test index values were 12 for P and 172 for K. In March, a fertilization application of 168 kg ha^{-1} of P_2O_5 and 112 kg ha^{-1} of K_2O was applied to two of the main plots (adequate and intermediate) in each replication to bring them to 100% sufficiency and the remaining main plot (low) was left unfertilized. Rainfall was not adequate throughout the growing season in 1988, so 5.1 cm of supplemental irrigation was applied on June 22 (Table 1).

Cool-season weed infestation was determined in all subplots on February 18, 1988 by randomly counting weeds in four 15.2 by 91.4 cm quadrats. On April 28, the heights of alfalfa, little barley (Hordeum pusillum Nutt. # HORPU), and rescuegrass (Bromus catharticus Vahl # BROCA) were taken on 20 plants in each subplot. Subplots to be kept weed-free were then treated in early March with a mixture of terbacil (0.56 kg ha^{-1}) and oryzalin (1.68 kg ha^{-1}) applied in a carrier volume of 187 L ha^{-1} with a hand-held CO_2 backpack sprayer. Alfalfa stem counts were taken on March 22 by randomly placing four 15.2 by 91.4 cm quadrats in each subplot.

A Carter[3] flail-type forage harvester with a sample size of 1 by 6.1 m was used for forage estimates for the first and second harvests in 1988 on May 13 and June 6,

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[3]Carter Mfg. Co. Inc., Brookston, IN 47923.

respectively. Forage weights were taken in the field and a subsample of approximately 400 grams was taken and oven dried at 50 C for 72 hrs for the determination of moisture percentage. The percent forage component composed of weeds was estimated before each of these two harvests. Dry matter yields were adjusted by weed estimates and converted to kg ha^{-1} yield of alfalfa and weeds.

After second harvest, two (15.2 by 91.4 cm) quadrats were randomly placed in each subplot and permanently marked by flagging two opposite corners of the quadrat. Alfalfa stem density, large crabgrass infestation, alfalfa and large crabgrass heights, and light intensity measurements at ground level were determined in all permanent subsamples on June 17. In addition, height measurements and light intensities were also determined on June 20, 22, 24, 29, and July 6. The light intensity measurements were taken across the diagonal of each quadrat with a Li-Cor Sensor[4] model number LI-191SB. The millivolt readings were adjusted to micromoles m^{-2} s^{-1} of photosynthetically active radiation. Alfalfa and large crabgrass forage was hand-clipped from the individual subsamples on July 7. The individual samples were oven dried and converted to kg ha^{-1} dry matter yields of alfalfa and large crabgrass.

After third harvest, two (15.2 by 91.4 cm) permanent

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[4]Li-Cor, Inc., Lincoln, NE 68504.

quadrats were again randomly selected in each subplot and permanently marked by flagging two opposite corners of the quadrat. Alfalfa stem density and large crabgrass infestation were determined in each subsample on July 22. In addition, light intensity measurements and alfalfa and large crabgrass heights were taken on July 22 and 29. The alfalfa and large crabgrass were hand-harvested on August 8 and oven dried to determine dry matter weights, and converted to kg ha^{-1} yields.

In January of 1989, 10 core samples of soil were taken to a depth of 15 cm from each subplot and composited to determine the fertility level of all subplots (Table 3). On March 13 the adequate fertility main plots were fertilized with 56 kg ha^{-1} P_2O_5 and 168 kg ha^{-1} K_2O to obtain a 100% sufficiency level. The intermediate fertility main plots were supplemented with 84 kg ha^{-1} K_2O and the low main plots were not fertilized. Adequate rainfall occurred throughout the summer of 1989, so there was no supplement irrigation in 1989 (Table 2).

Cool season-weed population in 1989 was determined on March 8 from three permanently marked 50 by 76 cm quadrats per subplot. The herbicide mixture of terbacil (0.56 kg ha^{-1}) and oryzalin (1.68 kg ha^{-1}) in a carrier volume of 187 L ha^{-1} was applied on March 15 to the weed-free subplots. Alfalfa stem density for first harvest was determined on March 21.

Forage harvest dates in 1989 were as follows: harvest one - May 8, harvest two - June 6, harvest three - July 5, harvest four - August 1, and harvest five - September 26. There were essentially no weeds at second harvest, therefore a Carter flail-type forage harvester was used for the second harvest. The percent forage component of second harvest composed of weeds was estimated and used to convert plot yields. All other forage harvests were hand clipped and hand separated from the permanent subsamples. These samples were oven dried and converted to kg ha^{-1} of oven dried forage.

After the second harvest, alfalfa and large crabgrass heights and light intensity measurements at ground level were determined in all the permanent subsamples on June 16, 21, and 26. In addition, alfalfa and large crabgrass heights were determined on June 29 and July 5. Alfalfa stem density was also determined on June 29 and the subsamples were hand-harvested and oven dried on July 5.

After the third harvest, alfalfa and large crabgrass heights were recorded on July 21, 27, and August 1 from the permanent subsamples. Alfalfa stem density was also determined on July 27 and the subsamples were hand-harvested and oven dried on August 1. No light intensity measurements were taken after the third harvest in 1989.

In addition to the four harvests in 1989 a fifth harvest was taken on September 26. Due to minimum alfalfa growth and high weed populations, only dry matter production of alfalfa and weeds were taken. In October, 10 core samples of soil per main plot in each of the four replications were taken to a depth of 15 cm and composited to determine the fertility level in the main plots at the termination of the study (Table 3).

RESULTS AND DISCUSSION

First Harvest

There were significant fertility by seeding rate and fertility by herbicide interactions associated with dry matter production of alfalfa in 1988. The fertility by seeding rate interaction was attributed to the lack of alfalfa yield response to increasing seeding rates with the low fertility level (Figure 1). With the low fertility level, alfalfa yield at the 4.5 kg ha^{-1} seeding rate was 2380 kg ha^{-1} and only increased to 2590 kg ha^{-1} with the highest seeding rate whereas the response with the adequate fertility level increased from 2920 to 4170 kg ha^{-1}. The fertility by seeding rate effect on alfalfa yield was primarily attributed to alfalfa height since there was also a fertility by seeding rate interaction effect on alfalfa height with the lines being very similar (Figure 1). With the low fertility level, alfalfa stem height at the 4.5 kg ha^{-1} seeding rate was 30 cm and did not increase with the highest seeding rate whereas the response with adequate fertility increased from 35 to 40 cm. Part of the increased alfalfa yield resulting with fertilizing higher seeding rates increased alfalfa stems since stem densities significantly increased as the seeding rates increased (Table 7).

The fertility by herbicide interaction was due to a significant increase in alfalfa production in the herbicide treated plots with adequate fertility. Alfalfa production in plots not treated with herbicide only increased from 2110 to 3260 kg ha^{-1} with the addition of fertilizer whereas in herbicide treated plots, the yield increased from 2960 to 4610 kg ha^{-1} with the addition of fertilizer. Alfalfa stem heights increased from 33 cm in the no herbicide plots to 37 cm in the herbicide treated plots and alfalfa stem densities were significantly increased in the herbicide treated plots (Table 7), so both alfalfa stem height and density contributed to increased alfalfa yield in herbicide treated plots.

By 1988 the weed population at first harvest had shifted from cheat to significant populations of rescuegrass and little barley. However, weeds did not make up a large portion of the forage production at first harvest in 1988. In the no herbicide plots there were 150 kg ha^{-1} of rescuegrass produced and this was significantly reduced to zero with the herbicide application (Table 5). A significant interaction was associated with the effect of fertility and weed control on little barley production (Table 6). In the no herbicide plots, little barley production increased from 320 kg ha^{-1} at the low fertility to 530 kg ha^{-1} with the adequate fertility while there was essentially no little barley produced in the herbicide treated plots.

In 1989, there were significant increases in alfalfa dry matter production at first harvest with the two higher fertility levels, with the three higher seeding rates, and with use of herbicides (Table 4). The increase in alfalfa yield with the adequate and intermediate fertility level was attributed to a 29% increase in alfalfa stem heights with the adequate and intermediate fertility levels. There was a significant fertility by seeding rate effect on alfalfa stem densities which resulted because there were low alfalfa stems m^{-2} to increasing seeding rates at the low fertility level, but there were some significant increases in alfalfa stems m^{-2} with increasing seeding rates with both adequate and intermediate fertility levels (Figure 2). This effect also contributed to the increased alfalfa yields associated with the two higher fertility levels and the three higher seeding rates.

The increase in alfalfa yield in the herbicide treated plots was due both to an increase in alfalfa stem density and height. Alfalfa stem densities were 270 stems m^{-2} in the no herbicide plots and this increased to 410 alfalfa stems m^{-2} in the herbicide plots (Table 7) and alfalfa heights were increased 29% in the herbicide treated plots.

There was also a significant seeding rate by herbicide interaction in dry matter production of cool-season weeds in 1989 (Table 6). This resulted because weeds were controlled in the herbicide plots whereas weed yields increased from 50 kg ha^{-1} at the high seeding rate to 180 kg ha^{-1} at the low seeding rate in the no herbicide plots.

Second Harvest

Alfalfa dry matter production at second harvest in 1988 was significantly increased with adequate fertility, the three higher seeding rates, and with herbicide treatment (Table 4). The 990 kg ha^{-1} increase in alfalfa yield with adequate fertility was primarily attributed to increased alfalfa growth. The increased alfalfa yield of 480 kg ha^{-1} averaged over the three higher seeding rates was attributed to the better alfalfa stem densities associated with these higher seeding rates. The 890 kg ha^{-1} increase in alfalfa yield associated with herbicide use is attributed to increased alfalfa stem densities and other residual benefits from previous control of weeds since there were very few weeds at second harvest.

There were minimum amounts of weed dry matter production at second harvest in 1988 and this was expected since most of the cool-season weeds are harvested at first harvest and warm-season weeds are either just germinating or starting to grow (Table 6). Total production of weeds averaged across the no herbicide treatments in 1988 was 110 kg ha^{-1} with composition being about equally split among little barley, rescuegrass, and large crabgrass. There was no weed production in the herbicide treated plots.

Alfalfa dry matter production at second harvest in 1989 was significantly increased with both adequate and intermediate fertility levels, with the three higher seeding rates, and with the herbicide treatment (Table 4). The increase in alfalfa production with both adequate and intermediate fertility levels was attributed to better alfalfa growth with fertility while the increases in alfalfa yield with the three higher seeding rates was attributed to increased alfalfa stem densities associated with these seeding rates. The 600 kg ha^{-1} increase in alfalfa production with herbicide use was attributed to residual benefits since very few weeds were present at second harvest in 1989.

As was the case in 1988, weed dry matter production at second harvest in 1989 was low, averaging only 110 kg ha^{-1} when averaged across the no herbicide treatments. Weed components at second harvest in 1989 were little barley, rescuegrass, and large crabgrass (Table 6). In the herbicide treated plots, weed production was eliminated in most plots except with the two lower seeding rates where 20 kg ha^{-1} was produced.

Third Harvest

There were significant fertility and herbicide main effects associated with alfalfa dry matter production at third harvest in 1988 (Table 4). There was an increased alfalfa yield of 630 kg ha^{-1} associated with adequate fertility and this related to significant increases in alfalfa height with adequate fertility (Tables 8 and 10). The three higher seeding rates significantly increased alfalfa stem densities (Table 7) but this increase did not significantly increase alfalfa production at the 5% level. The increased alfalfa yields of 570 kg ha^{-1} with the herbicide treatment is attributed to an increase of 30 alfalfa stems m^{-2} in the herbicide treatments as well as increased alfalfa heights and residual benefits from previous weed control affects (Tables 7, 8, and 10). All six light intensity measurements taken during the growth of third harvest were significantly reduced by adequate fertility and the three higher seeding rates significantly reduced the light intensity at the fourth and fifth samplings (Table 8). These decreases in light intensity were attributed to more shading due to thicker and taller alfalfa stems with adequate fertility and increased alfalfa stem densities with the three higher seeding rates. Reduced light intensity at the soil surface associated with alfalfa growing in adequately fertilized plots at all sampling periods suggests that adequately fertilized alfalfa would be more competitive.

In 1988, large crabgrass dry matter production was significantly reduced by the herbicide treatment (Table 5). This resulted since the herbicide treatment also significantly reduced large crabgrass plant density with only 10 large crabgrass plants m^{-2} emerging in the herbicide treated plots compared to 210 plants m^{-2} in the no herbicide plots. Seeding rate and fertility level had no effect on emergence of large crabgrass.

At third harvest in 1989, there was a fertility by seeding rate interaction effect (Figure 3) and a herbicide main effect on alfalfa dry matter production. The fertility by seeding rate interaction resulted because there was little alfalfa yield response to increasing seeding rates at the low fertility level, but there were some significant increases in alfalfa yield with increasing seeding rates with both intermediate and adequate fertility levels (Figure 3). Alfalfa heights in the three higher seeding rates were significantly increased by the adequate and intermediate fertility levels, so this plus increased alfalfa stems explains the increased alfalfa yields associated with these fertility levels (Tables 7 and 9). Alfalfa yield was increased by 780 kg ha^{-1} with herbicide treatment (Table 4). Associated with this increase was a significant increase of

80 alfalfa stems m^{-2} and significant increases in alfalfa heights at the third, fourth, and fifth sampling dates (Tables 7 and 9). Light intensity measurements at the soil surface were significantly reduced by the adequate and intermediate fertility levels at the second and third samplings, and by the no herbicide treatment at all three sampling dates (Table 9). Reduction of the light intensity with the better fertility levels suggests a more competitive alfalfa situation whereas reduction in the no herbicide plots suggests large crabgrass competition with the alfalfa and this competition significantly reduced alfalfa yields at third harvest in 1989.

There was only a herbicide main effect on large crabgrass dry matter production at third harvest in 1989 (Table 5). The herbicide treatment controlled the large crabgrass and what large crabgrass did escape was significantly reduced in height by an average of 5 cm at the time of third harvest (Table 9). Light intensity measurements at the soil surface were reduced when the weeds were not controlled because the large crabgrass plants were intercepting the photosynthetically active radiation and allowed more competition from the large crabgrass with alfalfa (Tables 9 and 10).

Fourth Harvest

Alfalfa dry matter production at fourth harvest in 1988 resulted in significant fertility and herbicide main effects (Table 4). The alfalfa yield was increased by 510 kg ha^{-1} when the fertility level was adequate and this alfalfa yield increase is attributed to significantly increased alfalfa heights associated with adequate fertility (Table 12). The 600 kg ha^{-1} increase in alfalfa yield from the herbicide treatment is attributed to significant increases of 60 alfalfa stems m^{-2} and increased alfalfa heights when weeds are controlled (Tables 7 and 12). Although the three higher seeding rates increased alfalfa stem densities, there was not a significant increase in alfalfa production at the 5% level (Table 7). There was a significant decrease in the light intensity measurements at the soil surface on both sampling dates in the no herbicide plots since large crabgrass had germinated earlier and was already present in these plots (Table 11). Therefore, clipped annual weeds already have an established root system and would be more competitive than germinating weeds.

Large crabgrass dry matter production at fourth harvest in 1988 resulted in a significant herbicide main effect (Table 5). Harvest four had the highest weed yield in 1988 with 880 kg ha^{-1} of large crabgrass produced in the no herbicide plots and this was reduced to 40 kg ha^{-1} with herbicide treatment. This increased large crabgrass production is attributed to the fact that the large crabgrass had already germinated and began active growth immediately after third harvest.

There was a fertility by seeding rate and a fertility by herbicide interaction on alfalfa dry matter production in 1989. The fertility by seeding rate interaction resulted because of a small alfalfa yield response to increased seeding rates when fertility was low compared to significant alfalfa production increases with the intermediate and adequate fertility levels with increased seeding rates (Figure 5). The fertility by herbicide interaction resulted because of only a small alfalfa yield response to increased fertility level when the weeds were not controlled compared to significant alfalfa production increases with fertility when weeds were controlled (Figure 4). When weeds were controlled there were significant increases in alfalfa stem densities of 150 alfalfa stems m^{-2} and alfalfa heights at the second and third sampling dates, so increased alfalfa yields in the herbicide treated plots is due to both taller and greater alfalfa stem densities (Tables 7 and 11). The adequate and intermediate fertility levels significantly increased alfalfa heights at all three sampling dates and this explains the increased alfalfa yields associated with these fertility levels (Table 11).

Large crabgrass dry matter production at fourth harvest in 1989 resulted in a fertility by herbicide and a seeding rate by herbicide interaction. Large crabgrass production in the no herbicide plots increased from 530 kg ha^{-1} in the low fertility to 780 kg ha^{-1} in the adequate fertility whereas it decreased from 200 kg ha^{-1} at low fertility to 130 kg ha^{-1} with adequate fertility in the herbicide plots (Figure 6). Therefore, the fertility by herbicide interaction resulted because of the little large crabgrass yield response to increased fertility level in the herbicide plots compared to significant large crabgrass production increases with fertility in the no herbicide plots. The seeding rate by herbicide interaction resulted because of the small large crabgrass yield response to increased seeding rates with herbicide treatment while there were significant large crabgrass production increases to increased seeding rates with the no herbicide plots (Figure 7). Although there was large crabgrass production in the herbicide treated plots, the herbicide treatment did significantly reduce large crabgrass yields at fourth harvest in 1989.

Total Production By Year

Total alfalfa production in both 1988 and 1989 were significantly affected by an interaction associated with fertility and seeding rate and by a herbicide main effect. The fertility by seeding rate interaction resulted because there were not alfalfa yield increases associated with increasing seeding rates at low fertility compared to significant total alfalfa production increases associated with increased seeding rates when the fertility level was adequate. For example, with low fertility, total alfalfa yield in 1988 and 1989 at the lowest seeding rate was 6110 and 3660 kg ha^{-1}, respectively, and this increased to 6660 and 4210 kg ha^{-1}, respectively, with the highest seeding rate. With adequate fertility, total alfalfa yield in 1988 and 1989 at the lowest seeding rate was 7990 and 5170 kg ha^{-1}, respectively, and this increased to 10980 and 6950 kg ha^{-1}, respectively, with the highest seeding rate. In 1988, total alfalfa production in the herbicide treatments averaged across all treatments was 9810 kg ha^{-1} and this compared to 7220 kg ha^{-1} in the no herbicide plots (Table 4). Total alfalfa production in the herbicide treated plots in 1989 was 6940 kg ha^{-1} and this compared to 4320 kg ha^{-1} in the no herbicide plots (Table 4). The increased total alfalfa production from the herbicide treatment in both years is attributed to increased alfalfa stem densities, alfalfa heights, reduced weed competition, and residual benefits from weed control in previous years (Tables 7, 8, 10).

Total weed production in 1988 had a significant herbicide main effect (Table 5). Total weed production in 1988 was only 100 kg ha^{-1} in the herbicide treated plots and this compared to 2020 kg ha^{-1} in the no herbicide plots. Total weed production in 1989 resulted in a significant fertility by herbicide interaction because total weed production in the no herbicide plots increased from 3270 kg ha^{-1} in the low fertility to 4100 kg ha^{-1} in the adequate fertility, but decreased from 1560 kg ha^{-1} at low fertility to 1430 kg ha^{-1} with adequate fertility in the herbicide plots.

CONCLUSIONS

In general, use of fertilizer increased alfalfa dry matter production and alfalfa stem heights, reduced light intensity readings, and essentially had no effect on alfalfa stem density or weed dry matter production. Therefore, an adequately fertilized stand of alfalfa would be more competitive than an inadequately fertilized alfalfa stand. The three higher seeding rates significantly increased alfalfa dry matter production at the first two harvests, but as alfalfa yields declined there was not a significant difference at the 5% level although alfalfa stem densities were increased. Light intensity was reduced twice in 1988 with the three higher seeding rates but there were no effects on alfalfa stem heights. Weed dry matter production also tended to decline with these seeding rates. Weed control significantly increased alfalfa dry matter production, alfalfa stem densities, alfalfa stem heights, and reduced weed dry matter production. There was also a significant effect on light intensity dependent upon whether the weeds were already present or not.

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Table 1. Precipitation data (0.1 cm quantities or more) - Agronomy Research Station, Perkins, Oklahoma. (January 1 - December 31, 1988).

Date	Centimeters	Date	Centimeters	Date	Centimeters
January 6	1.0	May 8	0.2	September 18	3.6
January 7	1.1	May 16	4.4	September 19	2.6
January 19	0.3	May 23	1.4	September 23	3.3
February 19	1.2	May 24	1.1	September 24	1.8
March 2	2.5	June 1	0.3	September 29	1.8
March 3	5.1	June 2	1.4	October 2	0.3
March 4	0.6	June 3	0.6	October 6	0.6
March 6	0.6	June 27	0.2	October 7	1.5
March 17	0.7	June 29	0.5	October 8	0.3
March 18	0.9	July 1	0.8	October 16	0.2
March 29	3.2	July 9	0.2	October 20	0.6
March 30	0.1	July 20	1.7	November 10	0.4
March 31	0.3	July 27	2.8	November 11	5.7
April 1	5.1	July 28	1.3	November 20	3.1
April 2	0.6	August 10	0.3	November 26	0.2
April 10	2.2	August 28	1.4	December 7	0.4
April 18	4.5	August 29	0.4	December 8	0.5
April 19	0.3	September 3	0.3	December 12	0.5
April 25	0.1	September 16	6.0	December 23	0.6
April 30	0.1	September 17	0.3	December 27	0.6
				December 31	0.2

Table 2. Precipitation data (0.1 cm quantities or more) - Agronomy Research Station, Perkins, Oklahoma. (January 1 - December 31, 1989).

Date	Centimeters	Date	Centimeters	Date	Centimeters
January 8	0.2	May 13	0.8	July 23	1.0
January 14	0.5	May 14	1.3	July 28	0.4
January 25	1.3	May 16	1.9	July 29	0.4
January 28	1.8	May 17	3.2	August 3	0.4
January 29	0.2	May 18	1.7	August 6	6.2
February 13	0.4	May 22	7.2	August 14	3.4
February 15	1.7	May 26	0.3	August 15	0.1
February 18	0.4	June 1	1.3	August 20	0.6
February 20	0.8	June 2	0.9	August 22	0.3
February 21	0.5	June 3	1.7	September 2	0.6
February 27	0.8	June 4	3.5	September 4	2.9
March 4	0.5	June 5	0.3	September 13	8.0
March 6	1.3	June 7	0.3	October 6	3.0
March 27	0.5	June 11	0.4	October 28	0.1
March 28	5.0	June 12	1.3	October 29	0.1
March 30	0.6	June 13	1.4	November 2	0.1
March 31	0.1	June 14	0.7	December 7	0.1
April 10	0.2	June 23	6.4	December 8	0.9
April 21	0.3	June 27	1.9	December 29	0.3
May 3	1.3	July 2	1.7		
May 4	3.8	July 13	0.4		
May 12	0.2	July 15	7.1		

Table 3. Soil phosphorus and potassium indexes (Spring and Fall 1989).

Replication	Adequate P	Adequate K	Intermediate P	Intermediate K	Low P	Low K
			SPRING 1989[a]			
I	81	198	36	208	12	198
II	70	189	73	201	9	175
III	67	176	39	183	15	178
IV	88	172	74	200	12	150
MEAN	77	184	56	198	12	175
			FALL 1989			
I	79	230	27	164	12	190
II	64	211	41	187	11	146
III	74	190	20	185	14	144
IV	82	174	64	181	13	162
MEAN	75	201	38	180	13	160

[a]Values within each main plot are an average of all subplots within each replication.

Table 4. Main effects on alfalfa dry matter production (1988 and 1989).

Treatments	Harvest 1	Harvest 2		Harvest 3		Harvest 4	Total	
	1989	1988	1989	1988	1989[a]	1988	1988[a]	1989[a]
	----------(kg ha^{-1})----------							
Main effects - fertility[b]								
Adequate	1850 a	3010 a	2620 a	1900 a	-	1470 a	-	-
Intermediate[c]	1660 a	-	2430 a	-	-	-	-	-
Low	1050 b	2020 b	1590 b	1270 b	-	960 b	-	-
Main effects - seeding rate[b]								
22.4 kg ha^{-1}	1640 a	2730 a	2320 a	1710 a	-	1340 a	-	-
13.4 kg ha^{-1}	1600 a	2720 a	2240 a	1690 a	-	1230 a	-	-
9.0 kg ha^{-1}	1570 a	2660 a	2280 a	1700 a	-	1270 a	-	-
4.5 kg ha^{-1}	1260 b	2220 b	2020 b	1440 a	-	1160 a	-	-
Main effects - herbicide[b]								
Herbicide	1780 a	3030 a	2510 a	1920 a	1630 a	1550 a	9810 a	6940 a
No herbicide	1260 b	2140 b	1910 b	1350 b	850 b	950 b	7220 b	4320 b

[a]Dashes within these columns signify an interaction was involved, therefore main effects were not presented.

[b]Within each main effect, values followed by the same letter are not significantly different at the 5% level according to protected LSD test.

[c]Dashes with the intermediate fertility in 1988 signify no intermediate fertility level in 1988.

Table 5. Main effects on weed dry matter dry matter production (1988 and 1989).

Treatments	Harvest 1	Harvest 3		Harvest 4	Total	
	1988 RG[a]	1988 CG[a]	1989 CG	1988 CG	1988	1989[b]
	---(kg ha^{-1})---					
Main effects - fertility[c]						
Adequate	100 a	180 a	450 a	410 a	1120 a	-
Intermediate[d]	-	-	480 a	-	-	-
Low	60 a	90 a	430 a	550 a	1050 a	-
Main effects - seeding rate[c]						
22.4 kg ha^{-1}	50 a	130 a	410 a	410 a	890 a	2520 a
13.4 kg ha^{-1}	70 a	120 a	470 a	470 a	1080 a	2520 a
9.0 kg ha^{-1}	80 a	130 a	440 a	450 a	1090 a	2590 a
4.5 kg ha^{-1}	90 a	160 a	490 a	520 a	1190 a	2670 a
Main effects - herbicide[c]						
Herbicide	0 b	20 b	20 b	40 b	100 b	-
No herbicide	150 a	250 a	890 a	880 a	2020 a	-

[a]Abbreviations are RG=rescuegrass and CG=large crabgrass.

[b]Dashes within this column signifies an interaction was involved, therefore main effects were not presented.

[c]Within each main effect, values followed by the same letter are not significantly different at the 5% level according to protected LSD test.

[d]Dashes with the intermediate fertility in 1988 signify no intermediate fertility level in 1988.

Table 6. Interactions on weed dry matter production (1988 and 1989).

	Harvest 1		Harvest 2			
	1988	1989	1988			1989
Treatments	LB[ab]	LB + RG[ab]	LB[ab]	RG[ab]	CG[ab]	LB + RG + CG[ab]
Fertility by herbicide	(kg ha^{-1})					
Adequate - herbicide	0	-	-	0	0	-
Adequate - no herbicide	530	-	-	60	40	-
Intermediate - herbicide[c]	-	-	-	-	-	-
Intermediate - no herbicide[c]	-	-	-	-	-	-
Low - herbicide	0	-	-	0	0	-
Low - no herbicide	320	-	-	20	20	-
LSD (0.05)[d]	120	-	-	20	10	-
LSD (0.05)[d]	250	-	-	20	20	-
Seed rate by herbicide						
22.4 kg ha^{-1} - herbicide	-	0	0	-	-	0
22.4 kg ha^{-1} - no herbicide	-	50	40	-	-	60
13.4 kg ha^{-1} - herbicide	-	0	0	-	-	0
13.4 kg ha^{-1} - no herbicide	-	90	30	-	-	110
9.0 kg ha^{-1} - herbicide	-	0	0	-	-	10
9.0 kg ha^{-1} - no herbicide	-	70	30	-	-	60
4.5 kg ha^{-1} - herbicide	-	20	0	-	-	10
4.5 kg ha^{-1} - no herbicide	-	180	60	-	-	200
LSD (0.05)	-	60	20	-	-	70

[a]Dashes within these columns signify no interaction was involved.

[b]Abbreviations are LB=Little barley, RG=Rescuegrass, CG=Crabgrass.

[c]Dashes with the intermediate fertility in 1988 signify no intermediate fertility level in 1988.

[d]The first LSD is used to compare means within each fertility level and the second LSD is used to compare all means within each respective column.

Table 7. Main effects on alfalfa stem counts (1988 and 1989).

Treatments	Harvest 1 1988	Harvest 1 1989[a]	Harvest 3 1988	Harvest 3 1989	Harvest 4 1988	Harvest 4 1989
Main effects - fertility[b]	(alfalfa stems m^{-2})					
Adequate	160 a	-	250 a	280 a	200 a	260 a
Intermediate[c]	-	-	-	270 a	-	250 a
Low	170 a	-	240 a	240 a	180 a	200 a
Main effects - seeding rate[b]						
22.4 kg ha^{-1}	190 a	-	260 a	280 a	220 a	250 a
13.4 kg ha^{-1}	170 b	-	260 a	260 ab	210 ab	240 a
9.0 kg ha^{-1}	160 c	-	240 a	250 b	200 b	230 a
4.5 kg ha^{-1}	120 d	-	220 b	260 ab	170 c	240 a
Main effects - herbicide[b]						
Herbicide	170 a	410 a	260 a	300 a	230 a	310 a
No herbicide	150 b	270 b	230 b	220 b	170 b	160 b

[a]Dashes within this column signify an interaction was involved.

[b]Within each main effect, values followed by the same letter are not significantly different at the 5% level according to protected LSD test.

[c]Dashes with the intermediate fertility in 1988 signify no intermediate fertility level in 1988.

Table 8. Main effects on alfalfa stem heights and light intensity readings during third harvest growth (1988).

Treatments	ALFHT1[a]	ALFHT5	ALFHT6	LTINT1[a]	LTINT2	LTINT3	LTINT4	LTINT5	LTINT6
	(cm)			(micromol m^{-2} s^{-1})					
Main effects - fertility[b]									
Adequate	12 a	34 a	42 a	1500 b	1440 b	1320 b	1160 b	440 b	350 b
Low	10 b	26 b	32 b	1600 a	1590 a	1450 a	1370 a	700 a	640 a
Main effects - seeding rate[b]									
22.4 kg ha^{-1}	12 a	30 a	38 a	1520 a	1480 a	1340 a	1230 b	550 b	470 a
13.4 kg ha^{-1}	11 a	30 a	37 a	1560 a	1510 a	1380 a	1260 b	540 b	470 a
9.0 kg ha^{-1}	12 a	31 a	39 a	1540 a	1500 a	1380 a	1240 b	510 b	440 a
4.5 kg ha^{-1}	11 a	30 a	37 a	1580 a	1560 a	1420 a	1340 a	640 a	560 a
Main effects - herbicide[b]									
Herbicide	11 a	31 a	39 a	1540 a	1490 a	1360 a	1260 a	580 a	500 a
No herbicide	11 a	30 b	37 a	1550 a	1530 a	1400 a	1280 a	540 a	470 a

[a]Abbreviations ALFHT=alfalfa height and LTINT=light intensity reading.

[b]Within each main effect, values followed by the same letter are not significantly different at the 5% level according to protected LSD test.

Table 9. Main effects on alfalfa stem heights, large crabgrass heights, and light intensity readings during third harvest growth (1989).

Treatments	ALFHT1[a]	ALFHT2	ALFHT3	ALFHT4	ALFHT5	CGHT1[a]	CGHT2	CGHT3	LTINT1[a]	LTINT2	LTINT3
	(cm)								--(micromol m^{-2} s^{-1})-		
Main effects - fertility[b]											
Adequate	9 a	17 a	26 a	35 a	42 a	7 a	7 a	8 a	1480 a	940 b	530 b
Intermediate	8 ab	16 a	26 a	33 a	40 a	7 a	7 a	9 a	1460 a	910 b	520 b
Low	7 b	13 b	21 b	27 b	32 b	6 a	6 a	8 a	1480 a	1090 a	730 a
Main effects - seeding rate[b]											
22.4 kg ha^{-1}	8 a	15 a	24 a	32 a	39 a	6 a	7 a	8 a	1490 a	980 a	570 a
13.4 kg ha^{-1}	8 a	15 a	24 a	31 a	38 a	7 a	6 a	8 a	1460 a	980 a	590 a
9.0 kg ha^{-1}	8 a	16 a	24 a	31 a	38 a	7 a	7 a	8 a	1460 a	980 a	610 a
Main effects - herbicide[b]											
Herbicide	8 a	15 a	25 a	33 a	40 a	4 b	4 b	6 b	1590 a	1050 a	630 a
No herbicide	8 a	15 a	23 b	30 b	36 b	10 a	9 a	11 a	1360 b	900 b	560 b

[a]Abbreviations ALFHT=alfalfa height and LTINT=light intensity reading.

[b]Within each main effect, values followed by the same letter are not significantly different at the 5% level according to protected LSD test.

NOTE: No alfalfa heights, large crabgrass heights, or light intensity readings were taken on the 4.5 kg ha^{-1} seeding rate in 1989.

Table 10. Fertility by herbicide interactions on alfalfa heights in 1988 and large crabgrass heights in 1989 during third harvest growth.

Treatments	1988 ALFHT3[a]	1988 ALFHT4	1989 CGHT4[a]	1989 CGHT5
	(cm)			
Fertility by herbicide				
Adequate - herbicide	22	23	6	7
Adequate - no herbicide	22	23	15	23
Intermediate - herbicide[b]	-	-	8	9
Intermediate - no herbicide[b]	-	-	16	23
Low - herbicide	18	19	8	12
Low - no herbicide	15	17	11	15
LSD (0.05)[c]	3	2	2	2
LSD (0.05)[c]	3	3	2	4

[a]Abbreviations are ALFHT=alfalfa height and CGHT=large crabgrass height.

[b]Dashes with the intermediate fertility in 1988 signify no intermediate fertility level in 1988.

[c]The first LSD is used to compare means within each fertility level and the second LSD is used to compare all means within each respective column.

Table 11. Main effects on light intensity readings in 1989 and alfalfa heights in 1989 during fourth harvest growth.

Treatments	1988		1989		
	LTINT1[a]	LTINT2	ALFHT1[a]	ALFHT2	ALFHT3
	(micromol m^{-2} s^{-1})		-----------(cm)-----------		
Main effects - fertility[b]					
Adequate	1420 a	840 a	10 a	17 a	23 a
Intermediate[c]	-	-	10 a	17 a	21 b
Low	1480 a	1010 a	9 b	15 b	19 c
Main effects - seeding rate[b]					
22.4 kg ha^{-1}	1430 a	860 a	9 a	17 a	21 a
13.4 kg ha^{-1}	1460 a	920 a	9 a	16 a	21 a
9.0 kg ha^{-1}	1440 a	880 a	10 a	16 a	21 a
4.5 kg ha^{-1}[d]	1490 a	1000 a	-	-	-
Main effects - herbicide[b]					
Herbicide	1600 a	1050 a	10 a	17 a	21 a
No herbicide	1310 b	780 b	9 a	16 b	20 b

[a]Abbreviations are LTINT=light intensity readings and ALFHT=alfalfa height.

[b]Within each main effect, values followed by the same letter are not significantly different at the 5% level according to protected LSD test.

[c]Dashes with the intermediate fertility in 1988 signify no intermediate fertility level in 1988.

[d]Dashes with the 4.5 kg ha^{-1} seeding rate in 1989 signifies no 4.5 kg ha^{-1} seeding rate in 1989.

Table 12. Fertility by herbicide interactions on alfalfa and large crabgrass heights (1988) and large crabgrass heights (1989) during fourth harvest growth.

Treatments	1988				1989		
	ALFHT1[a]	ALFHT2	CGHT1[a]	CGHT2	CGHT1	CGHT2	CGHT3
	(cm)						
Fertility by herbicide							
Adequate - herbicide	16	27	2	3	6	9	14
Adequate - no herbicide	16	28	11	13	8	9	12
Intermediate - herbicide[b]	-	-	-	-	5	9	12
Intermediate - no herbicide[b]	-	-	-	-	8	10	13
Low - herbicide	14	24	5	7	6	9	13
Low - no herbicide	13	21	10	12	7	7	10
LSD (0.05)[c]	2	3	2	3	1	1	1
LSD (0.05)[c]	2	5	2	3	1	2	2

[a]Abbreviations are ALFHT=alfalfa height and CGHT=large crabgrass height.

[b]Dashes with the intermediate fertility in 1988 signify no intermediate fertility level in 1988.

[c]The first LSD is used to compare means within each fertility level and the second LSD is used to compare all means within each respective column.

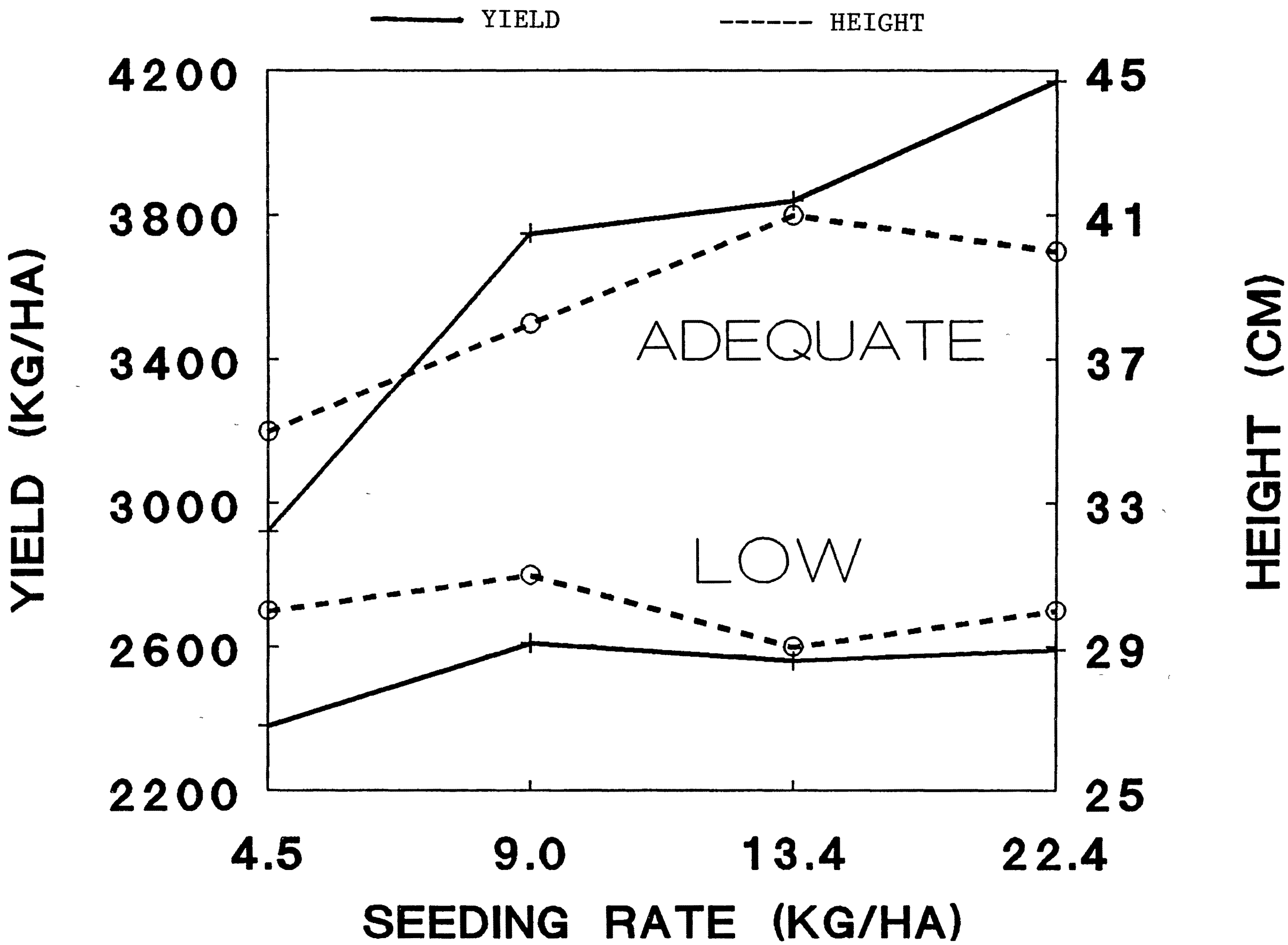

Figure 1. Fertility by seeding rate interaction on first harvest alfalfa production and alfalfa stem density (1988).

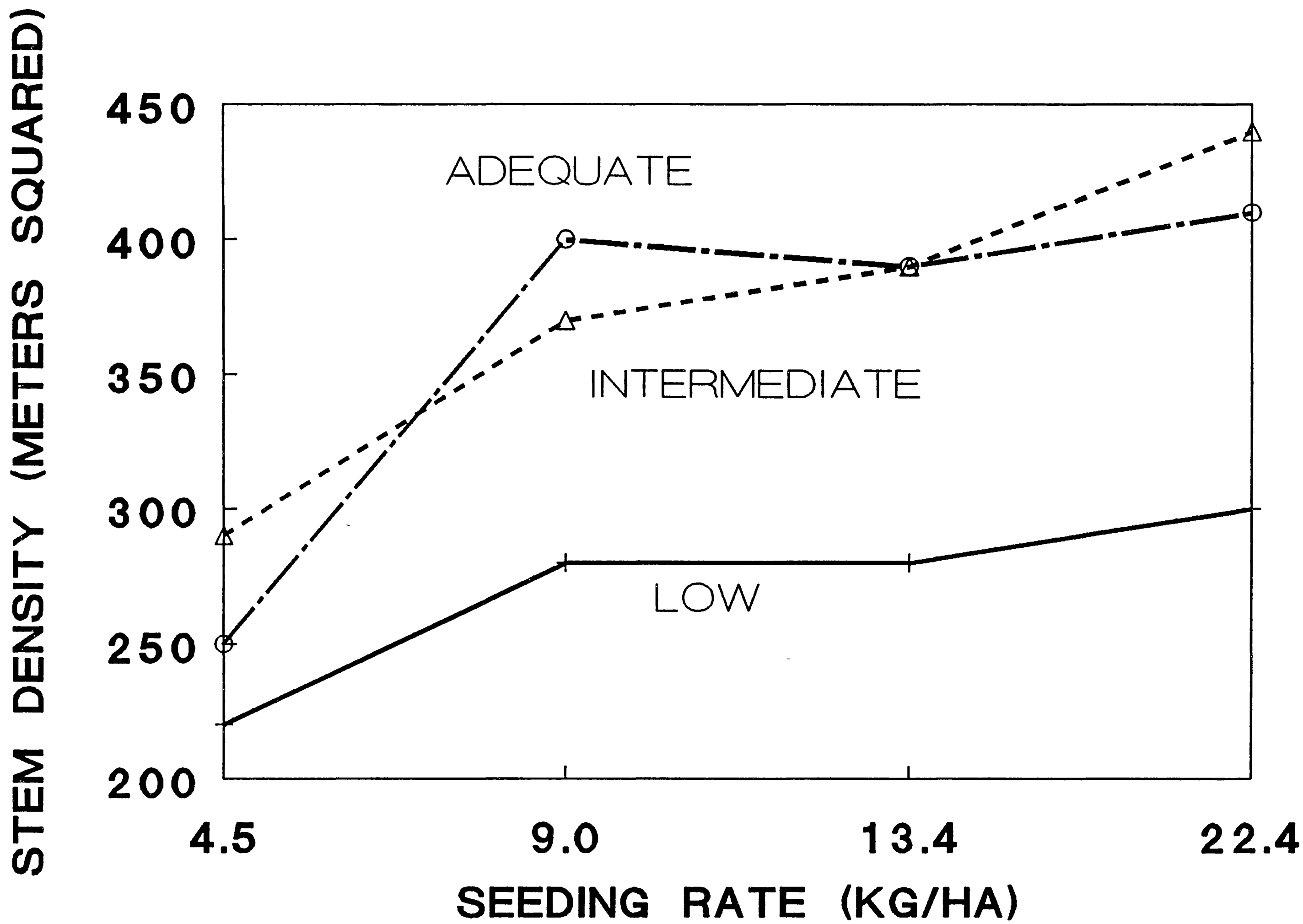

Figure 2. Fertility by seeding rate interaction on first harvest alfalfa stem density (1989).

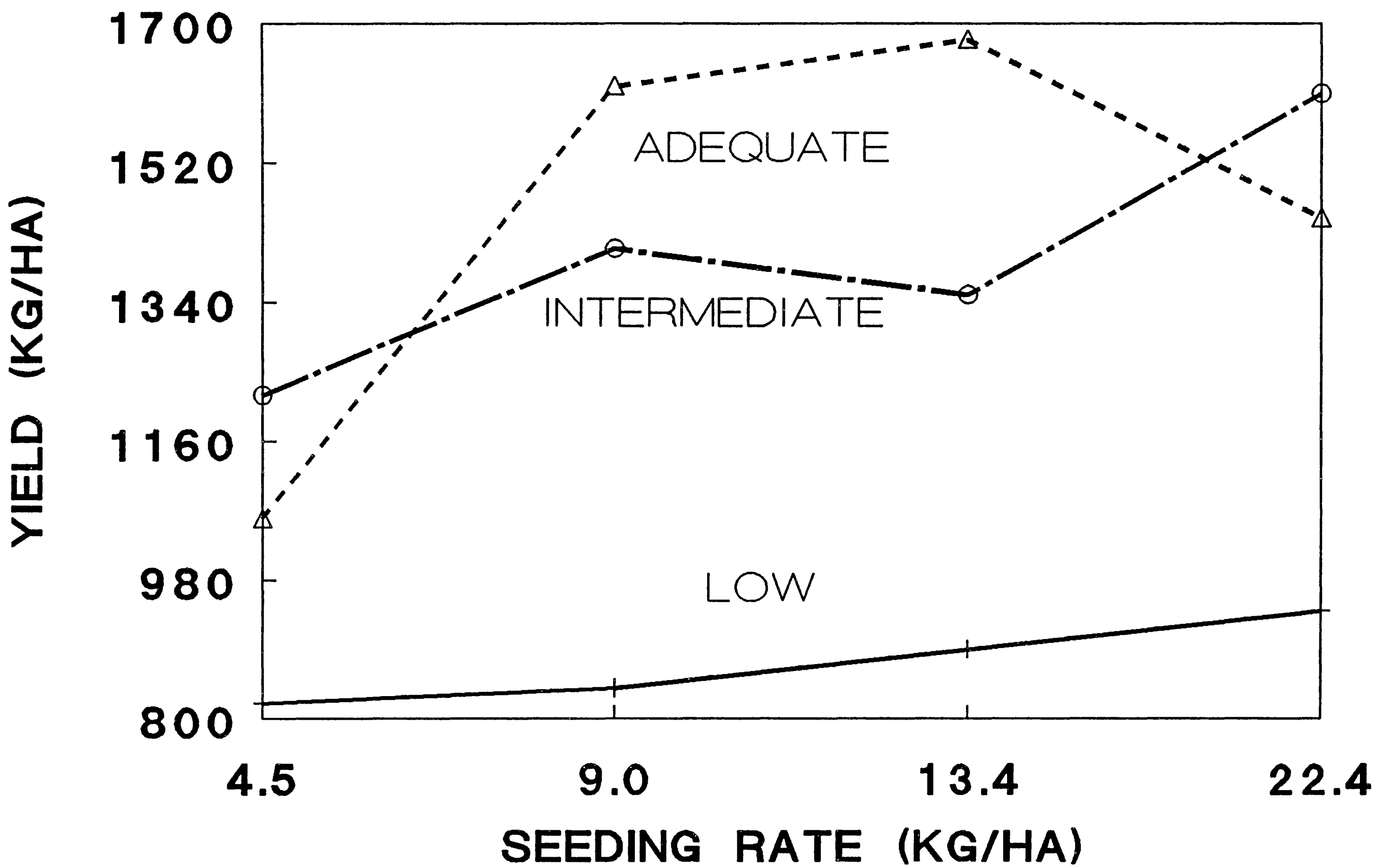

Figure 3. Fertility by seeding rate interaction on third harvest alfalfa production (1989).

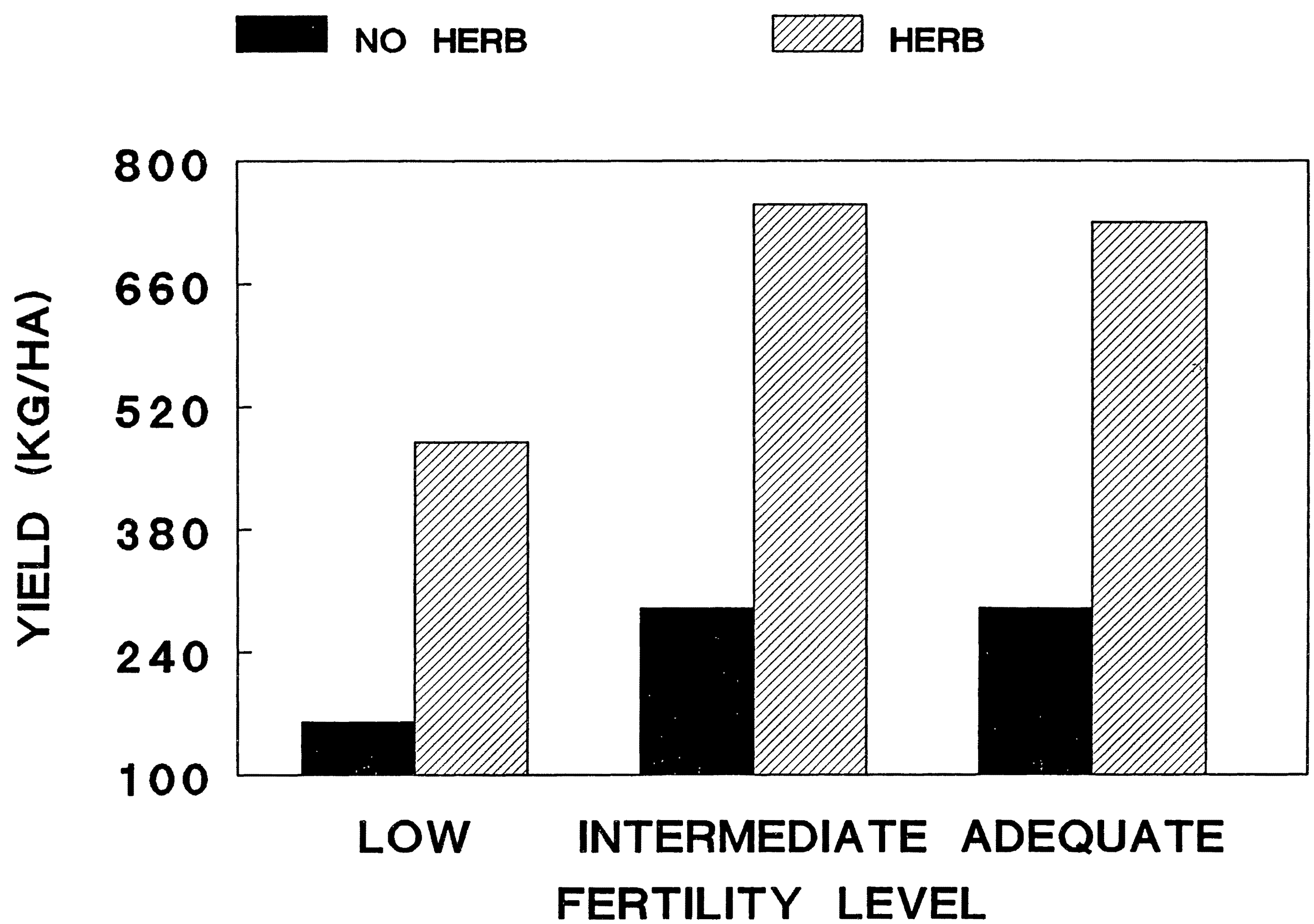

Figure 4. Fertility by herbicide interaction on fourth harvest alfalfa production (1989).

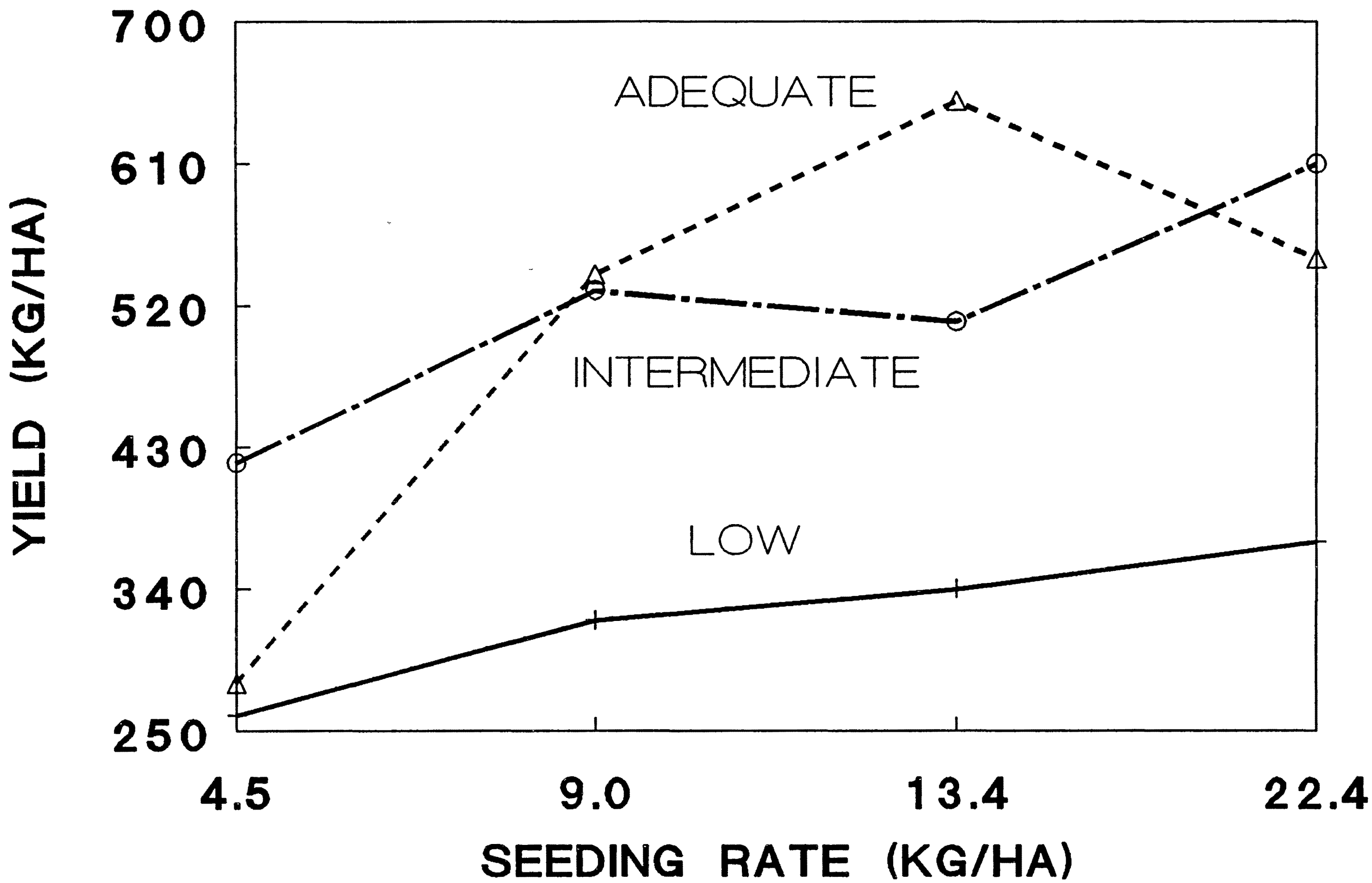

Figure 5. Fertility by seeding rate interaction on fourth harvest alfalfa production (1989).

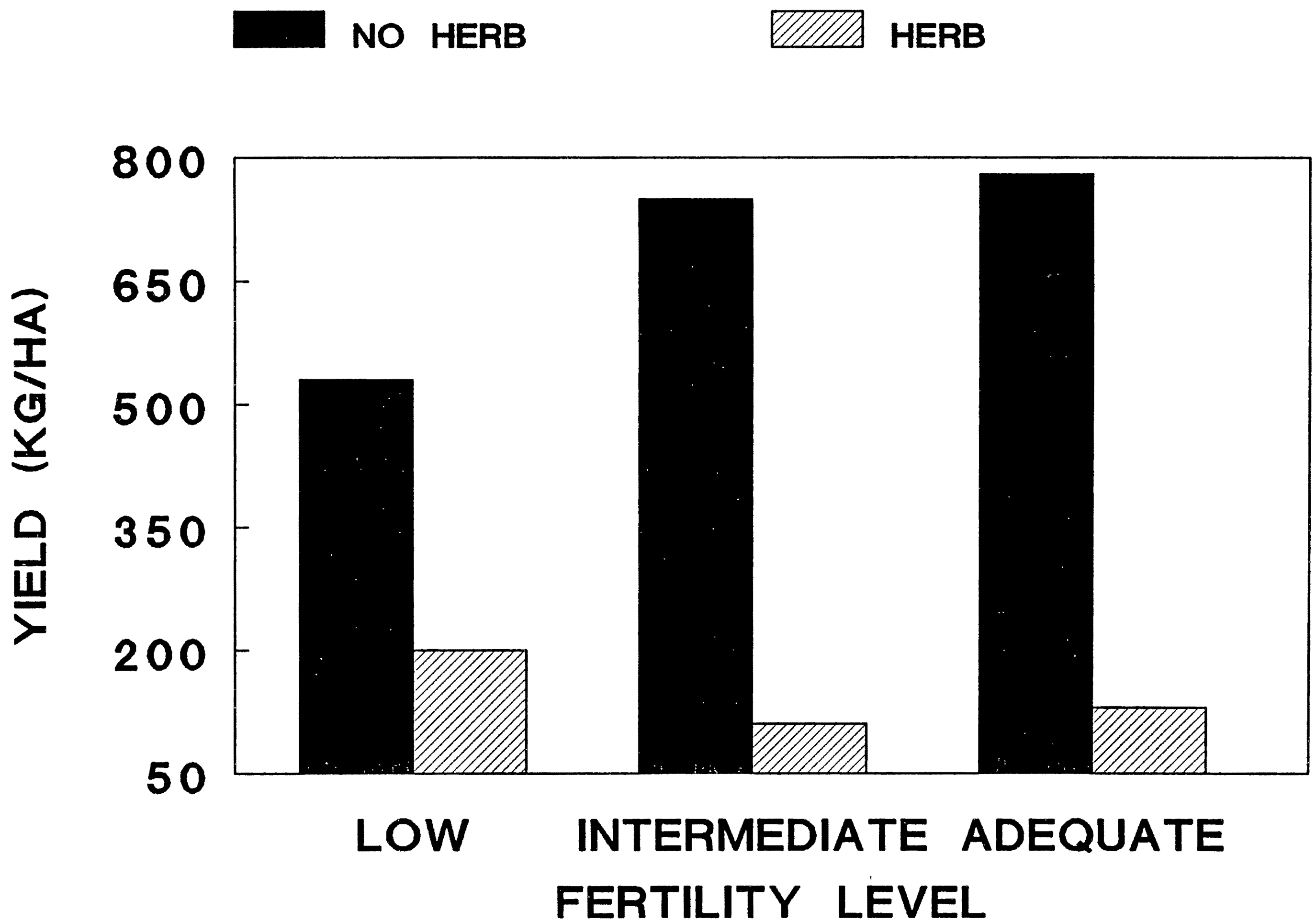

Figure 6. Fertility by herbicide interaction on fourth harvest large crabgrass production (1989).

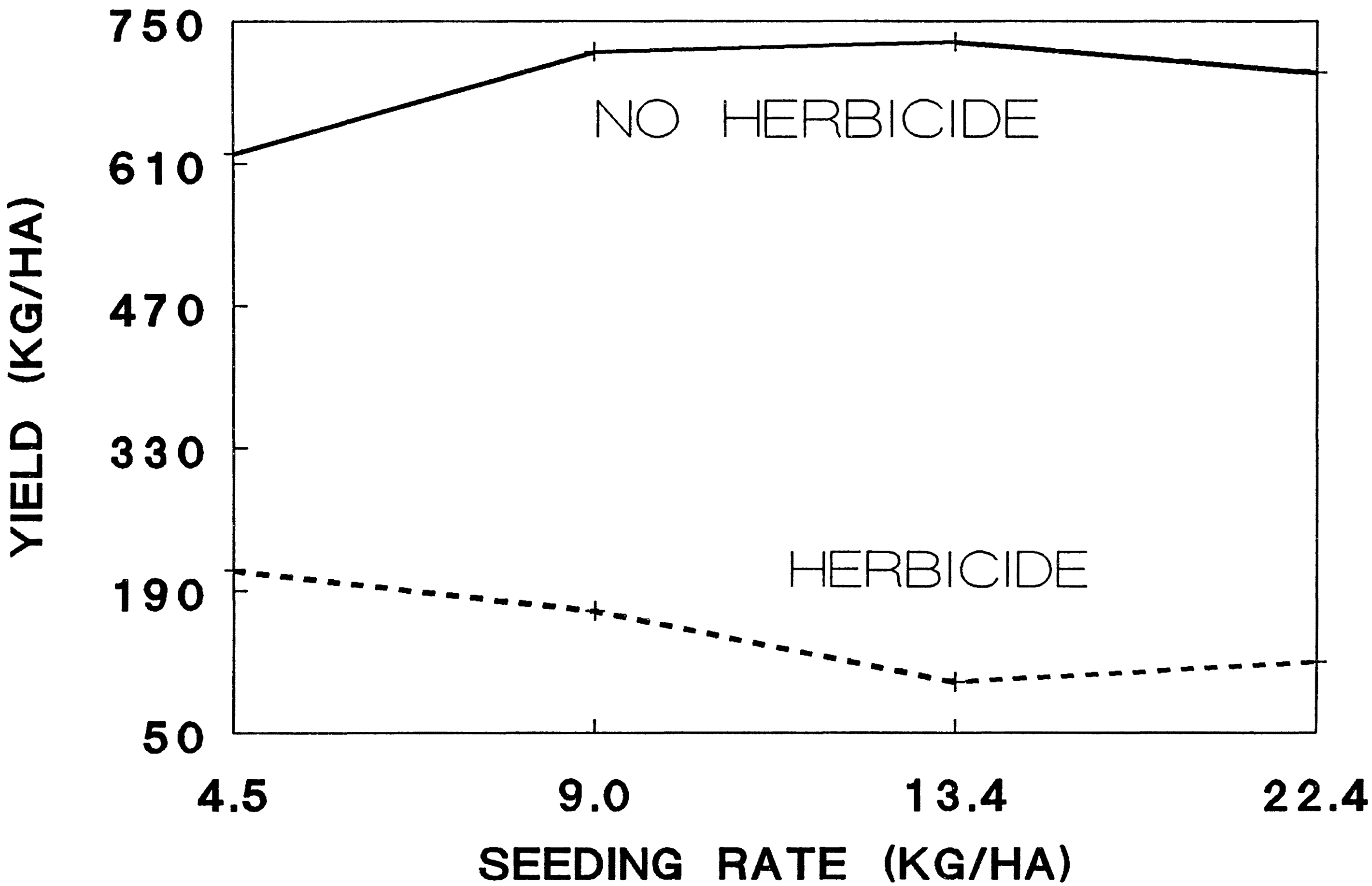

Figure 7. Seeding rate by herbicide interaction on fourth harvest large crabgrass production (1989).

VITA 2

John Vincent Altom

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF FERTILITY, SEEDING RATE, AND WEED CONTROL ON ALFALFA (Medicago sativa) FORAGE PRODUCTION IN AN ESTABLISHED STAND

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