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EFFECT OF THREE PLANT GROWTH REGULATORS
AND TWO NITROGEN REGIMES ON GROWTH AND PERFORMANCE
OF CREEPING BENTGRASS (*Agrostis palustris* Huds.)

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Ronald Nigel Calhoun

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Major professor

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By

Ronald Nigel Calhoun

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ABSTRACT

EFFECT OF THREE PLANT GROWTH REGULATORS AND TWO NITROGEN REGIMES ON GROWTH AND PERFORMANCE OF CREEPING BENTGRASS (*Agrostis palustris* Huds.)

By

Ronald Nigel Calhoun

Research was initiated in 1994 to study the interaction of nitrogen fertilization and PGRs on fairway height creeping bentgrass (*Agrostis palustris* H.) performance, clipping production, divot recovery, and wear tolerance. Two nitrogen regimes and three PGRs at three rates were applied in a randomized complete block design. The PGRs chosen were flurprimidol{α-(1-methylethyl)-α-[4-(trifluoro-methoxy)phenyl]-5-pyrimidine-ethanol}, paclobutrazol {(±)-(R*,R*)-β-[(4-chlorophenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol}, and trinexapac-ethyl {4(cyclopropyl-α-hydroxy-methylene)-3,5-dioxocyclohexanecarboxylic acid ethyl ester}. Three montly PGR applications were made in 1994 and four were made in 1995. The high nitrogen regime doubled clipping production, increased turf quality, and enhanced divot recovery and wear tolerance. Clipping reduction >60% was observed after the first PGR application but not after the second application. The high nitrogen regime accelerated divot closure by 10 days compared to the low nitrogen regime. There was little effect of PGRs on divot closure rate. PGRs generally increased visual turfgrass quality. Flurprimidol treatment decreased wear tolerance on the low nitrogen regime.

To My Family

Kristi and Emily
your love, support, and understanding

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INTRODUCTION

Plant Growth Regulators

Plant growth regulators are any number of naturally occurring or synthetic compounds that regulate plant growth and development. Plant growth regulators can have endogenous or exogenous sources. Plants produce several compounds such as abscisic acid, auxins, cytokinins, ethylene, gibberellins, and polyamines that all regulate plant growth processes. Although these naturally occurring plant growth regulators control plant functions, most synthetic plant growth regulators are applied to turfgrass to reduce seedhead or clipping production. Kaufmann (1986) and Watschke (1985), classified plant growth regulators (PGRs) used in turf as Type I and Type II.

Type I PGRs can temporarily reduce inflorescence appearance and vegetative growth of turfgrass by inhibiting cell division and cell elongation through the disruption of cytokinin biosynthesis in the plant. Mefluidide, introduced in the early 1970's, is an example of a Type I PGR. The injury to turf that often accompanied mefluidide applications was unacceptable for golf course turf and limited its use.

Type II PGRs suppress cell elongation through inhibition of gibberellin biosynthesis. Type II growth regulators tend to extend the period of growth reduction and have less injury to turf than Type I compounds but have little effect on seedhead production (Watschke, 1981). Two Type II PGRs, flurprimidol and paclobutrazol, were labeled for turf use in the 1980's. These products were primarily used for clipping reduction and conversion of mixed species stand to a monoculture. The 1993 labeling of trinexapac-ethyl as a PGR for turfgrass rekindled research in this area. Most Type II PGRs, such as flurprimidol and paclobutrazol, are absorbed by the crown and root (Beard, 1985, Batten, 1983 and Barrett & Bartuska, 1982), inhibit gibberellin biosynthesis through interference with cytochrome P-450-dependent reactions which blocks the oxidation of *ent*-Kaurene to *ent*-Kaurenoic acid (Jennings et al., 1993). Trinexapac-ethyl is foliar absorbed and affects a different site of action by blocking the 3β-hydroxylation of GA_{20} to GA_1 in gibberellin biosynthesis. Due to the differences of these Type II PGRs, Watschke and DiPaola (1995) reclassified PGRs used on turf into three groups. The Type II PGRs were broken into two groups. They listed trinexapac-ethyl as a Class A PGR because of its activity at the final step in gibberellin biosynthesis and fewer reported side-effects. Flurprimidol and paclobutrazol were labeled as Class B PGRs due to a different site of action, uptake, and perceived increase in turfgrass injury that occurred from their application. Class C PGRs are the mitotic inhibitors that are used for turfgrass seedhead inhibition and included all Type I PGRs.

Most of the recent PGR research on turf has included the Type II PGRs and their effects on clipping production as measured by mowing frequency (Johnson, 1992, 1993, 1994) and secondary plant processes such as tillering, carbohydrate partitioning, and root growth (Hanson & Branham, 1987, Menn et al., 1991, Hull, 1992, Lee & Diesburg, 1993, Spak et al., 1993, Christians, 1994).

Golf course managers use Type II PGRs to reduce clipping production which results in lower labor and equipment maintenance costs. Clipping production is also a concern as clipping disposal becomes cost prohibitive or unavailable. PGRs may reduce shoot growth so that bagging is not necessary and clippings can be returned to the turf without interference with turf usage. With increased use in turfgrass, questions arise regarding the effect of PGRs on clipping production, recovery from injury, and tolerance to stresses.

The reduction in shoot growth in response to PGRs is commonly accepted as well as the PGR influence, positive or negative, on turfgrass quality. The reduction in shoot elongation from PGRs can be dramatic. Johnson (1992, 1993, 1994) has characterized the responses of many warm and cool season turfgrasses to PGRs. He observed a reduction in mowing frequency needed to maintain roadside and landscape turfgrass. Overall reduction has been measured as high as 83% without loss to turfgrass quality (Razmjoo et al., 1994). However, PGR application is commonly associated with a loss of turfgrass quality.

Turfgrass quality is defined by several characteristics, including color, texture, density, and uniformity. Turfgrass color has a major impact on overall quality. Turfgrass quality losses from PGRs, usually foliar burn, are typically observed when the PGR chemicals are applied at rates required to achieve desired growth reduction (Elkins et al., 1974). DiPaola et al. (1985) reported that turfgrass discoloration from PGRs can be increased by moisture stress. However, turfgrass quality losses that occur after PGR applications are usually temporary and are often followed by improved turfgrass quality as compared to untreated plots. Johnson and Faulkner (1985) reported that paclobutrazol treated plots were initially discolored and then observed darker green foliage 3 to 4 weeks after application. PGRs applied to warm season turfgrass increased turfgrass density (Menn et al., 1991). McElroy (1984) observed darker green foliage after the PGR effects wore off and that while the dark green turfgrass color was a desirable attribute of PGR usage, foliar appearance of a sward may not necessarily reflect its overall quality.

The optimum time for PGR application is in the spring when PGRs will not delay the greening of the turfgrass and greatest growth reduction is realized. Watschke et al. (1992) listed several researchers who observed rapid growth flushes following foliar suppression that may negate the savings from reduced mowing experienced earlier in the season. Most of the published research on PGR use is based on single, not multiple PGR applications. It seems useful to consider the benefit of multiple PGR applications through the season to reduce the growth rebound and extend the growth reduction period.

Research examining the divot recovery of PGR treated turfgrass has been limited. This research has almost exclusively focused on warm season turfgrass species. The effect of PGRs on the tillering and rhizome growth and total nonstructural carbohydrate levels of turfgrass has been reported for flurprimidol, paclobutrazol (Hanson and Branham, 1987), and trinexapac-ethyl (Han and Fermanian, 1995). This information may indicate what effect PGR applications will have on divot closure. Flurprimidol has been shown to increase density of treated stands of Kentucky bluegrass (Dernoeden, 1984). Tillering of some turfgrasses was enhanced but lateral growth was greatly reduced. Shearing and Batch (1982) reported that the stems and stolons of paclobutrazol treated turfgrass became thicker and more prostrate and rosette-like in growth habit. Hanson and Branham (1987) measured increase photosynthate partitioning into tillers of Kentucky bluegrass at 2 to 4 weeks following application of flurprimidol and paclobutrazol. In most studies tillering and turfgrass density were increased by PGR application. This was attributed to a reduction in internode length. Increased turfgrass density does not necessarily indicate accelerated divot closure. As shoot growth is inhibited it would follow that stolon growth would also be reduced. PGR treatment would most likely result in delayed divot closure for turfgrass.

Brueninger and Watschke (1982) found that regardless of the PGR type used, treated golf course roughs did not tolerate traffic as well as nontreated areas. They concluded that the recuperative potential of PGR treated turfgrass is reduced, if wear damage occurs, due to the decreased shoot growth. This conclusion did not consider whether the wear tolerance, resistance to damage, of turf was altered by PGR application. Testing wear tolerance, not recuperative potential, would measure any change in the amount of wear required to induce damage to a PGR treated turfgrass. Recuperative potential measures turf recovery after damage occurs. Traffic on untreated turfgrass caused visible wear damage but had less obvious effects on shoot growth and root growth (Cuddeback and Petrovic, 1985). Although winter hardiness and thatch accumulation were reduced by traffic they found little or no effect on root growth. Traffic includes compaction and wear components. Any experiment that examines wear should take care to separate wear from traffic. Wear damage should be evaluated 1 to 2 days after the damage has been imposed (Carrow and Petrovic, 1992).

Nitrogen

The beneficial effects of nitrogen on turfgrass are often assumed. A wealth of published information is available on the specific influences of nitrogen on turfgrass systems. Nitrogen fertilization is one of the main tools used by golf course superintendents to maintain healthy, playable turfgrass surfaces on golf courses. The aesthetics of fine turfgrass are enhanced with nitrogen leading to greater uniformity and darker green color. While nitrogen increases color there is also a decrease in the total nonstructural carbohydrate levels in rhizomes (Goatley et al., 1994). Snyder and Schmidt (1972) showed that nitrogen enhanced turfgrass appearance and shoot growth but severely reduced root growth. Finally, light frequent applications of nitrogen have been shown to provide the overall best turfgrass quality but were not correlated closely with root growth (Carrow, 1989).

Many types of turfgrass injury are remedied by application of nitrogen fertilizers. Divots and wear damaged turfgrass recover more rapidly when nitrogen is readily available to the turfgrass. Divot recovery was more rapid if clippings were returned and increased nitrogen was provided (Shearman, 1989). Under traffic conditions turfgrass quality increased with increased nitrogen nutrition (Shearman, 1989). Eggens and Carey (1988) evaluated wear from riding mowers on creeping bentgrass fairways. Moderate nitrogen fertility can enhance wear tolerance by increasing total cell wall content on a dry weight basis and recuperative potential of turfgrass (Beard, 1973). Very high nitrogen levels can have deleterious effects on turfgrass wear tolerance due to hydration of the plant cell and thinning of the cell wall (Beard, 1973). Unfortunately, the nitrogen rates necessary to maintain recuperative potential of turfgrass also inhibit root production and increase the shoot growth creating greater clipping production. It would be desirable if a balance existed where the turfgrass community retained the benefits realized from nitrogen without excess top growth.

If a decrease in top growth is associated with the enhancement of other plant processes then perhaps plant growth regulators could be used to force secondary growth during the non-optimal conditions that occur in the summer. Initially, concerns were raised as to the effectiveness of PGRs on high maintenance turfgrass. However, trinexapac-ethyl and flurprimidol remain effective at reducing tissue production in high and low nitrogen regimes (Christians, 1994).

The objectives of this research were a) to determine the effects of three plant growth regulators on the production of clippings and on the quality of a creeping bentgrass fairway throughout the season maintained under a high and low nitrogen fertility regime, b) to evaluate the effect of three plant growth regulators on divot closure and wear tolerance of a creeping bentgrass fairway, and c) to evaluate the benefit of single vs. multiple applications of PGRs on clipping production through the season.

MATERIALS AND METHODS

This research was initiated during 1994 at the Hancock Turfgrass Research Center in East Lansing, MI. The turfgrass used in this experiment was a 3-year-old 'Penncross' creeping bentgrass (*Agrostis palustris* Huds.) maintained at 1.6 cm. Soil type was a Marlette sandy loam soil (fine-loamy, mixed, mesic Glossoboric Hapludalfs). Soil tests determined that phosphorus and potassium were not limiting. The plots were irrigated to prevent drought stress and received at least 2.5 cm irrigation or rain per week. Three PGRs each at three rates were applied on two nitrogen regimes. In addition, a control plot was included on each nitrogen regime. The treatments were arranged in a randomized complete block design with three blocks for a total of 60 plots. These plots were established inside a 334 m^2 irrigation block. Individual plots measured 1.22 by 4.27 m. The plots were divided into three areas for evaluation purposes. Clipping production and turfgrass quality were measured on a 1.22 by 2.44 m area of each plot. Divot recovery was measured on a 1.22 by 0.91 m area of each plot. Wear tolerance was evaluated on the remaining 1.22 by 0.91 m area of each plot. Wear tolerance was only evaluated in 1995.

The PGRs included in this experiment were flurprimidol, paclobutrazol, and trinexapac-ethyl. Each PGR was applied at 0.25, 0.50, and 1X, where X equals the current label rate for creeping bentgrass maintained at fairway height. Those rates are

0.56, 0.28, and 0.2 kg ha^{-1} for flurprimidol, paclobutrazol, and trinexapac-ethyl, respectively. PGR treatments were made on June 7, July 5, and August 2 of 1994. Application dates for 1995 were May 1, May 29, June 27, and July 24. PGR application was made using a CO_2-pressurized four-nozzle backpack sprayer that was calibrated to deliver 518 L ha^{-1} at 276 kPa.

Two fertility regimes were established with nitrogen levels of 125 and 250 kg ha^{-1} year^{-1}. Monthly applications of urea (46-0-0) were made from May 15 to November 15. For the 250 kg N ha^{-1} year^{-1} regime, 50 kg N ha^{-1} were applied in May, June, September, and November and 25 kg N ha^{-1} were applied in July and August. Rates were reduced by 1/2 for the 125 kg N ha^{-1} year^{-1} regime. The urea was applied using a CO_2-pressurized four-nozzle walk-behind sprayer. The sprayer was calibrated to 320 L ha^{-1} at 215 kPa.

Clippings were collected with a John Deere 20 SR7, Moline, IL., walk behind reel mower. One mower pass was made down the center of the plots collecting clippings from a 1 m^2 area. Clippings were taken once per week after three days growth. Clippings were oven dried for 48 h at 50° C and weighed. The entire plot area was mowed two more times per week with a riding fairway mower. The clippings were removed but not weighed from these two additional mowings.

Divots were made with a divot tool. The divot tool was developed to ensure consistent divot size. The divot tool was constructed with a cutting blade attached to a wooden handle that pivoted on an axle above the ground (Figure 1). The machine cut an arc that was 1.25 cm deep by 9 cm long by 5 cm wide. One divot was made in each plot on a weekly basis for four weeks after the first PGR application. To evaluate

Figure 1: Radial Sod Extraction Device (Divot Cutter)

recovery, a template was made to the size of the original divot. The recovery template consisted of a grid of 72 sections. Each grid section measured 50 by 75 mm. Percent recovery was determined by dividing the observed number of filled sections by 72 and multiplying by 100. Divot recovery was rated weekly until the entire grid filled. Divot recovery data were analyzed using linear regression to estimate days to 90 percent closure.

Visual ratings of the plots were done to determine the effects of fertility regime and growth regulator treatment on overall turfgrass quality. These ratings were based on a 1-9 scale where 1=dead, 5=acceptable, and 9=excellent.

Minor modifications in the experiment were made in 1995. An additional PGR application was made in May of 1995. Weekly nitrogen treatments were substituted for monthly fertilizer applications in an attempt to minimize the growth surge associated with monthly fertilizer applications. Weekly applications of urea were made from April 18 to September 26, 1995. For the 250 kg N ha^{-1} $year^{-1}$ regime 62.5 kg N ha^{-1} were applied in May, 50 kg N ha^{-1} were applied in June and September, and 30 kg N ha^{-1} were applied in April, July, and August. Rates were reduced by 1/2 for the 125 kg N ha^{-1} $year^{-1}$ regime. Clippings were collected twice per week in 1995, and at no time were the plots mowed with a riding unit, hence all clippings were collected. One divot was made in each plot for four weeks after the first and second PGR applications for a total of eight divots per plot. The second set of divots correspond by date to the June divots made in 1994. Divot recovery was measured twice per week in 1995 to more precisely predict the rate of recovery.

Wear tolerance of creeping bentgrass as affected by PGR treatment and nitrogen regime was evaluated in 1995. A drag sled was developed to provide wear (Figure 2) to the turfgrass. The drag sled was made of a 17.5 mm thick plywood that measure 1.22 by 2.13 m. The entire contact surface of the sled was covered with a 6.4 mm thick polypropylene sheet. Structural support for the sled and the tongue were made of lineal lumber. The gross weight of the drag sled was 90 kg and applied 0.003 kg cm^{2-1} of compaction. In comparison a person walking applies about 0.365 kg cm^{2-1} of compaction, so compaction was considered nil.

The sled was effective in applying wear damage to the turf. However, the number of passes needed to induce damage led to extreme injury of turf in the tire tracks. The wear sled was pulled across the plots 15 times per day, six days per week for three weeks. The smooth polypropylene sheet did not provide enough resistance to efficiently apply wear. Covering the bottom of the sled with a canvas tarp (or other abrasive material) would decrease the number of passes required for damage to occur. Although this was not done in this study.

The turfgrass disease dollar spot (*Sclerotinia homoeocarpa*), was very active in 1995. Dollar spot is often exhibited as 2 to 3 cm circles of necrotic turf. If left untreated these necrotic circles eventually coalesce. This disease was controlled with a contact fungicide in 1995. Before fungicide treatment the number of dollar spot centers of infection were recorded. Two observations were made during the summer in 1995 when clear differences between PGR treatments and nitrogen fertility were observed.

Figure 2: Turfgrass Wear Sled

Clipping production data and quality ratings were transformed to percent of control for analysis. Data were transformed by dividing by the corresponding low or high nitrogen control for each block. Analysis of variance was performed (Table 1) on all data and means were separated using Fisher's protected LSD procedure at the 0.05 level of probability.

Table 1: Analysis of variance table for a 3-factor RCBD.

K Value	Source	Degrees of Freedom
1	Replication	2
2	Nitrogen Regime	1
4	PGR Type	2
6	N x PGR	2
8	PGR Rate	2
10	N x Rate	2
12	PGR x Rate	4
14	N x PGR x Rate	4
-15	Error	34
	Total	53

RESULTS AND DISCUSSION

Clipping Production

The clipping production from a creeping bentgrass fairway, not treated with PGR, as affected by nitrogen regimes of 125 and 250 kg ha^{-1} $year^{-1}$ and daily mean temperature is shown in Figures 3a and 3b for 1994 and 1995, respectively. Maximum turfgrass growth occurred during the month of June in both years. Clipping production decreased markedly at the end of June and rebounded in mid-July only to decline in August. An additional growth peak occurred in 1995 in response to high temperatures in August. Nitrogen applied at 250 kg ha^{-1} $year^{-1}$ increased clipping yield. Clipping production for the seasons were 121 and 228 gm m^{-2} in 1994 and 125 and 220 gm m^{-2} in 1995 for the low and high nitrogen regimes, respectively.

The influence of nitrogen fertility level and three plant growth regulators each applied at three rates on clipping production was analyzed as a multifactorial design. Main effects are reported in Figures 4 to 6 as less than 20 percent of the observation dates had significant interactions. Clipping production of a creeping bentgrass fairway as affected by nitrogen regime, averaged over PGR and PGR rate, is shown in Figures 4a and 4b for 1994 and 1995 for the 125 and 250 kg N ha^{-1} $year^{-1}$ regimes, respectively. On a percentage basis clipping production was reduced similarly by the three PGRs at both

Figure 3a: Clipping production of an unregulated creeping bentgrass fairway as affected by two nitrogen regimes of 125 and 250 kg ha^{-1} $year^{-1}$ and daily mean temperature. Arrows on the x-axis indicate fertilization dates for 1994.

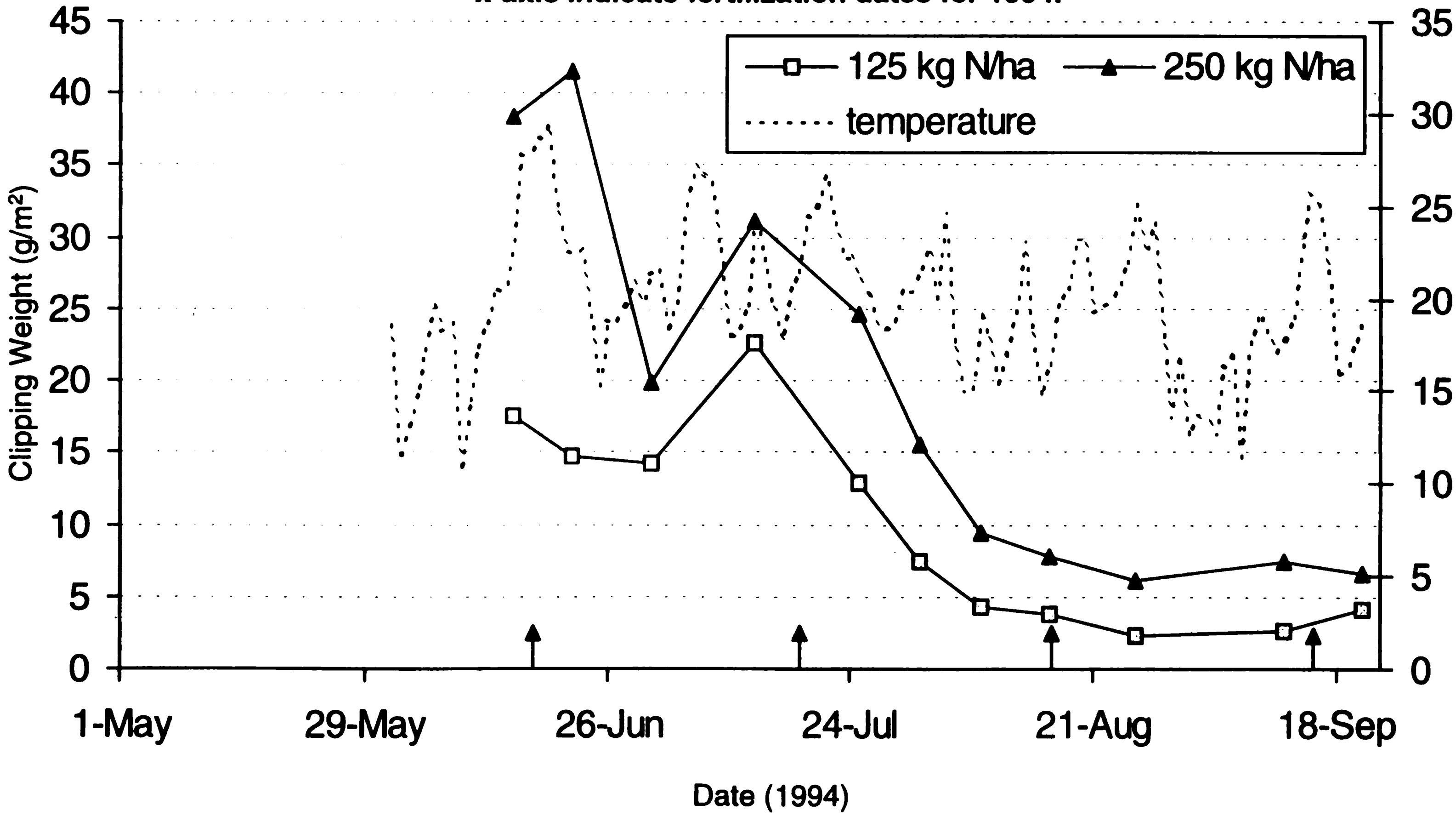


Figure 3b: Clipping production of an unregulated creeping bentgrass fairway as affected by two nitrogen regimes of 125 and 250 kg ha^{-1} year^{-1} and daily mean temperature.

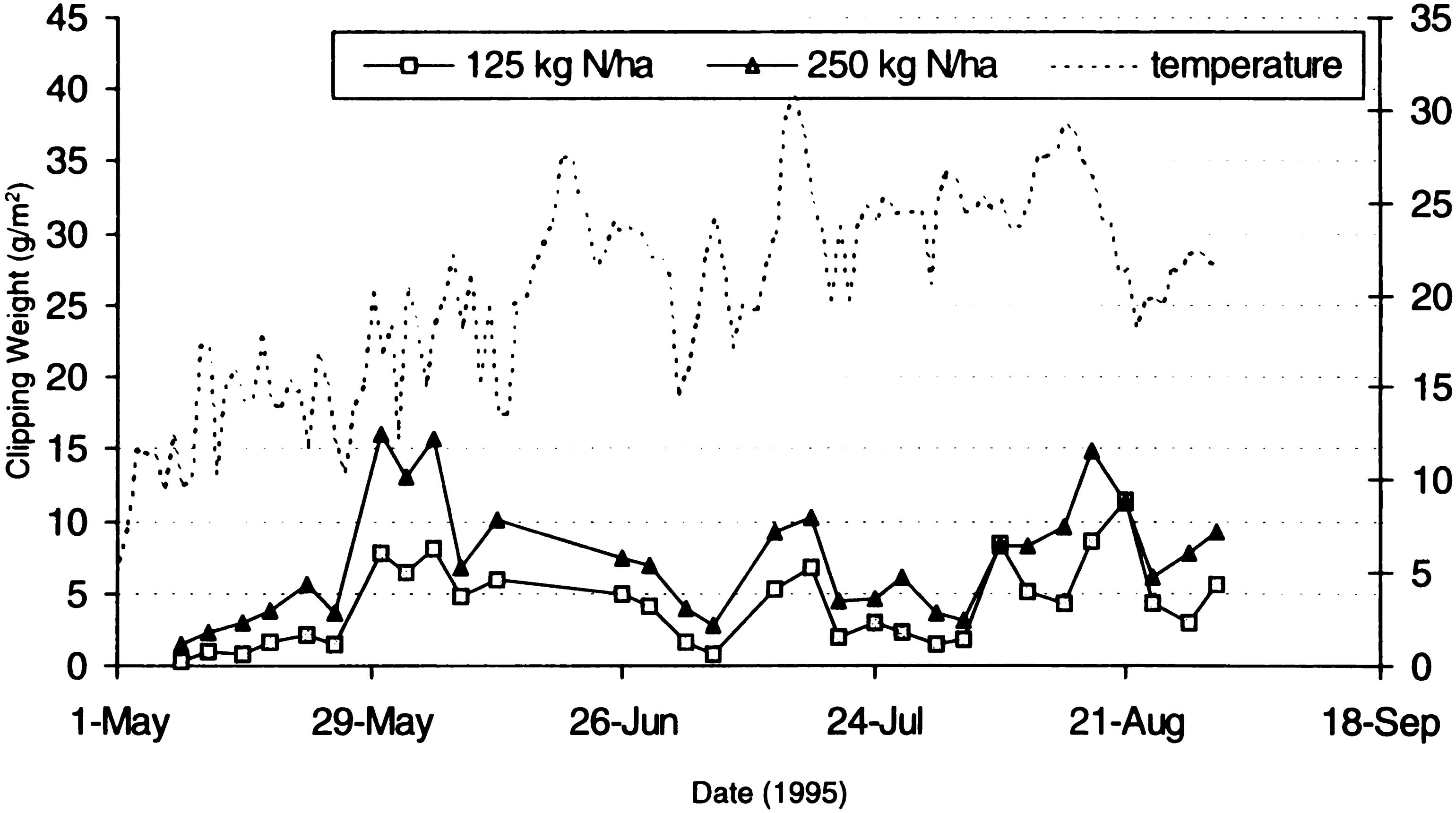


Figure 4a: Clipping production of a creeping bentgrass fairway as affected by the main effect of nitrogen.

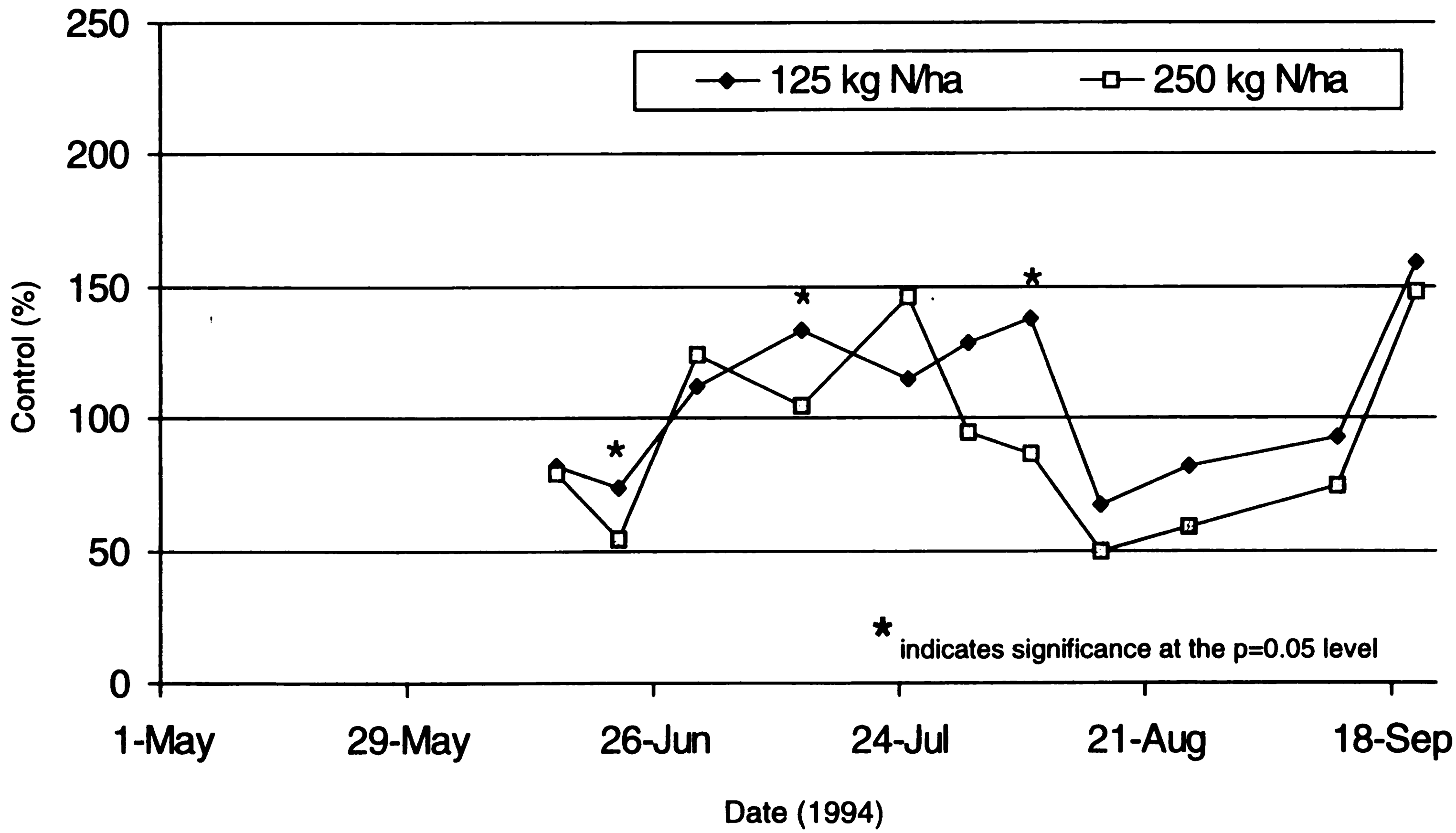
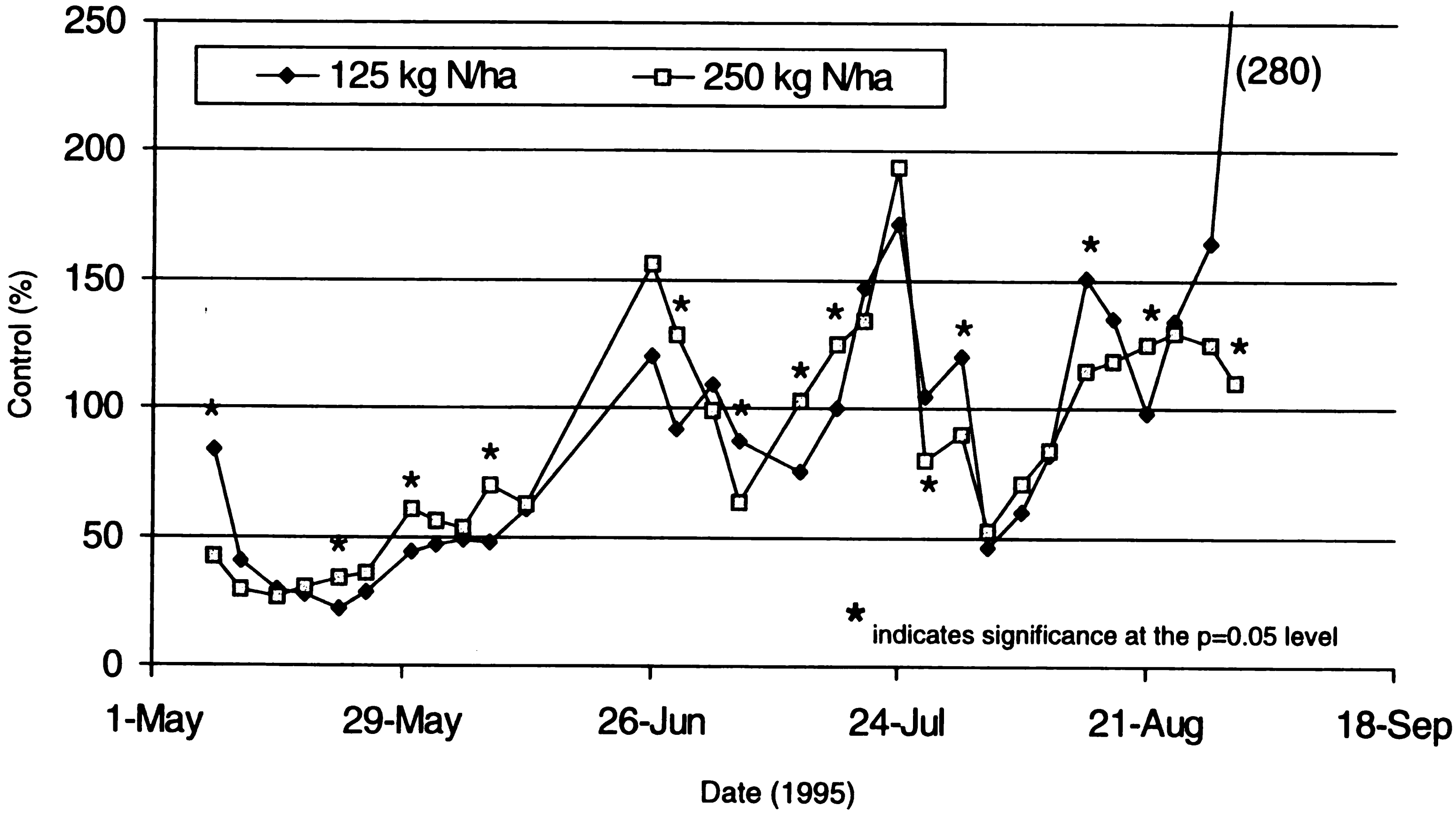


Figure 4b: Clipping production of a creeping bentgrass fairway as affected by the main effect of nitrogen.



nitrogen regimes. However, for the entire 1994 season, a greater percentage reduction was observed for the 250 kg N ha^{-1} $year^{-1}$ regime than the 125 kg N ha^{-1} $year^{-1}$ regime. The short period of growth reduction (<28 days) in 1994 was attributed to the monthly application of nitrogen that was applied 14 days after the PGR treatments. Nitrogen applications were made two weeks after each PGR treatment and coincided with the observed growth surge in the PGR treated plots.

In 1995, PGRs provided more growth reduction for the 125 kg N ha^{-1} $year^{-1}$ regime than the 250 kg N ha^{-1} $year^{-1}$ regime. Growth reduction from PGR treatment was again followed by a growth surge, although nitrogen applications were made weekly in 1995.

PGRs were effective at reducing clipping production on both low and high nitrogen regimes. The effect of PGR, averaged over nitrogen regime and PGR rate, on clipping production of a creeping bentgrass fairway is shown in Figures 5a and 5b for 1994 and 1995, respectively. In 1994, all three PGRs provided similar levels of growth reduction. There were periods of growth reduction observed after the first and third PGR application date. However, there was no reduction from the second PGR application. Periods of growth reduction were followed by a growth surge when the clipping production of PGR treated turfgrass plots exceeded the production of the control plots.

Creeping bentgrass treated with PGRs in 1995 followed the same trend of growth reduction followed by growth surge. The maximum growth reduction was observed after the first PGR application and lasted 4 to 6 weeks. No additional reduction was realized from the second PGR application and by the third application date the clipping

Figure 5a: Clipping production of a creeping bentgrass fairway as affected by the main effect of plant growth regulator.

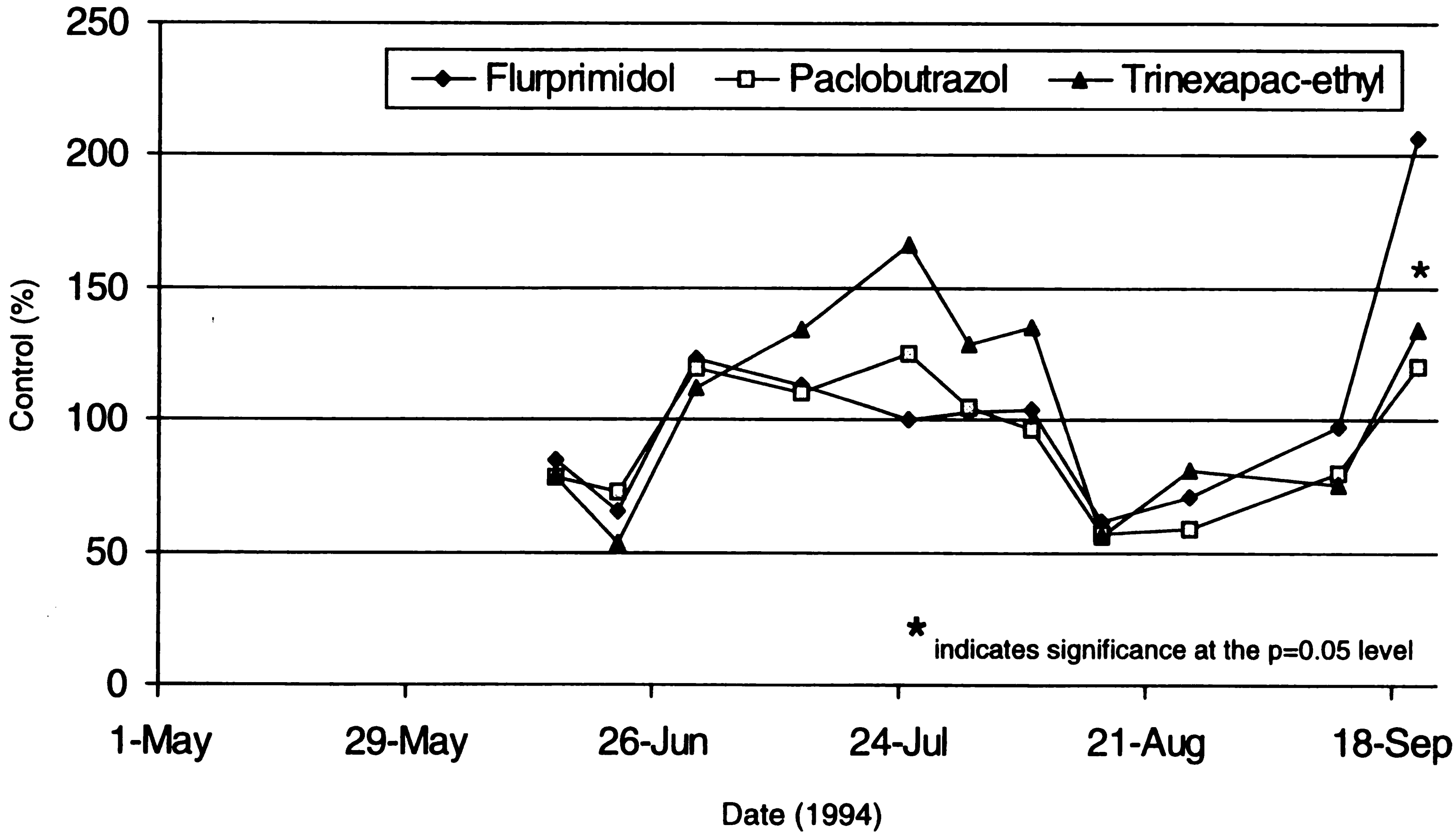
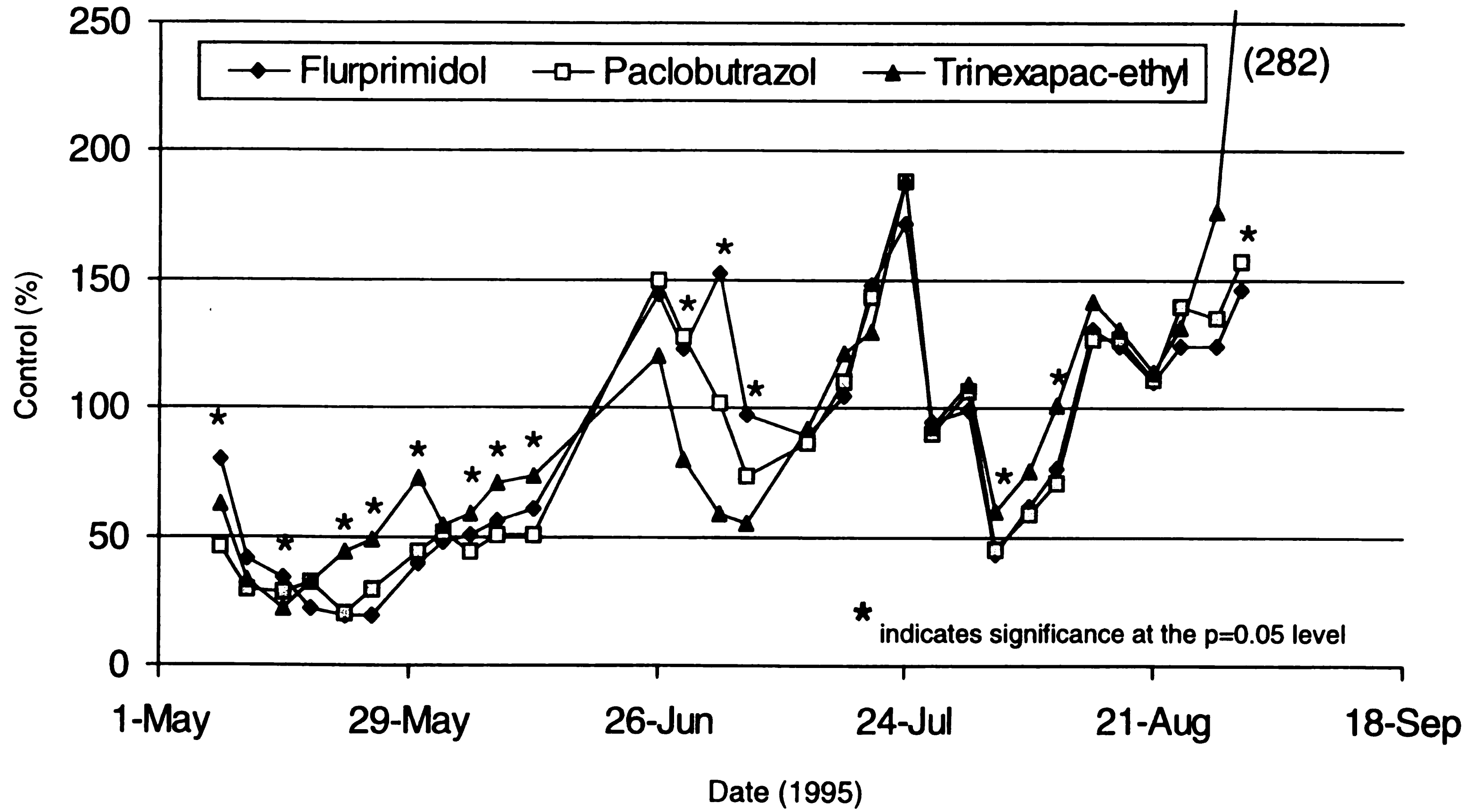


Figure 5b: Clipping production of a creeping bentgrass fairway as affected by the main effect of plant growth regulator.



production from all plots treated with PGRs exceeded the production of control plots. A short period of growth reduction followed the third PGR application but the growth again rebounded and exceeded that of the controls. PGR treatments from the fourth application caused the same pattern of growth reduction and growth surge.

The effect of PGR rate, averaged over PGR type and nitrogen regime, on clipping production of a creeping bentgrass fairway is shown in Figures 6a and 6b for 1994 and 1995, respectively. The highest (1X) rate caused the greatest growth reduction in 1994. The PGRs at the lowest two rates did not reduce the amount of clippings produced as compared to the control in 1994. The PGRs at the highest rate were also most effective at reducing clipping production in 1995, but the reduction of clipping production was lost to an increase in the rebound amplitude for the plots receiving the high PGR rate. The PGR treatments causing the greatest reduction of clipping weight also exhibited the largest rebound peaks during the growth surges.

Following the first PGR application in 1995, differences in duration of the growth reduction period were observed. The PGRs applied at the 0.5 and 1X rates reduced clipping weight >50 percent for six weeks where the PGRs applied 0.25X rate reduced clipping weight >50 percent for four weeks. Greater separation of clipping production between PGR rates existed in 1994 than in 1995. PGRs at the 1X rate provided more growth reduction than the other rates. Differences in growth reduction from PGR rate were only observed after the first PGR application. No differences in growth reduction were evident from PGR rate after the first PGR application in either year.

Figure 6a: Clipping production of a creeping bentgrass fairway as affected by the main effect of rate averaged over PGR and nitrogen.

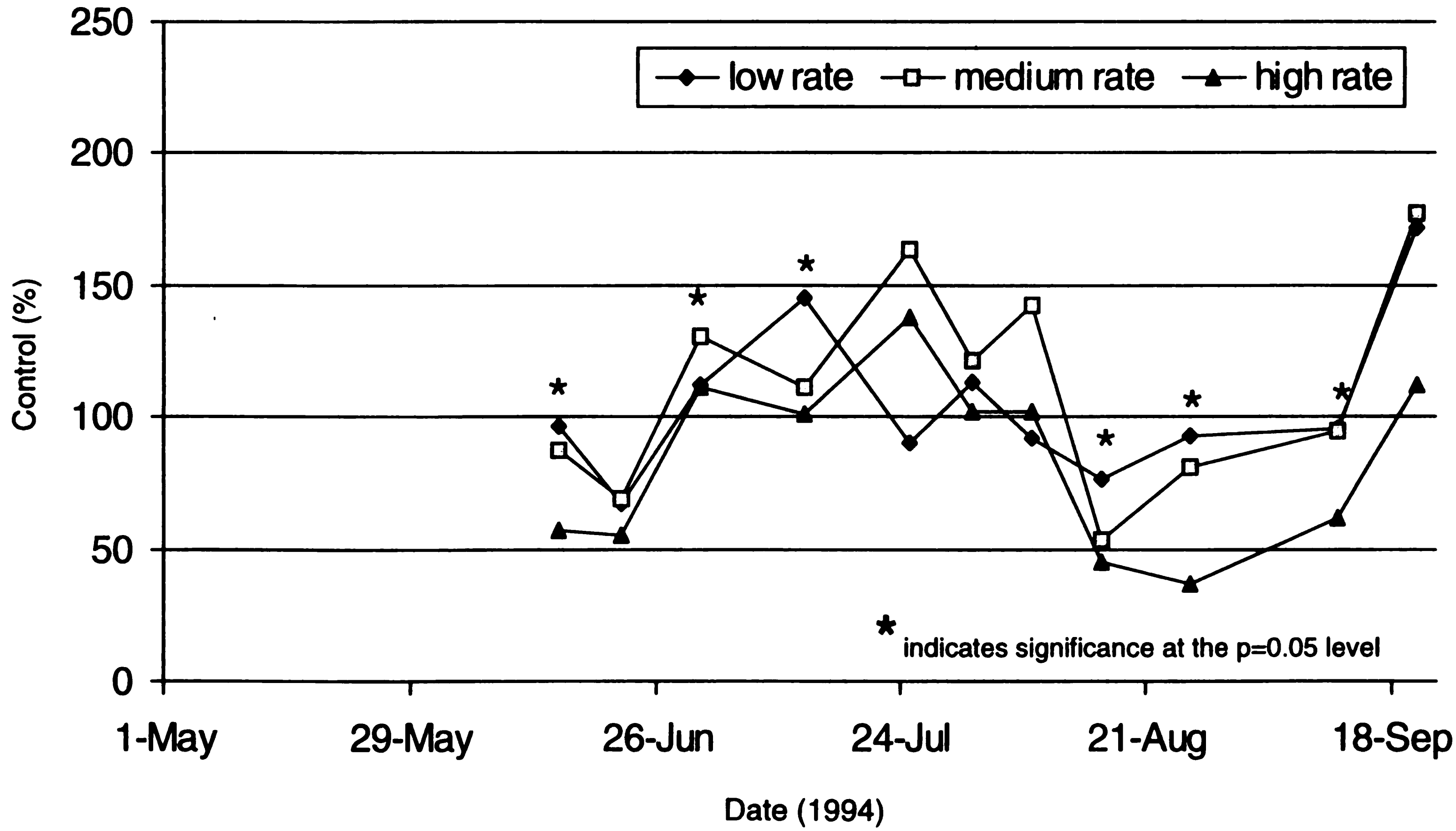
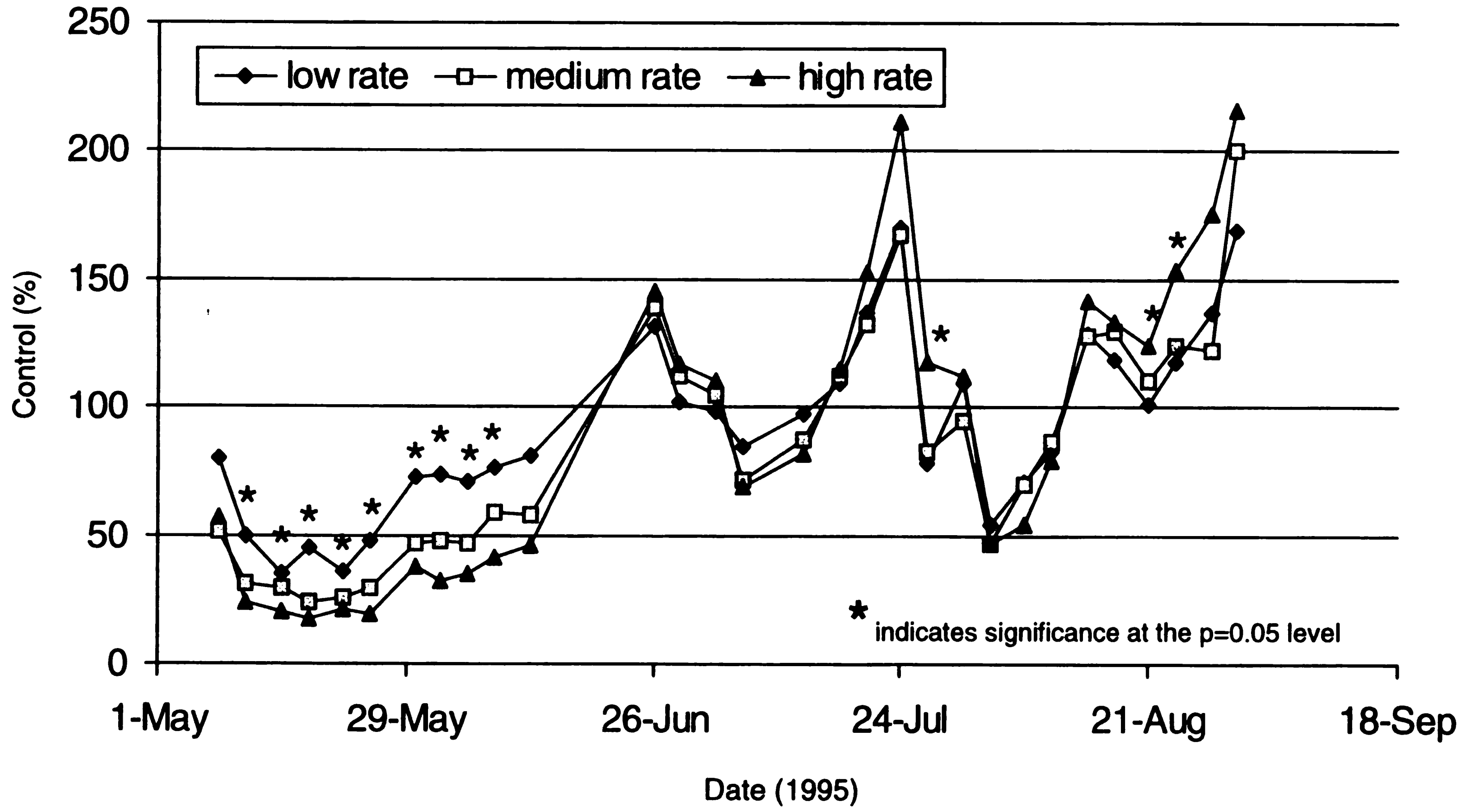


Figure 6b: Clipping production as affected by the main effect of rate averaged over PGR and nitrogen.



It is possible that the growth surge could be a side effect of PGR treatment and not solely attributable to nitrogen fertilization. One explanation is while PGRs inhibit specific sites of gibberellin biosynthesis, the formation of GA_1 precursors most likely continues. These precursors, if not broken-down or translocated, may accumulate in the GA biosynthesis pathway. When the PGRs no longer inhibit gibberellin biosynthesis, abnormally high concentrations of GA_1 could result. GA_1 is usually found in very small amounts in the plant. PGR treatment is not considered to affect carbohydrate production in the plant. With an adequate carbohydrate source, higher than normal levels of GA_1 could lead to greater cell elongation and increased clipping production. The consistent presence and increasing amplitude of this growth surge or rebound may indicate that the production of carbohydrates and gibberellin biosynthesis precursors continues during foliar growth reduction. These products may not necessarily be redistributed through the plant during foliar growth reduction. On the contrary, it appears that sugars and GA precursors are accumulating in the plant during the growth reduction period and then cause a growth surge when the inhibition wears off. Clipping production for a given treatment period is then redistributed in time, counteracting some of the reduction effects with subsequent growth surges.

When analyzing the data on a growth reduction basis (percent of control), growth reduction was greater on the high nitrogen plots in 1994, but in 1995 the opposite was true (Table 2). There was no statistical difference between the effect of PGRs on clipping production in 1994, but in 1995 turf treated with flurprimidol and paclobutrazol displayed greater growth reduction than turf treated with trinexapac-ethyl. Finally, the

Table 2: The influence of nitrogen regime, PGR type, and PGR rate on cumulative growth reduction of a creeping bentgrass fairway.

Main Effect	1994	1995
	—% of control—	
125 kg N/ha[1]	101.6 b[4]	83.2 a
250 kg N/ha	83.5 a	89 b
Flurprimidol[2]	91.6 a	82.6 a
Paclobutrazol	90.7 a	82.9 a
Trinexapac-ethyl	95.4 a	92.7 b
Low Rate[3]	98.5 b	88.2 a
Medium Rate	99.6 b	83.7 a
High Rate	79.6 a	86.3 a

[1] Low and high nitrogen effect averaged over PGR type and PGR rate.
[2] PGR type effect averaged over nitrogen regime and PGR rate.
[3] PGR rate effect averaged over nitrogen regime and PGR type.
[4] Means followed by the same letter are not different according to Fisher's Protected LSD at the 0.05 significance level. Do not compare means across main effects.

growth reduction response to PGR rate showed that in 1994 the high rate was needed for maximum seasonal growth reduction whereas in 1995 all treatments elicited the same response. This illustrates the effect of the growth rebound since the high PGR rate reduced growth more than the other treatments but also had a greater growth surge.

Creeping bentgrass treated with plant growth regulators can provide growth reduction for 4 to 6 weeks after the initial application on either low or high nitrogen regimes. The growth reduction benefits of repeat applications of PGRs on 28 day spacing are minimal. These additional applications of PGRs reduce clippings of a creeping bentgrass fairway for only a short time followed by a growth surge where the clipping production of PGR treated turfgrass exceeds the clipping production of turfgrass in the control plots. On a seasonal basis the growth surge that occurs from PGR applications counteracts some of the growth reduction that was earlier realized. This rebound in growth was initially attributed to nitrogen applications but when nitrogen was applied weekly instead of monthly the rebound in growth was still evident and determined to be an effect of PGR application. Creeping bentgrass treated with PGRs applied at the full label rate displayed the greatest growth reduction. However, the turfgrass in these plots also experienced the largest growth rebound peaks. Future studies should examine the rebound growth of creeping bentgrass from application of Type II PGRs. These studies could incorporate shorter PGR application intervals (<28 days) using full and sub-label rates. The current understanding PGRs suggests that while cell elongation is reduced from PGR application, secondary plant growth processes are enhanced. This may be true, but the data from this study indicate that sugars and GA_1

precursors may be accumulating during the inhibition period and are not being used elsewhere in the plant or breaking down. When the PGR no longer functions to stop gibberellin biosynthesis, the large store of precursors in the pathway generate a greater growth rate than before inhibition occurred.

The clipping production of a PGR treated turf for the season, is then very similar to the clipping production of turfgrass that did not receive PGR treatment. This is illustrated by the >50 percent growth reduction for four weeks after the first PGR application in 1995. However, growth reduction for the season is not dramatic. Although the clipping weights for the season are not reduced, there could still be benefits to be realized from PGR treatment.

Depending on the objective, PGRs may or may not be a cost effective management tool for creeping bentgrass fairways. If clipping reduction is the main objective then maximum growth suppression is desired. Reduced clipping production would lower the labor and handling costs. Reduced clipping production would also decrease the time required to mow fairways. The operator would not have to empty the buckets as often and could mow more area before needing to dispose of the collected clippings. The maximum turf growth occurs in the spring. PGRs appear to be very effective when applied at this time. However, growth surges that occur during the summer appear to negate clipping reduction from earlier in the season. A growth surge may not necessarily be detrimental to the objective. Turf growth is less rapid in the summer. A more vigorous growth rate in the summer when the controls are growing slowly, will increase turfgrass tolerance to disease and wear.

Maximum growth reduction, for the purpose of reduced mowing frequency or reduced clipping disposal, may be difficult to consistently attain with multiple applications of PGRs. Reducing growth in order to return clippings to the turf is perhaps a more attainable objective. The amount of growth reduction necessary to work clippings into the turf would be less than that required to reduce mowing frequency. Daily turf growth may be reduced by PGRs so that the amount of clippings returned to the turf does not interfere with playability. Growth surges that follow growth suppression would not necessarily violate this objective. Growth at 200 percent of control would be irrelevant if the clipping production remained below the tolerance threshold. If the clippings produced did not interfere with playability, returning clippings to the turf would equate to significant labor savings. The operator could remain on the mower during the time that was previously spent emptying mower buckets. Using PGRs in order to return clippings to the turf may be a more achievable goal.

Whether using PGRs for clipping disposal reduction or to allow re-incorporation of clippings to the turf, well defined objectives will help to determine the success of the PGR program.

Turfgrass Quality

The effects of three plant growth regulators, averaged over nitrogen regime and PGR rate, on quality ratings of a creeping bentgrass fairway are given in Table 3 for 1994 and 1995. The effects of increased nitrogen on turfgrass quality were always evident and are not reported. The enhancement of turfgrass quality from PGR applications that has been reported by other researchers was observed in this study. However, the injury

Table 3: The effect of three plant growth regulators on a creeping bentgrass fairway.

PGR	1994	1995
	—% of control—	
Flurprimidol	104.9 ab[1]	113.7 a
Paclobutrazol	100.1 b	111.5 a
Trinexapac-ethyl	108.3 a	113.1 a

[1] Means followed by the same letter are not different according to Fisher's Protected LSD at the 0.05 significance level.

associated with PGR treatments was subtle. Turfgrass treated with trinexapac-ethyl had significantly higher quality for 1994 than the turfgrass in the controls or the paclobutrazol treated plots. All PGRs positively enhanced turfgrass quality in 1995. Quality ratings were regressed against clipping production to check for a correlation between low quality and growth reduction. There was not a strong relationship between these two sets of observed data (r=0.48, 1994)(r=0.43, 1995).

Divot Closure

The effect of the interaction of nitrogen regime, plant growth regulator, and rate on divot closure rate of a creeping bentgrass fairway is shown in Table 4 for 1994 and 1995. Nitrogen at the 250 kg ha^{-1} $year^{-1}$ regime accelerated divot closure rate of the control plots by an average of ten days in both years on all divots observed. The effects of PGRs was generally more dramatic on the divot closure rate of the turfgrass receiving 125 kg N ha^{-1} $year^{-1}$. Although inhibition of divot closure from PGR was hypothesized, this was not observed in 1994. Divot closure rate was similar to the control for all treatment combinations in 1994. Large differences among PGR treatments on divot closure rate were not evident. Creeping bentgrass treated with the 0.25 and 0.5X rates of flurprimidol and the 0.5X rate of paclobutrazol displayed the fastest divot closure rate for 1994. Two sets of divots were made in 1995, one set of four divots after the first and second PGR applications. Turfgrass treated with PGRs displayed some inhibition of divot closure rate in 1995. Divots made on turfgrass treated with trinexapac-ethyl provided the most consistent divot recovery results in 1995. The divot closure rate of trinexapac-ethyl treated turf was no different (1st set) or slightly faster (2nd set) than the divot closure rate

Table 4: The effect of the interaction of nitrogen regime, PGR type, and PGR rate on divot closure rate of a creeping bentgrass fairway.

PGR	Rate	1994		1995 1st set		1995 2nd set	
	kg ha^{-1}	Low N	High N	Low N	High N	Low N	High N
		days to 90% divot closure					
Control		34	23	34	25	42	30
Flurprimidol	0.28	27	24	38	27	45	32
Flurprimidol	0.42	29	24	46	28	45	33
Flurprimidol	0.56	32	25	43	34	45	38
Paclobutrazol	0.07	31	23	34	27	36	29
Paclobutrazol	0.14	28	25	38	32	45	33
Paclobutrazol	0.28	34	25	53	34	46	34
Trinexapac-ethyl	0.05	33	22	40	26	41	26
Trinexapac-ethyl	0.1	33	19	34	24	38	28
Trinexapac-ethyl	0.2	32	22	36	27	36	32
LSD (p=0.05)		5		6		6	

of the controls. The divot closure rate of turfgrass treated with the 0.5 and 1X rate of flurprimidol and paclobutrazol was slower for the first set than the second set of divots in 1995. The divot closure rate of turfgrass in the control plots for the second set of divots was slower than the divot closure rate of turfgrass in the control plots for the first set of divots by 5 to 10 days. The inhibitory effect of flurprimidol on divot closure rate that was observed in the first set of divots was only present at the 1X rate in the 250 kg N ha-1 year-1 regime. No inhibition of divot closure rate was seen on turfgrass treated with paclobutrazol on the second set of divots in 1995.

PGRs did not inhibit divot closure rate as much as had been expected. Although divot closure rate of turfgrass treated with flurprimidol and paclobutrazol displayed some delay in divot closure in 1995, divot recovery rate of turfgrass treated with both products was enhanced in 1994. Divot closure rate of the creeping bentgrass, in general, was not inhibited by PGR treatment. It was initially thought that divots made during growth reduction would be obvious for a longer period of time. This would allow a longer window for weed encroachment and a disruption to the playability of the turfgrass. The creeping bentgrass turf treated with PGRs did not effect the divot closure rate for 1994. The 1X rate of flurprimidol and paclobutrazol delayed divot closure in 1995 on the first set of divots. Trinexapac-ethyl did not change divot closure rate from the control plots for either set of divots in 1995. Statistical differences in divot closure rate do not necessarily indicate biological significance. The additional number of days required to allow weed encroachment may be greater than that observed in this study. Inhibition of divot closure from Type II PGRs on creeping bentgrass may not be a great concern to the turfgrass practitioner.

Wear Tolerance

The effect of plant growth regulator treatment and nitrogen regime on wear tolerance of a creeping bentgrass fairway is shown in Table 5 for 1995. Wear can affect turf quality by reducing density and vigor. Quality ratings were used to evaluate wear damage. In this scale a 1=dead, 5=acceptable, and 9=excellent. Quality ratings for creeping bentgrass that did not receive PGR application under wear conditions were increased to acceptable levels under the 250 kg N ha^{-1} $year^{-1}$ regime. Trinexapac-ethyl was the only PGR treatment that resulted in acceptable turfgrass quality ratings on the low nitrogen regime. The turfgrass quality values under the low nitrogen regime were similar to those under the high nitrogen regime for those plots treated with trinexapac-ethyl. Creeping bentgrass treated with the 0.5X rate of flurprimidol and paclobutrazol and all rates of trinexapac-ethyl displayed acceptable turfgrass quality in the high fertility regime. Turfgrass quality under the high nitrogen regime was not statistically different from the high nitrogen control. Wear tolerance of creeping bentgrass was not enhanced by the application of flurprimidol or paclobutrazol. Both products decreased turfgrass quality observed on the low nitrogen regime although it was not always statistically different from the control plots. All plots treated with trinexapac-ethyl displayed acceptable turfgrass quality. Flurprimidol treated plots exhibited higher quality ratings at the 250 kg N ha^{-1} $year^{-1}$ regime. Nitrogen fertilization did not affect the quality trinexapac-ethyl treated creeping bentgrass.

Table 5: The effect of plant growth regulator treatment and nitrogen regime on wear tolerance of a creeping bentgrass fairway.1995

PGR	Rate	Low N	High N
	$kg\ ha^{-1}$	——Quality Index[1]——	
Control		4.3	5.0
Flurprimidol	0.28	3.1	4.2
Flurprimidol	0.42	1.4	5.1
Flurprimidol	0.56	1.8	4.0
Paclobutrazol	0.07	3.3	4.7
Paclobutrazol	0.14	4.4	5.3
Paclobutrazol	0.28	3.1	4.7
Trinexapac-ethyl	0.05	5.1	5.7
Trinexapac-ethyl	0.1	6.3	5.7
Trinexapac-ethyl	0.2	5.5	5.5
LSD (p=0.05)		1.5	

[1] Quality rating taken on 1-9 scale where 1=dead, 9=excellent, and 5=acceptable.

Disease Activity

The fungal disease Dollar Spot (*Sclerotinia homoeocarpa*) was very active in 1995. Casual observations were made of dollar spot incidence. As would be expected, the number of centers of infection of dollar spot were dramatically reduced for plots in the high nitrogen regime (Table 6). However, PGR treatment also reduced the severity of dollar spot infestation as compared to the control plots. The greatest reduction of number of dollar spot lesions was observed on turfgrass treated with paclobutrazol. The fungicidal activity of flurprimidol and paclobutrazol can be related to their chemical structures. There are several different chemistries that yield sterol biosynthesis inhibition. Examples of sterol inhibiting compounds are pyridines, pyrimidines, imidazoles, and 1,2,4-triazoles. Flurprimidol and fenarimol, a commercial fungicide, are pyrimidine compounds. The 1,2,4-triazole chemistry, which includes paclobutrazol, includes commercial fungicides triadimefon and propiconazole. The relationship between these PGRs and sterol inhibiting fungicides is clearly shown in their chemical structures and fungicidal activity.

Table 6: The effect of plant growth regulator treatment and nitrogen regime on number of centers of dollar spot infection on a creeping bentgrass fairway. 1995

PGR	Rate	Season Average Low N	Season Average High N
	$kg\ ha^{-1}$	number per plot	
Control		75	24
Flurprimidol	0.28	53	20
Flurprimidol	0.42	37	20
Flurprimidol	0.56	29	13
Paclobutrazol	0.07	48	27
Paclobutrazol	0.14	41	21
Paclobutrazol	0.28	13	8
Trinexapac-ethyl	0.05	50	35
Trinexapac-ethyl	0.1	55	28
Trinexapac-ethyl	0.2	51	23
LSD (p=0.05)		17	

APPENDIX

Figure A: Clipping production as affected by flurprimidol at three rates where nitrogen regime is 125 kg N ha^{-1} $year^{-1}$.

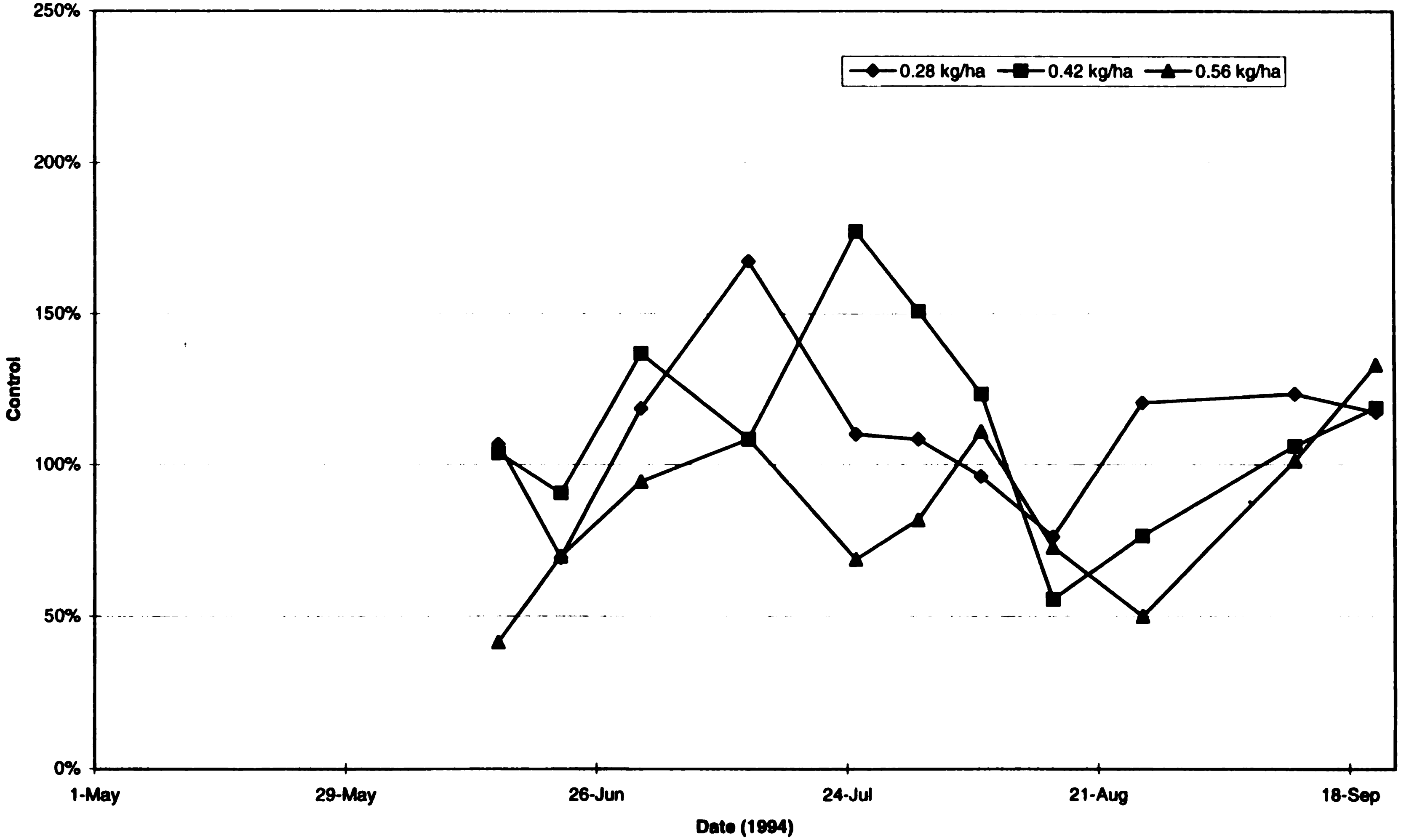


Figure B: Clipping production as affected by paclobutrazol at three rates where nitrogen regime is 125 kg N ha^{-1} $year^{-1}$.

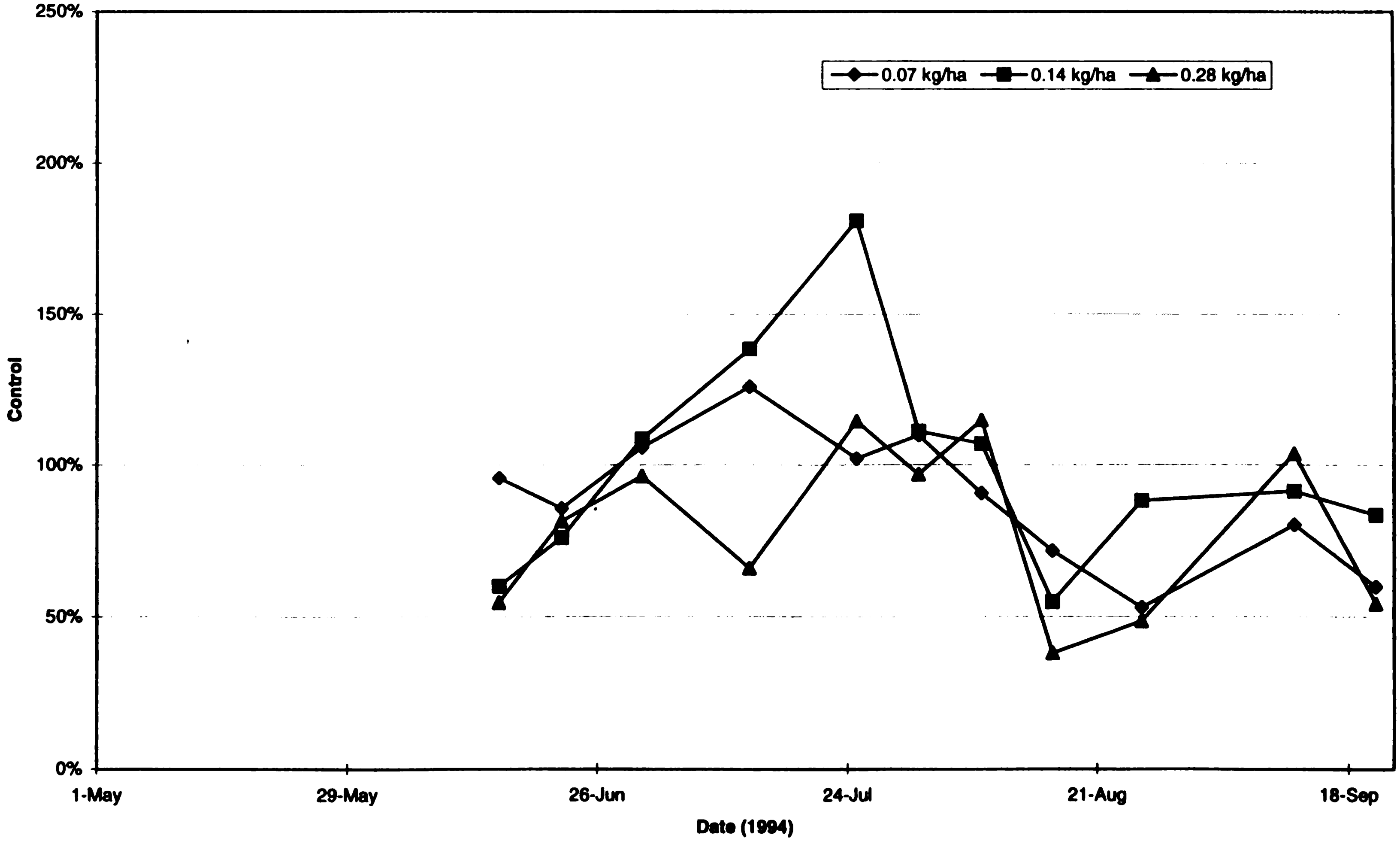


Figure C: Clipping production as affected by trinexapac-ethyl at three rates where nitrogen regime is 125 kg N ha^{-1} $year^{-1}$.

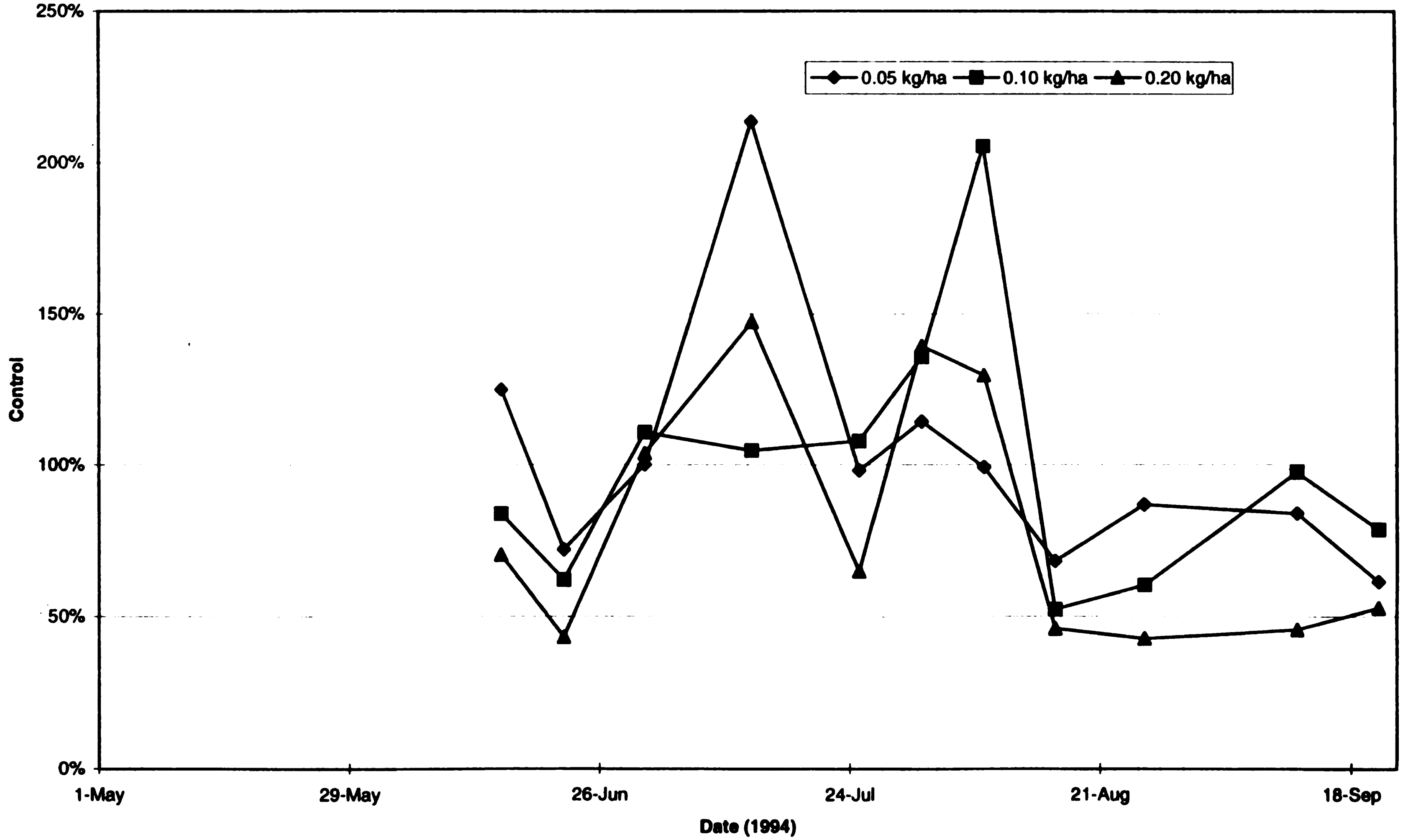


Figure D: Clipping production as affected by flurprimidol at three rates where nitrogen regime is 250 kg N ha^{-1} $year^{-1}$.

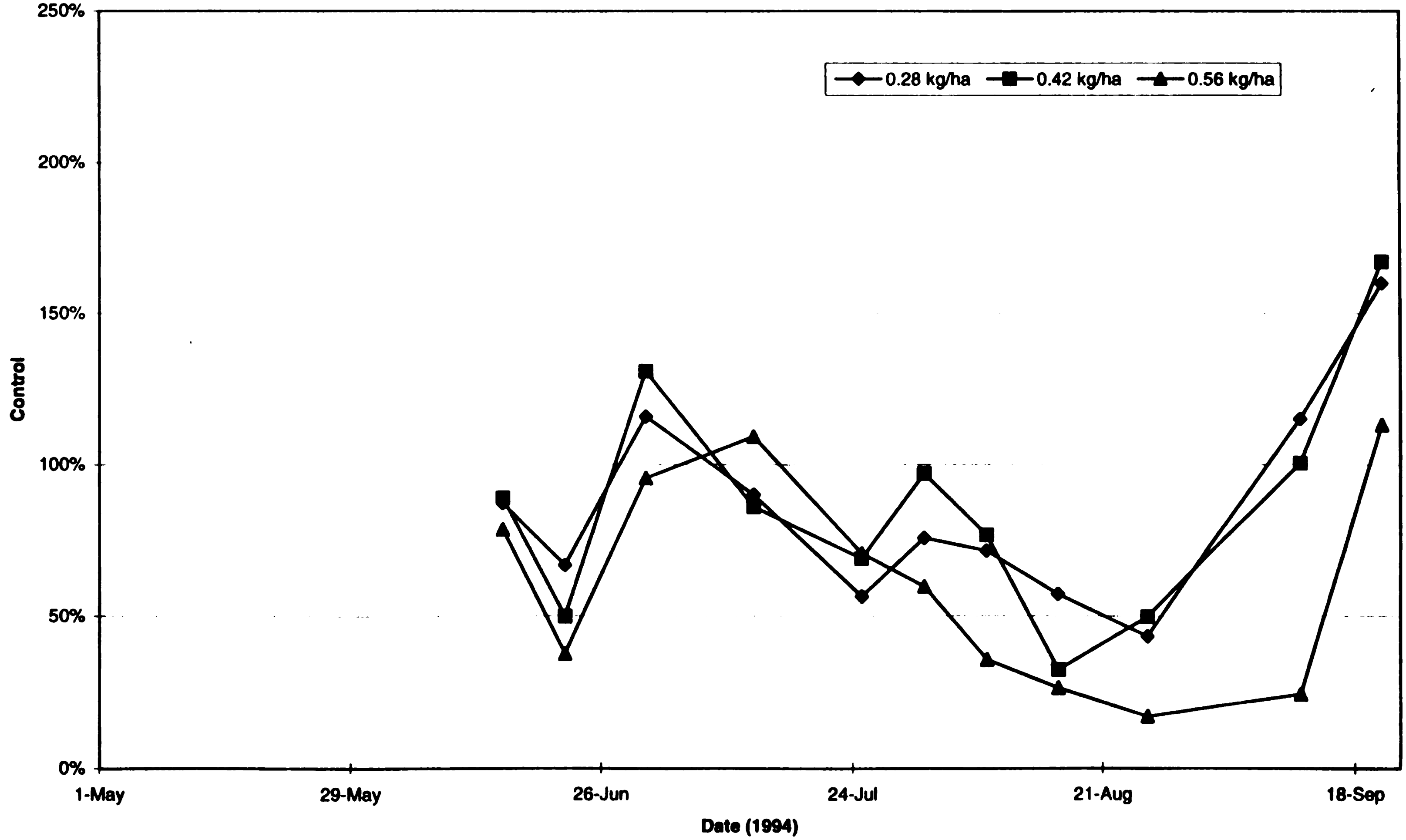


Figure E: Clipping production as affected by paclobutrazol at three rates where nitrogen regime is 250 kg N ha^{-1} $year^{-1}$.

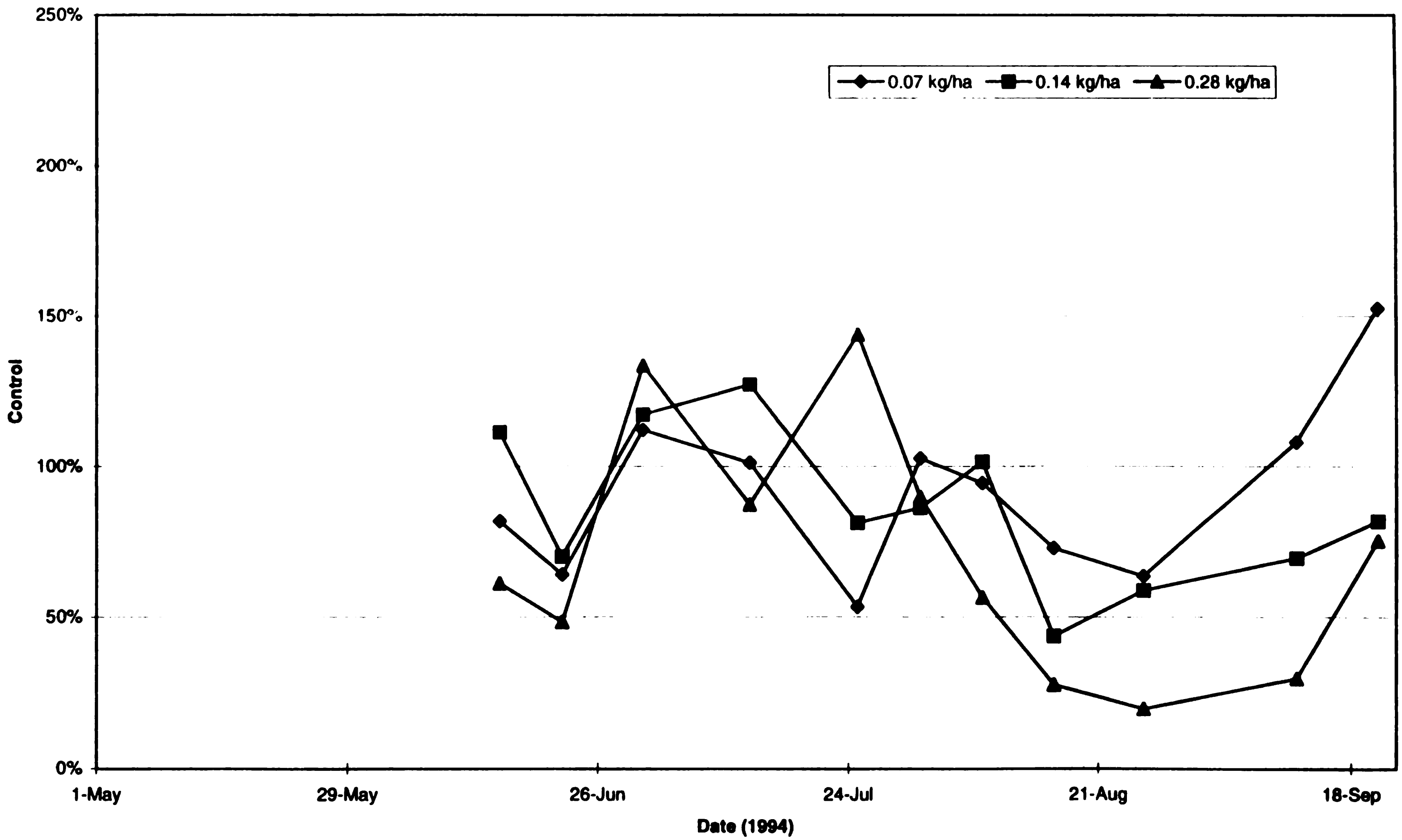


Figure F: Clipping production as affected by trinexapac-ethyl at three rates where nitrogen regime is 250 kg N ha^{-1} $year^{-1}$.

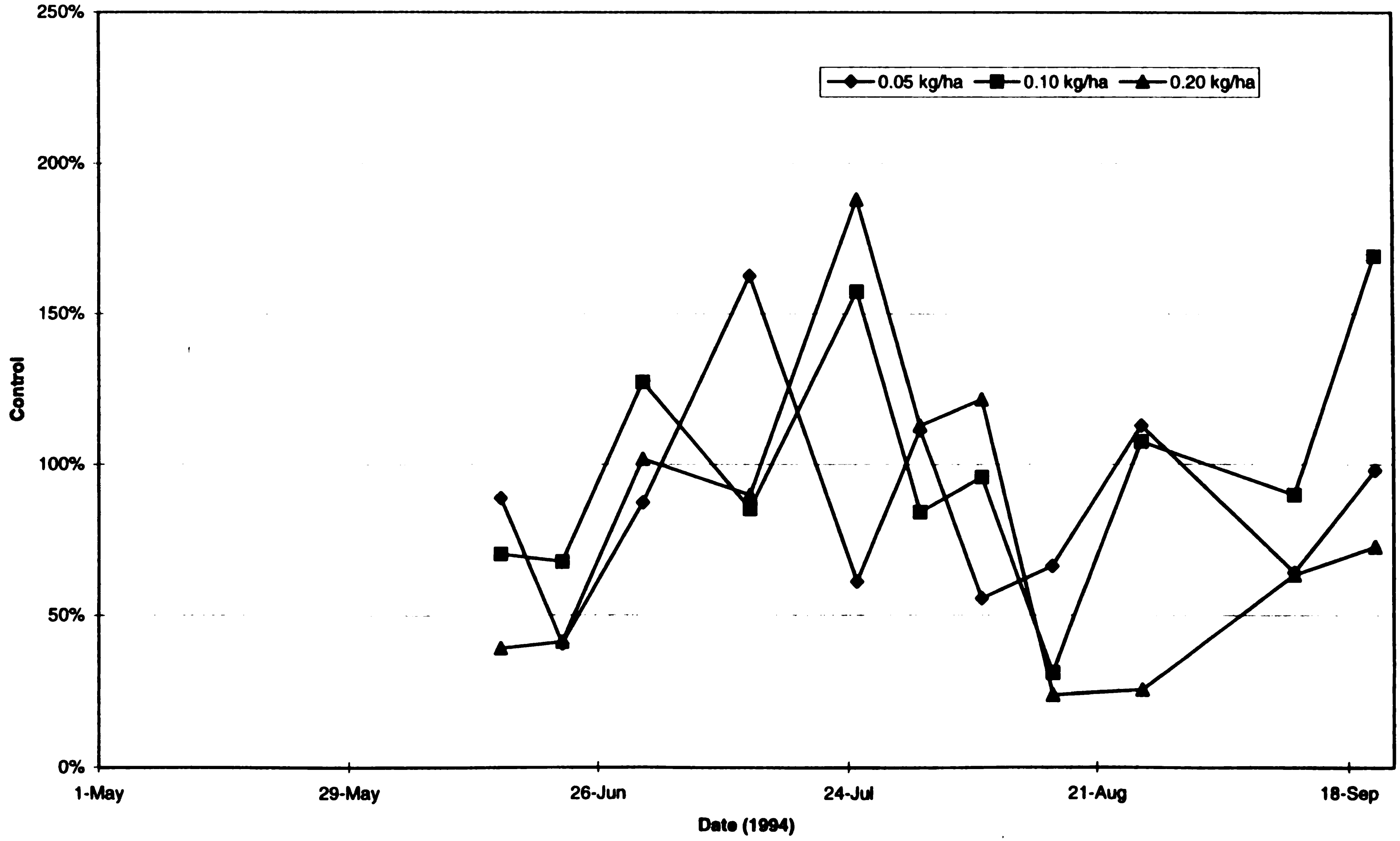


Figure G: Clipping production as affected by flurprimidol at three rates where nitrogen regime is 125 kg ha^{-1} year^{-1}.

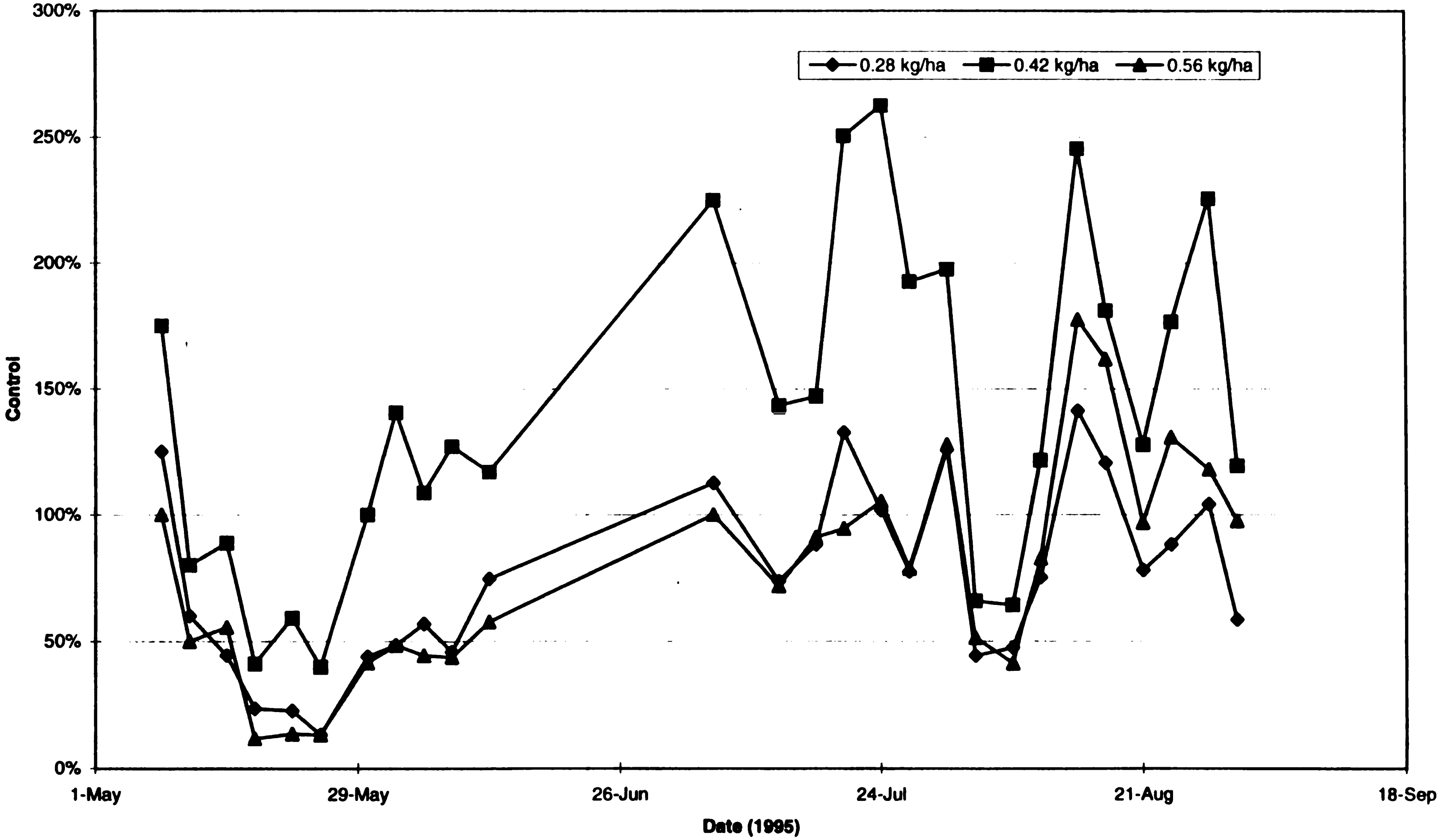


Figure H: Clipping production as affected by paclobutrazol at three rates where nitrogen regime is 125 kg ha^{-1} $year^{-1}$.

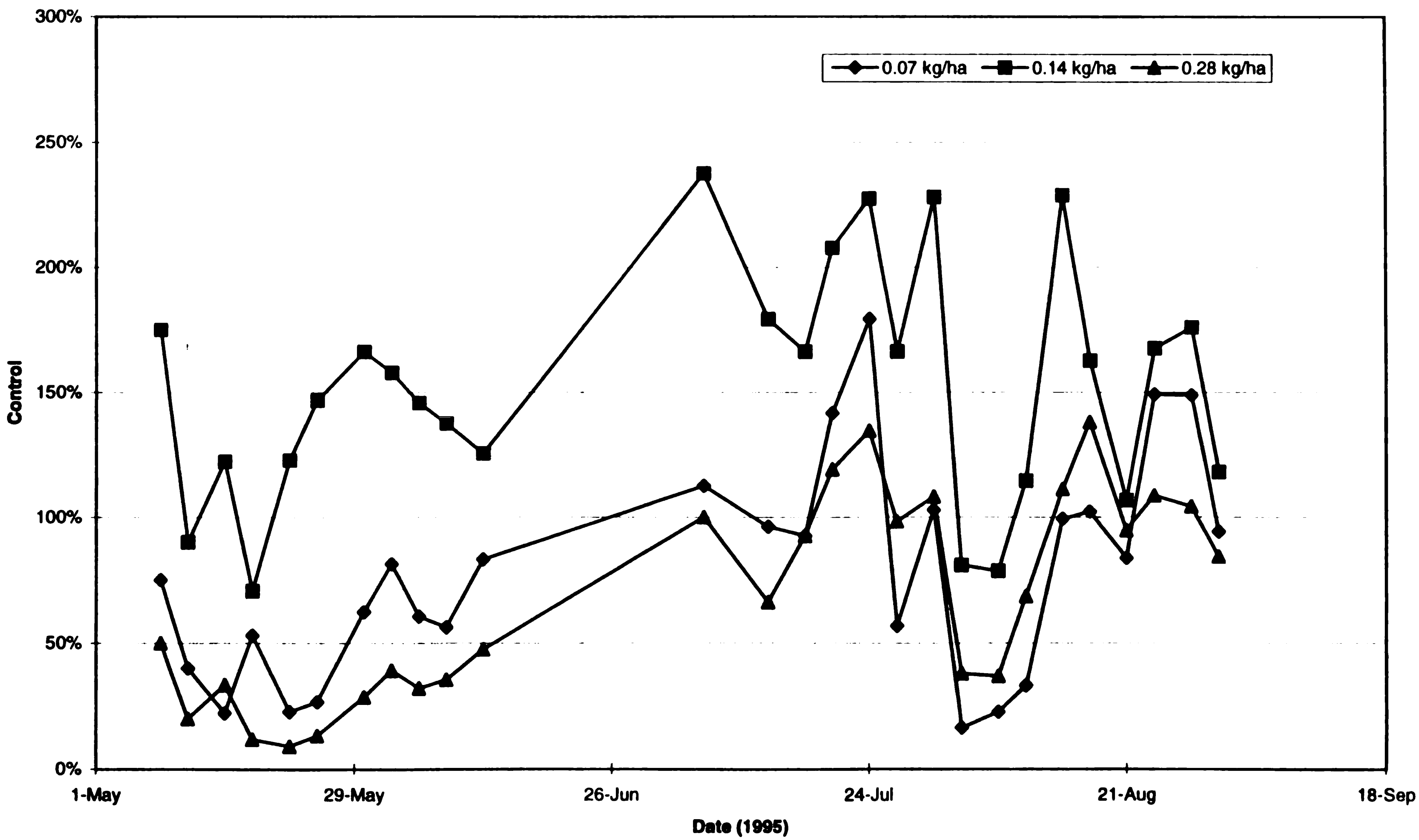


Figure I: Clipping production as affected by trinexapac-ethyl at three rates where nitrogen regime is 125 kg ha^{-1} $year^{-1}$.

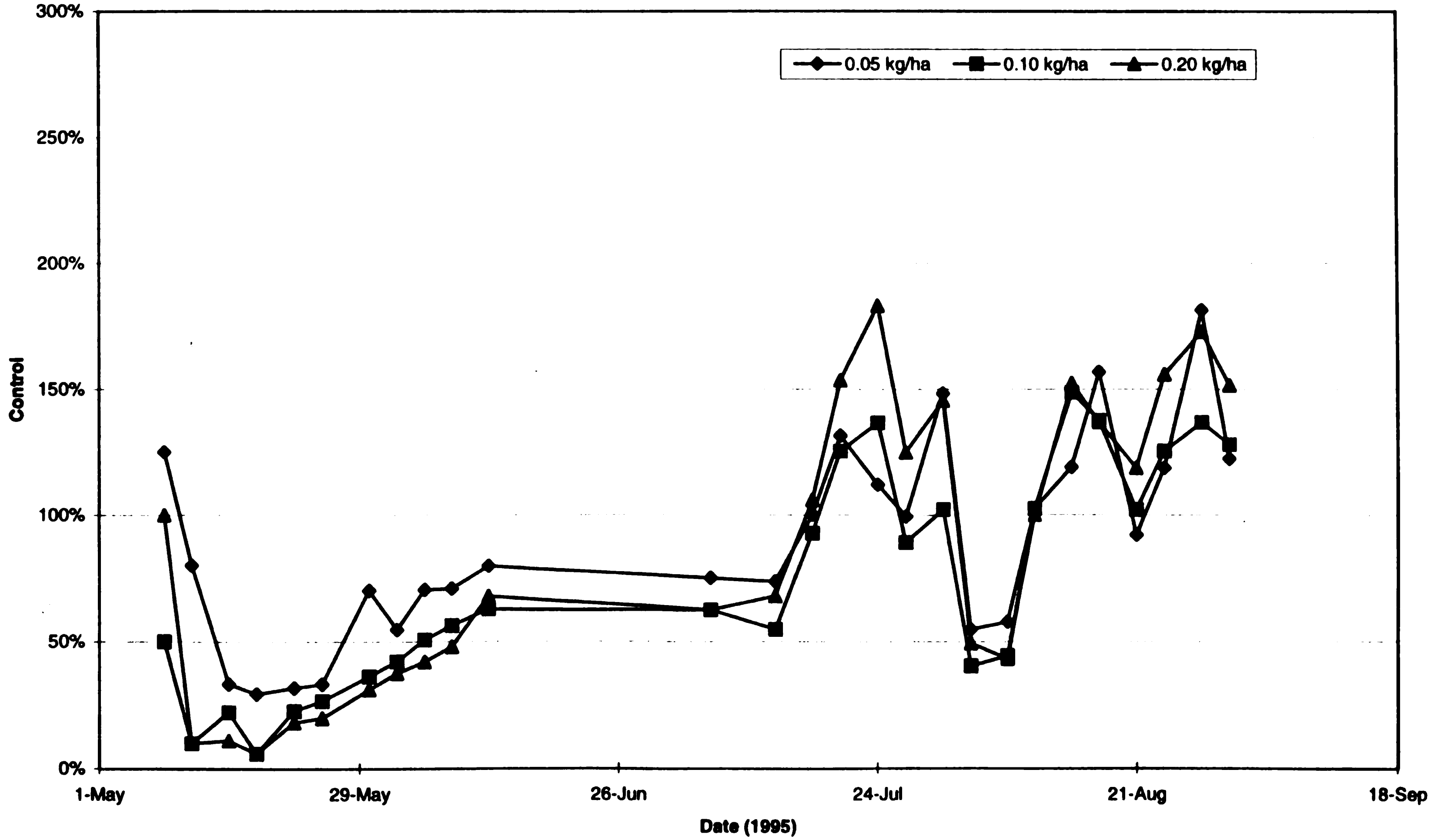


Figure J: Clipping production as affected by flurprimidol at three rates where nitrogen regime is 250 kg ha^{-1} $year^{-1}$.

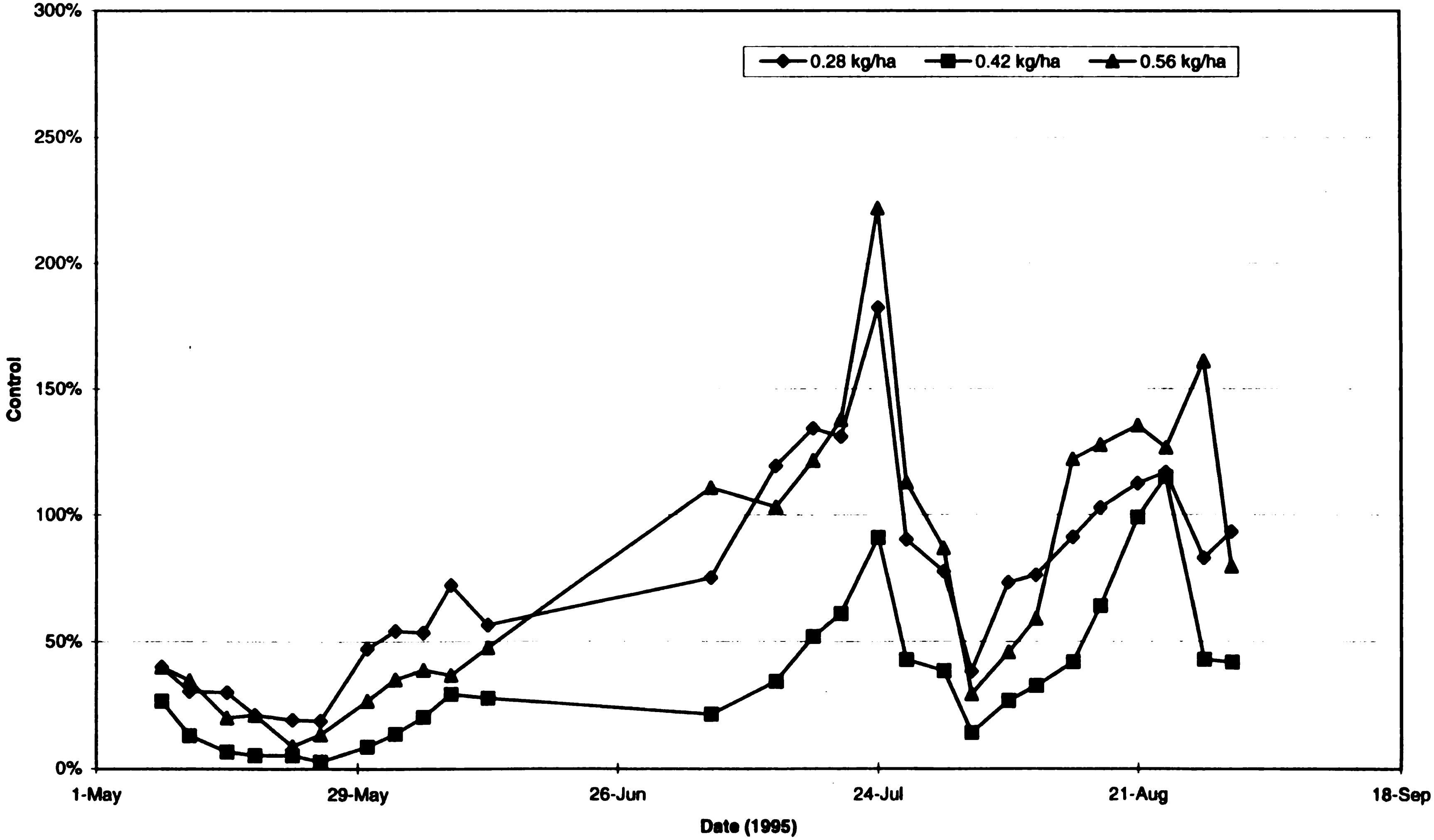


Figure K: Clipping production as affected by paclobutrazol at three rates where nitrogen regime is 250 kg ha^{-1} $year^{-1}$.

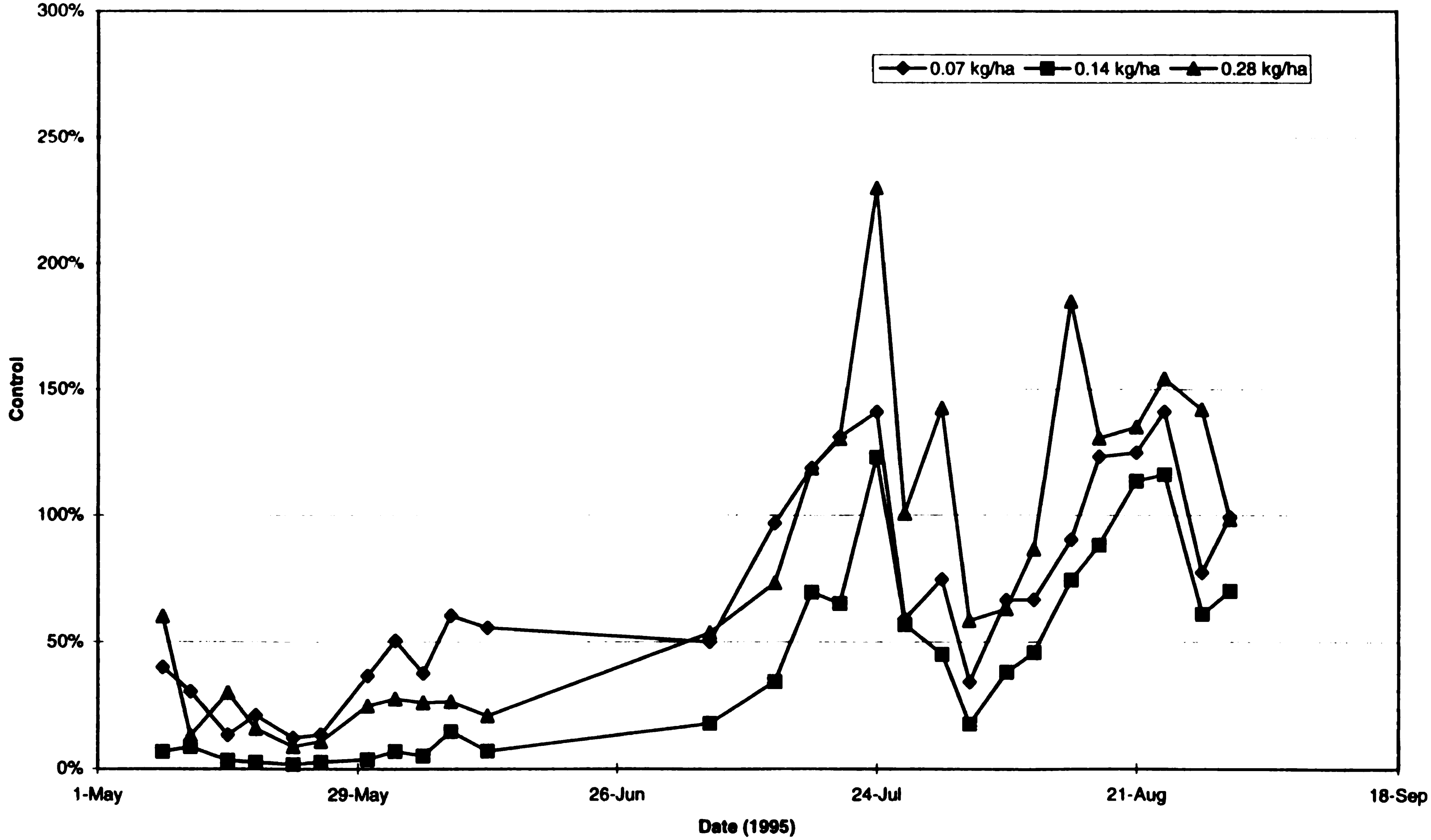


Figure L: Clipping production as affected by trinexapac-ethyl at three rates where nitrogen regime is 250 kg ha^{-1} year^{-1}.

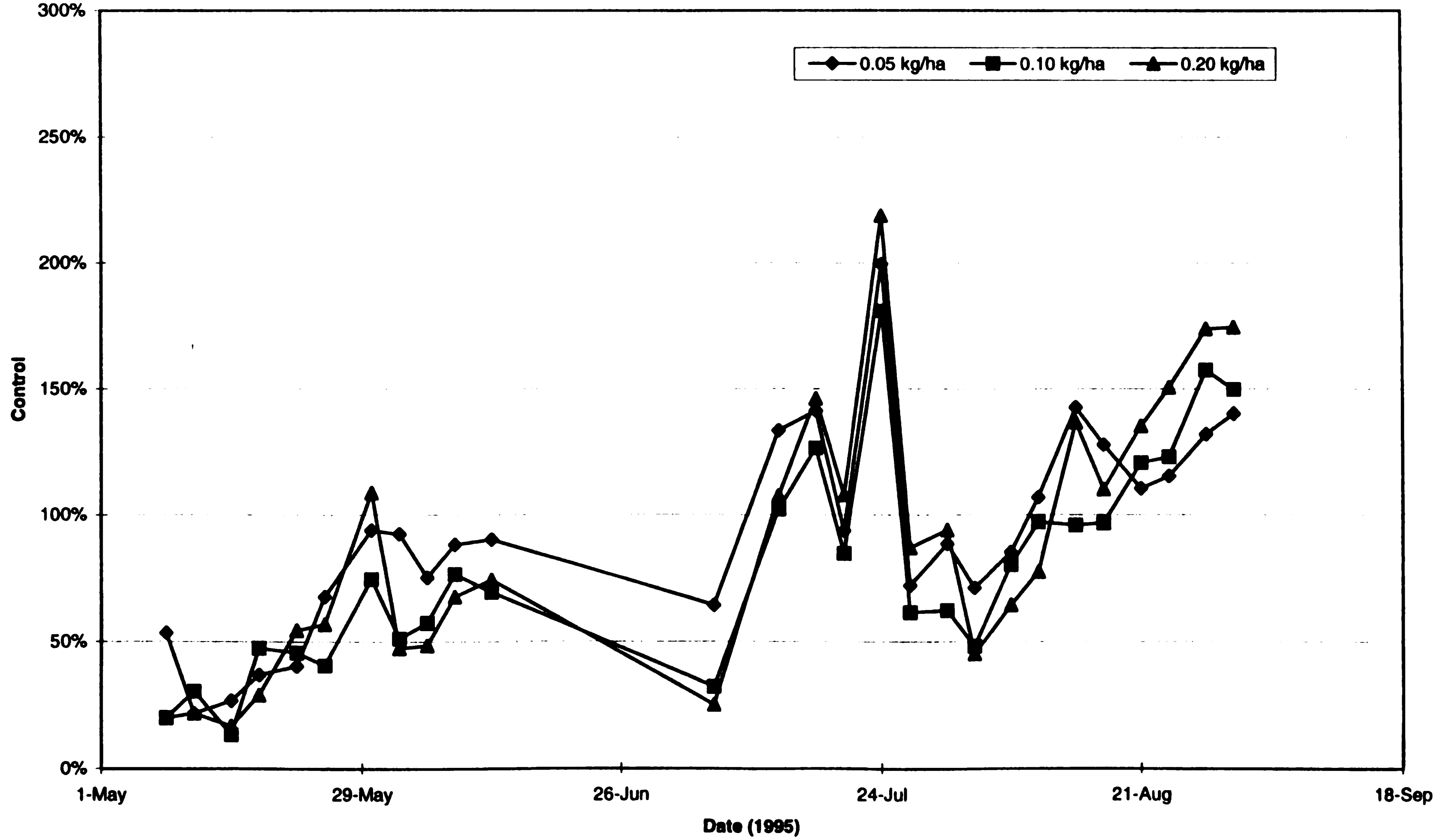


Figure M: Cumulative observations of quality indicies of a creeping bentgrass fairway as affected by plant growth regulator treatment and nitrogen regime. 1994

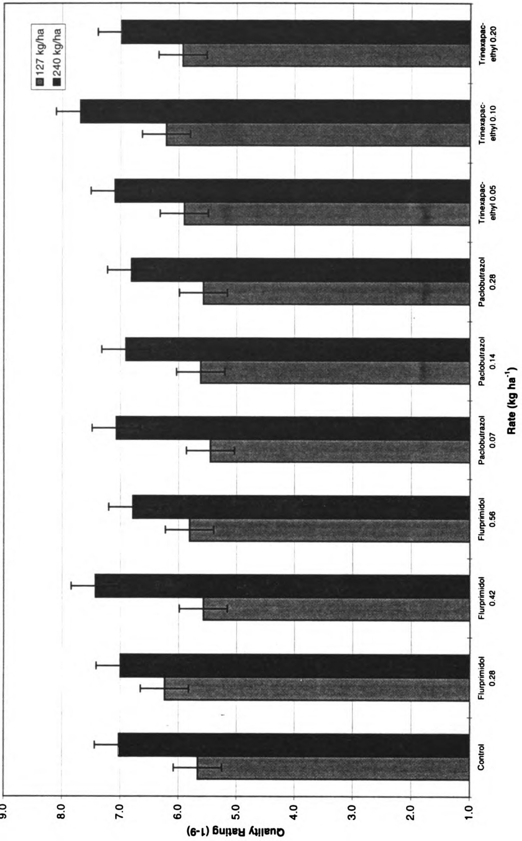


Figure N: Cumulative observations of quality indicies of a creeping bentgrass fairway as affected by plant growth regulator treatment and nitrogen regime. 1995

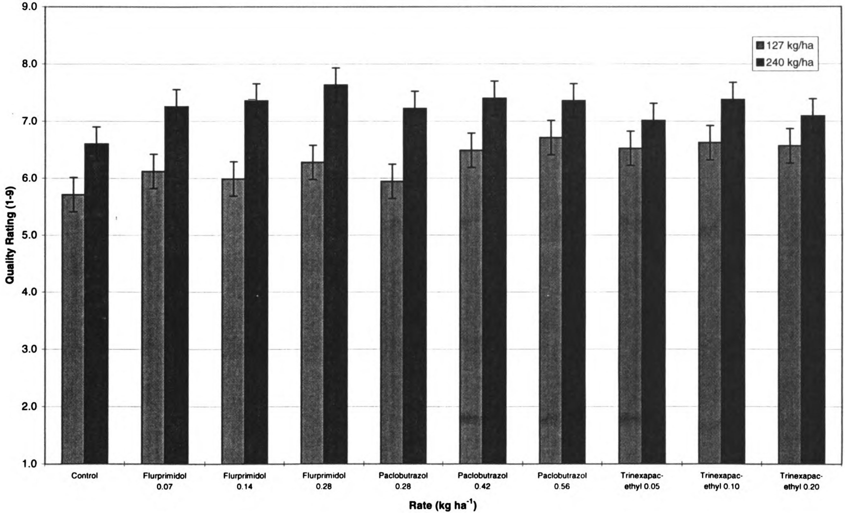
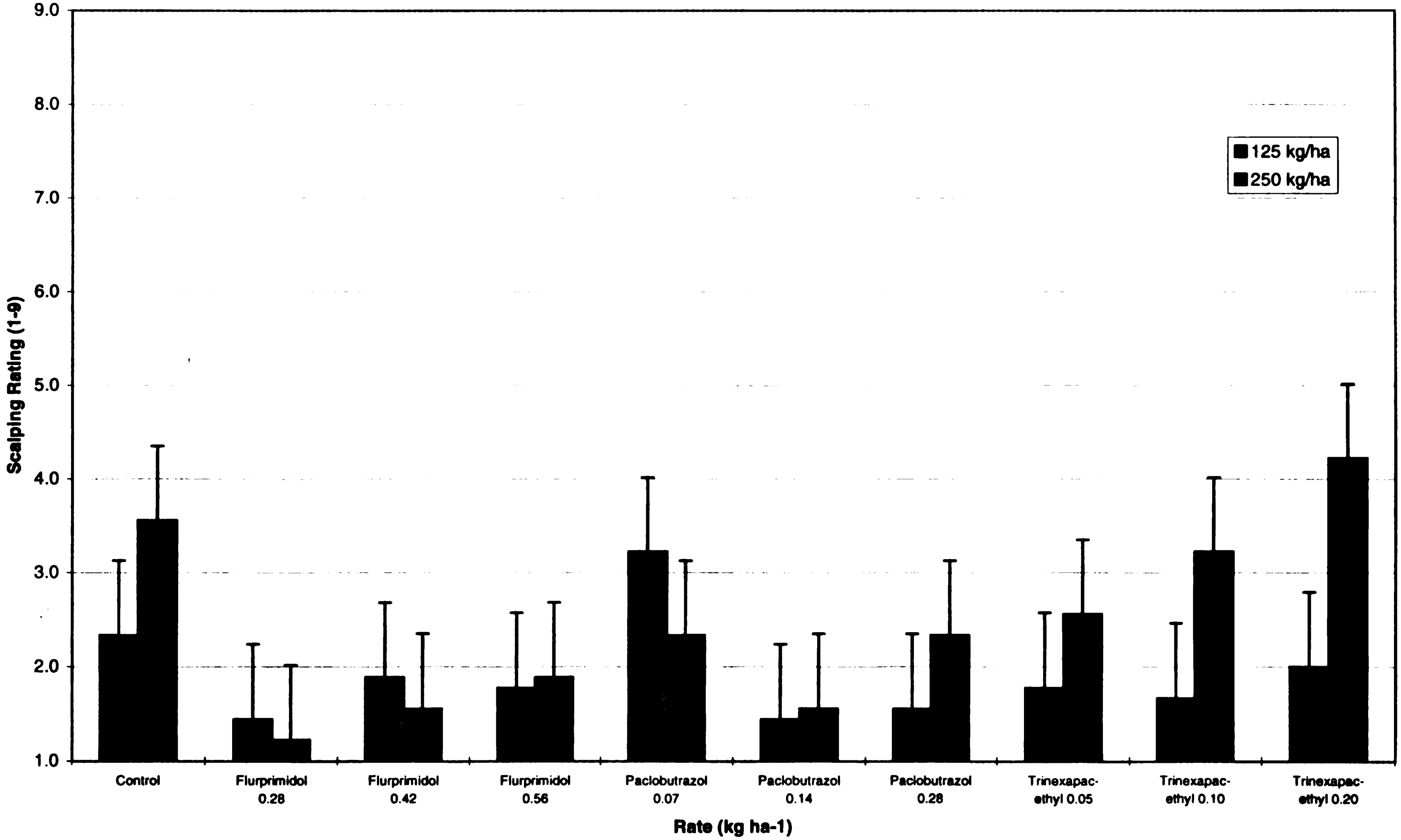


Figure O: Casual observations of scalping severity of a creeping bentgrass fairway as affected by plant growth regulator treatment and nitrogen regime. 1995



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