LITTLE BLUESTEM TILLER DEFOLIATION PATTERNS UNDER CONTINUOUS AND ROTATIONAL GRAZING

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The ability to regulate the severity (frequency and intensity) of plant defoliation is a major goal of grazing resource managers. Accomplishing this goal will require the integration of plant selection patterns by grazing animals, plant growth patterns, stocking rate, and adequate rest periods for defoliated plants. Interdisciplinary approaches will need to be taken when conducting research in these areas due to complex interacting parameters.

During the past decade, grazing resource managers have moved towards implementing rotational grazing management systems with proposed benefits including more uniform utilization of available forage, flexible livestock movement schedules, increased stocking rate capability, and higher livestock gain per land unit area. These systems are in contrast with continuous grazing, which allows unrestricted selective grazing of available plant species throughout a grazing season, no livestock movement schedules, higher amounts of gain per head, but lower amounts of gain per land unit area.

Tiller defoliation patterns play a major role in determining the impact various grazing management systems have on the land resource, as the tiller is the basic unit of grass communities. Therefore, the foundation for comparisons between and among grazing management systems should be tiller defoliation patterns. Prediction equations acquired from studies investigating tiller defoliation patterns would enable grazing resource managers to accurately assess, develop, and implement specific management plans promoting a sustained ecosystem approach. This study was initiated with the objective of determining the effect of continuous and rotational grazing under a range of stocking rates on little bluestem tiller defoliation patterns in tallgrass prairie.

The following chapter is an extensive review of the current literature concerning tiller defoliation patterns on rangelands and comparisons of continuous and rotational grazing. The primary focus of the literature is on little bluestem, but additional information concerning other plant species has been included for a broader understanding of tiller defoliation patterns. Chapter III presents the results of the study and is written in a form for immediate submission to the *Journal of Range Management.*

CHAPTER II

LITERATURE REVIEW

Little bluestem [*Schizachyrium scoparium* (Michx.) Nash] is surpassed by few native species in its wide range of habitats, distribution, and importance as a forage grass in North America. It is one of the most important grasses in the tallgrass and mixed-grass prairies and responds to grazing as a decreaser (Brown and Stuth 1984). Yet, with large numbers of tillers per plant and a prominent caespitose growth form, little bluestem often appears underutilized. This condition results from a high frequency (the number of times a plant is defoliated in a given time period) and intensity (the amount of plant material removed) of defoliation on a small percentage of the tillers (Hinnant and Kothmann 1986).

Grazing, over a period of years, can influence little bluestem morphology. Little bluestem may not persist if exposed to multiple, close defoliations during the growing season (Mullahey et al. 1990). Dwyer et al. (1963), from clipping studies in Oklahoma, indicates increased frequency rather than high intensity is more detrimental to little bluestem. Mullahey et al. (1990) recommends little bluestem be defoliated a single time in June or July; a single defoliation in August or multiple defoliations severely reduce annual dry matter yield, tiller number, tiller weight, and bud number. Intense herbivory reduces individual little bluestem plant basal area and increases plant density by fragmenting individual large plants (Butler and Briske 1988). Clipping little bluestem after apical meristems have been elevated stimulates tillering the first year

(Jameson and Huss 1959). Vogel and Bjugstad (1968), however, report two successive years of clipping in late July greatly reduces spring tillering of little bluestem. Thus, little bluestem plants should not have multiple defoliations in consecutive years unless the purpose is to weaken large plants so that remaining tillers at the periphery will form new, smaller plants (Mullahey et al. 1990). This change in the size of plants and plant parts commonly occurs in response to heavy grazing (Hanson et al. 1931, Holscher 1945, Weaver and Darland 1947). The rate of vegetation change resulting from heavy stocking may decelerate with prolongation of the treatment - as changes in plant size and response permit the approach to a new equilibrium between vegetation and the grazing animal (Peterson 1962).

For results of field studies on grazing systems to be widely useful, research should focus on dynamics of plant growth, disappearance, and defoliation as well as animal performance or plant species composition. Pierson and Scarnecchia (1987) state research should be designed to provide researchers and managers with predictive equations describing defoliation effects by livestock over time, rather than comparisons of mean defoliation effects between specific grazing systems.

Arnold (1964) reports better knowledge of the interactions between individual plants and grazing animals is necessary for developing management practices to improve forage utilization. Investigations of tiller defoliation patterns can provide information for evaluating grazing management strategies. Three concepts have been verified: 1) the relationship between defoliation intensity and forage availability (Hodgson 1966, Morris 1969, Briske and Stuth 1982, Curll and Wilkins 1982, Hart and Balla 1982, Jensen et al. 1990); 2) the relative relationship between defoliation frequency and intensity (Cassady 1953, Owensby et al. 1974, Buwai and Trlica 1977, Gammon and Roberts 1978c, Clark et al. 1984, Gillen et al. 1990, Mullahey et al.

1990); and 3) the importance of tiller architecture i.e., height, total lamina length and location in the canopy, in determining defoliation probabilities (Greenwood and Arnold 1968, Hodgson and Ollerenshaw 1969, Bartham and Grant 1984, Pierson and Scarnecchia 1987, Heitschmidt et al. 1990).

Stocking rate influences the amount of leaf material removed from tillers, with increased stocking rate removing more leaf material, thus minimizing senescence. Hodgson (1966), Hodgson and Ollerenshaw (1969), Allison and Kothmann (1979), Briske and Stuth (1982), and Curll and Wilkins (1982) all confirm that high stocking rates increase efficiency of defoliation. Brown and Stuth (1984) suggest it is possible to modify patterns and degree of utilization by altering stocking rate. The pattern of tiller defoliation will obviously change if stocking rate is significantly increased and all other factors remain constant (Heitschmidt et al. 1982). Gillen et al. (1990) report stocking rate has little effect on the height at which tillers of big bluestem (*Andropogon gerardii* Vitman) and little bluestem are defoliated.

The intensity of tiller defoliation is influenced to a large extent by the architectural attributes of a species (Heitschmidt et al. 1990). Tillers are grazed in direct proportion to their pré-defoliation tiller heights. This agrees with other findings on frequency and intensity of tiller defoliation (Morris 1969, Briske and Stuth 1982, Hart and Balla 1982, Clark et al. 1984). About 20-30% of the pre-defoliation tiller height is observed to be removed per defoliation event by sheep or cattle (Heitschmidt et al. 1990).

It is commonly assumed that repeated defoliation during continuous grazing is chiefly the result of selection for regrowth from previously defoliated material. Intervals between defoliations are affected by the rate of regrowth of defoliated tillers, the degree of selection for or against previously defoliated tillers, and the pattern of changes in preference between species (Gammon and Roberts 1978c). Morris (1969) suggests individual small areas in continuously grazed pastures are defoliated rotationally.

Rotational grazing provides an opportunity, through manipulation of grazing period duration, to improve control of the frequency, intensity, and uniformity of defoliation (Hinnant and Kothmann 1986). Denny and Barnes (1977) concur that rotational grazing allows more control over frequency and intensity of defoliation. Rapid rotation of livestock may also prove to enhance the efficiency of harvest, particularly for short-lived annual grasses and forbs (Heitschmidt et al. 1982). If rate of rotation is too slow, many highly preferred annual plants may not be utilized in certain pastures because they will have reached an advanced stage of maturity prior to livestock being permitted to graze them. Similar patterns of selection occur under continuous and rotational grazing, however, on the Matopos Sandveld of Rhodesia (Gammon and Roberts 1978b). Continuous and rotational grazing produce similar grazed heights; differences in frequencies of defoliation between continuous and rotational grazing are small (Gammon and Roberts 1978a). A small proportion of the tillers in the study did receive excessively frequent defoliation (four or more defoliations) under continuous grazing, while no tillers were defoliated greater than three times under rotational grazing (Gammon 1978). Hart et al. (1993), using western wheatgrass (*Agropyron smithii* Rydb.) and blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.], also found frequency and intensity of defoliation were similar between continuous and rotational grazing. Clark et al. (1984) in a study involving perennial ryegrass (*Lolium perenne* L.), browntop (*Agrostis* spp.), and white clover (*Trifolium repens* L.) observed all species were defoliated more frequently under continuous grazing than rotational grazing when rest periods exceeded 21 days. Less than 60% of the tillers from the most selected species were grazed in a single grazing period under rotational grazing (Gammon and Roberts 1980).

In Texas, Briske and Stuth (1982) investigated tiller defoliation patterns by yearling steers under moderate and heavy grazing treatments. Tillers of brownseed paspalum (*Paspalum plicatulum* Michx.) under the moderate grazing treatment were nonuniformly defoliated and had a wide range of tiller heights at the termination of grazing. By the end of the moderate grazing trial 82% of the tillers had been defoliated at least once, 31% at least twice, and 10% at least 3 times. A large percentage of the tillers within a pasture remained not defoliated or were only lightly defoliated even at relatively high stock densities. Since a portion of the tillers within a pasture remained not defoliated and a portion were defoliated frequently and intensively this results in an inefficient harvest of available tillers and a potential delay or reduction in the productivity of those tillers severely defoliated. The high frequency of defoliation under heavy grazing illustrates the need for short grazing periods when high stocking densities are combined with low herbage allowances in rotational grazing strategies.

Hart and Balla (1982) measured removal from tillers of western wheatgrass and crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.] under two stocking rates. Tillers of both species were defoliated more frequently under the higher stocking rate. Only at the higher stocking rate on crested wheatgrass were all tillers defoliated at least once in a grazing season. A small percentage of tillers remained not defoliated under all other grazing treatments.

Hart et al. (1993), comparing continuous and rotational grazing at moderate and heavy stocking rates, determined western wheatgrass tillers were defoliated more frequently under heavy than moderate stocking. Blue grama tillers were defoliated more frequently under heavy than under moderate stocking in both years of the study under rotational grazing, but only in one year under continuous grazing. Under heavy and moderate stocking, respectively, they found 19% and 36% of western wheatgrass tillers and 42% and 54% of blue grama tillers were not defoliated throughout the grazing season. Few western wheatgrass tillers were defoliated more than twice, and few blue grama tillers were defoliated more than once. Their conclusion was stocking rates have much greater potential than grazing systems for altering frequency and intensity of defoliation.

Rotational grazing, through control of frequency, intensity, and uniformity of grazing, should lead to an increase in range condition. The increase would be a result of alleviating grazing pressure and reducing the number of defoliation events per tiller in a grazing season on decreaser plant species, while increasing utilization of increaser and invader plant species. Rotational grazing on mixed-grass range in Wyoming had no significant effect on botanical composition of peak standing crop compared to continuous grazing, however, after 6 years (Hart et al. 1988). Rotational grazing also did not increase or decrease range condition compared to continuous grazing on the Texas High Plains over 4 years (Pitts and Bryant 1987). O'Reagain and Turner (1992) found continuous and rotational grazing systems differ little in terms of their effects on range condition in southern Africa. Denny et al. (1977) report no differences in short term vegetation change between continuous and rotational grazing. They did find steers on the rotational grazing pastures had lower quality diets and selectivity was reduced. Hart et al (1993) concluded stocking rates, rather than grazing systems, have much greater potential for changes in botanical composition of range plant communities. No long term studies have been published regarding the effect of rotational grazing on range condition.

CHAPTER III

LITTLE BLUESTEM TILLER DEFOLIATION PATTERNS UNDER CONTINUOUS AND ROTATIONAL GRAZING

Abstract

Little bluestem [*Schizachyrium scoparium* (Michx.) Nash] tiller defoliation patterns on tallgrass prairie were compared using continuous and rotational grazing systems on six 24-ha pastures for each system under a range of stocking rates (0.28 to 0.49 AU ha^{-1}) in 1991-92. Crossbred yearling cattle grazed the pastures from late April to late September (150 days). Rotational system pastures were subdivided into 8 paddocks with 4 grazing cycles (3-7 day graze periods) per grazing season. Tillers were sampled biweekly in continuous system pastures and before, midpoint of, and after each grazing period in rotational system pastures. Multiple regression prediction equations were developed for grazed height, number of defoliation events in a grazing season, percent of tillers defoliated per sampling period (for continuous system) and per cycle (for rotational system), and number of defoliation events within a grazing cycle (for rotational system). Grazed height decreased as stocking rate increased, but was not influenced by grazing system. Increasing the stocking rate increased cumulative defoliation events per tiller over the grazing season. Under similar stocking rates, continuous system grazing resulted in more tillers defoliated during the grazing season. Within both grazing systems, percentage of tillers defoliated increased with increased stocking rates. The percentage of tillers defoliated biweekly in continuous system pastures was similar over the grazing season; the percentage of tillers defoliated per cycle increased as grazing periods lengthened in rotational system pastures. More tillers were defoliated during the second half of each grazing period. Less than 10% of tillers were regrazed within a grazing cycle, even at the highest stocking rate and longest graze period.

Introduction

Little bluestem [*Schizachyrium scoparium* (Michx.) Nash], is one of the most important grasses in the tallgrass prairie and responds to defoliation as a decreaser (Brown and Stuth 1984). Yet, with large numbers of tillers per plant and a prominent caespitose growth form, little bluestem often appears underutilized. This condition results from a high frequency (the number of times a plant is defoliated in a given time period) and intensity (the amount of plant material removed) of defoliation on a small percentage of the tillers (Hinnant and Kothmann 1986).

It is commonly assumed that repeated defoliation of tillers under continuous grazing is chiefly the result of selection for regrowth from previous defoliations. This unrestricted selective grazing of plant species throughout the grazing season often leads to frequent and intensive defoliation eventually reducing the vigor and productivity of preferred species (Kothmann 1980). Intervals between defoliations are affected by the rate of regrowth of defoliated tillers, the degree of selection for or against previously defoliated tillers, and the pattern of changes in preference among species (Gammon and Roberts 1978c).

Rotational grazing provides an opportunity, through manipulation of grazing period length, to improve control of the frequency, intensity, and uniformity of defoliation (Denny and Barnes 1977, Hinnant and Kothmann 1986). Gammon and Roberts (1978a, 1978b), however, found heights of grazing and patterns of selection were similar between rotational and continuous systems; frequency of defoliation between the two systems differed little.

The specific objective of this study was to determine the effect of continuous and rotational grazing systems under a range of stocking rates on little bluestem tiller defoliation patterns in tallgrass prairie. The major emphasis was to obtain prediction equations to be used as tools by land resource managers in assessing, developing, and implementing grazing management strategies.

Study Area

The study area is located on the Oklahoma State University Research Range about 21 km southwest of Stillwater, Oklahoma (36° 3´ N 97° 14´ W). The climate is continental with an average frost-free growing period of 204 days extending from April to October. Average precipitation at Stillwater is 831 mm with 65% falling as rain from May to October. Mean temperature is 15°C with average minimum and maximum temperatures ranging from -4.3°C in January to 34°C in August (Myers 1982).

Major range sites found on the area are shallow prairie (33%), loamy prairie (25%), and eroded prairie (22%). Sandy savannah dominates the remaining area. The shallow prairie sites have Grainola series soils (fine, mixed, thermic Vertic Haplustalf), which have a loam surface with silty clay subsoil. Coyle series soils (fine-loamy, siliceous, thermic Udic Argiustoll) comprise the loamy prairie sites. These soils have fine sandy loam surfaces with sandy clay loam subsoils. The eroded prairie sites are on old fields and have Renfrow (fine, mixed, thermic Udertic Paleustoll), Mulhall (fine-loamy, siliceous, thermic Udic Paleustoll), and Coyle series soils.

The study area vegetation is currently in a high seral state. Vegetation composition on a dry weight basis, determined by the dry weight rank method in August 1991, consisted of 28% little bluestem, 25% combined big bluestem (*Andropogon gerardii* Vitman) and indiangrass [*Sorghastrum nutans* (L.) Nash], 25% midgrasses, 13% forbs, 5% switchgrass (*Panicum virgatum* L.), and 4% shortgrasses and annual grasses. The study area was not burned in either year of the study.

Methods

Experimental treatments consisted of continuous and rotational grazing systems under a range of stocking rates (0.28 to 0.49 AU ha^{-1}). Stocking rate was not replicated within or between grazing systems. Each grazing system had six, 24-ha pastures. Rotational system pastures were subdivided into 8 paddocks. Within the rotational grazing system 4 grazing cycles were used. Graze periods were 3, 4, 5, and 7 days for the first, second, third, and the fourth grazing cycle, respectively. Data were not taken from the first grazing cycle in 1991. Grazing by crossbred yearling cattle, with initial weights of 205 kg $head^{-1}$ (0.65 AU), began in late April and ended in late September (approximately 150 days).

Individual tillers of little bluestem were permanently marked with orange colored wire rings at the start of the grazing season in each pasture. Ten tillers were systematically located along 3, 20-m permanent transects at each of three locations (100, 200, and 300 m from livestock water), for a total of 30 tillers at each location and 90 tillers per pasture. Data were pooled over the three locations.

Two paddocks, numbers 3 and 7 in the grazing sequence, were used as subsamples for each rotational system pasture. Paddocks grazed third in the grazing sequence in 1991 were grazed seventh in 1992 and vice versa. Data from the two paddocks were averaged over a grazing cycle.

Tillers in the continuous system pastures were sampled biweekly throughout the grazing season (total of 11 sample dates). Tillers in the rotational system pastures were sampled before, midpoint of (middle), and after (exit) each grazing period. Lost tillers were replaced with the nearest available tiller. Tiller measurements included the presence/absence of defoliation, total tiller height with leaves extended, and the minimum height at which defoliation had occurred. Grazed edges of leaves and stems were marked with white latex paint to determine subsequent defoliation events. Means for grazed height were based on defoliated tillers only. Only tillers not replaced during the grazing season were used in categorizing the number of defoliation events in a grazing season per tiller.

All data were analyzed using general linear model techniques for a completely randomized design with repeated measures. Grazing system and stocking rate were main factors while year, sample date (continuous), grazing cycle (rotational), and observation within cycle (middle and exit, rotational) were repeated factors. Pastures were experimental units. Tiller means within pastures were used as observations for the analysis. Independent variables for the general linear models were quantitative and qualitative. Quantitative variables included stocking rate, stocking rate squared, and grazing cycle. Qualitative variables included grazing system, year, observation (rotational), and sample date (continuous). All possible interaction variables were included. Significant ($P<0.05$) variables from the general linear models were used to develop multiple regression prediction equations. Prediction equations were developed for grazed height, defoliation events in a grazing season, percent of tillers defoliated per sampling period (for continuous system) and cycle (for rotational system), and defoliation events within a grazing cycle (for rotational system).

Results and Discussion

Precipitation for the water year November-October was 81% and 101% of average for 1991 and 1992, respectively. Growing season precipitation (May-August) was 92% of average for 1991 and 143% of average for 1992. As a result of the above average growing season precipitation in 1992, forage production levels were above average while utilization of little bluestem tillers declined.

Between Grazing Systems

Grazed Height

Grazed height decreased as stocking rate increased, but was not influenced by grazing system (Fig. 1). Gammon and Roberts (1978a) also found grazed heights did not differ between continuous and rotational grazing on the Matopos Sandveld in Rhodesia. Although year was a significant variable in the prediction equation for grazed height, its effect may be biased due to the lack of data taken during the first grazing cycle from the rotational system pastures in 1991. Predicted grazed height (averaged over year) for the lightest stocking rate (0.28 AU ha^{-1}) was 23.9 cm and 11.4 cm for the heaviest stocking rate (0.49 AU ha^{-1}).

Number Of Defoliations In A Grazing Season

Individual multiple regression prediction equations were developed for the eight defoliation event categories (Table 1). The amount of variation explained by the regression equations was greatest in the two lowest category levels (0 and 1 defoliation events). As stocking rate increased for both grazing systems, frequency distribution of defoliated tillers was shifted toward the higher category classes (Fig. 2).

The percentage of tillers not defoliated during the grazing season declined from 32 to 5% in rotational system pastures and from 22 to 0% in the continuous system pastures, as stocking rate increased from 0.3 to 0.5 AU ha^{-1}. Hart et al. (1993) found 19% and 36% of western wheatgrass (*Agropyron smithii* Rydb.) tillers and 42% and 54% of blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.] tillers were not defoliated throughout the grazing season under heavy (1 steer 2.25 ha^{-1}) and moderate (1 steer 3.0 ha^{-1}) stocking, respectively.

Comparing the two grazing systems at the same stocking rate results in continuous grazing systems having fewer tillers not defoliated during the grazing season (Fig. 2). Clark et al. (1984), using perennial ryegrass (*Lolium perenne* L.), browntop (*Agrostis* spp.), and white clover (*Trifolium repens* L.), observed all species were defoliated more frequently under continuous grazing than rotational grazing when rest periods exceeded 21 days. Hart et al. (1993) also determined frequency of defoliation was similar between continuous and rotational grazing systems. Gammon and Roberts (1978a) also found small differences in frequencies of defoliation between continuous and rotational grazing systems; a small proportion of the tillers received more than four defoliations under continuous grazing, while no tillers were defoliated more than three times under rotational grazing (Gammon 1978).

Within Grazing Systems

Continuous Grazing

Stocking rate, sample date and their interaction influenced grazed heights in the continuous grazing system (Table 2). Increasing the stocking rate resulted in a decrease in grazed height. From the prediction model, grazed height at a light stocking rate (0.28 AU ha^{-1}) would be 17 cm at the beginning and 26 cm at the end of the grazing season; corresponding values at a heavy stocking rate (0.48 AU ha^{-1}) would be 10 and 11 cm (Fig. 3). Grazed height increased as sample date progressed during the grazing season. The interaction variable modified this increase, however, in that grazed height increased 0.9 cm per sample date at the light stocking rate and 0.1 cm per sample date at the heavy stocking rate.

The percentage of tillers defoliated per sampling period increased as stocking rates increased up to 0.41 AU ha^{-1} and then declined as stocking rates progressed to 0.48 AU ha^{-1} (Fig. 4). Hart et al (1993) found more western wheatgrass tillers were defoliated under heavy than under moderate stocking.

There were 8.5% fewer tillers defoliated in 1992 than in 1991, reflective of the increased forage production. Sample date did not influence the percentage of tillers defoliated in 1991 and resulted in a slight decrease of 0.3% tillers defoliated per sample date in 1992 (Table 2). At a given stocking rate the percentage of tillers defoliated biweekly was generally similar over the grazing season.

Rotational Grazing

Increasing stocking rates resulted in decreasing both the middle and exit grazed heights of little bluestem across the grazing cycles (Fig. 5). Gillen et al. (1990), however, reported stocking rate in rotational grazing had little effect on grazed height. Grazed heights were reduced by 1 cm with each advance in the grazing cycle during 1991, but increased by 2.5 cm with each advance during 1992 (Fig. 6). This may be attributed to the differences in growing season precipitation between 1991 and 1992. With the increased forage production in 1992 grazed heights should accordingly have been higher. There was a reduction of 0.5 cm in grazed heights from the middle observation to the exit observation ($P<0.10$), indicating more grazing pressure on little bluestem tillers during the second half of each grazing period (Table 3).

The percentage of tillers defoliated in both the middle and exit observations across the grazing cycles was increased by increasing the stocking rate (Table 3). Heitschmidt et al. (1982) state the pattern of tiller defoliation will change if stocking rate is increased and all other factors remain constant. An increase in stocking rate will result in defoliation of a greater number of tillers of the same species or a greater number of plant species (Heitschmidt et al. 1982). Hart et al. (1993) found fewer blue grama tillers were not defoliated and more were defoliated once under heavy than under moderate stocking.

There were 12% fewer tillers defoliated in 1992, reflective of increased forage production. With each advance in grazing cycle, 3.5% more tillers were defoliated (Fig. 7). This was to be expected due to the lengthening of the grazing period over the grazing season.

Six percent more tillers were defoliated in the exit observations compared to middle observation in 1991. At light stocking rates in 1992 differences in percent of tillers defoliated between the middle and exit observations were small; larger differences were found at heavy stocking rates in 1992 (Fig. 8). This indicated more grazing pressure on little bluestem during the second half of each grazing period. Walker et al. (1989) found cattle were more selective at the beginning of a rotational grazing period than at the end.

Prediction equations were obtained for number of defoliations within a grazing cycle using individual models for defoliation categories none, once, and twice (Table 4). Increasing stocking rate resulted in a decline in tillers not defoliated and an increase in tillers defoliated once and twice (averaged over cycles, Fig. 9). Less than 10% of tillers were regrazed within a cycle, even with heavy stocking rates. Hart and

Balla (1982) found tillers of western wheatgrass and crested wheatgrass [*Agropyron desertorum* (Fisch. ex Link) Schult.] were defoliated more frequently under higher stocking rates. Hart et al (1993) determined defoliation frequency of western wheatgrass and blue grama tillers increased with stocking rate.

As the grazing cycles progressed, tillers not defoliated decreased and tillers defoliated once and twice increased (averaged over stocking rates, Fig. 10). Comparison of cycle 1 to cycle 4 using the prediction models yields the following: tillers not defoliated decreased from 67% to 50%, tillers defoliated once increased from 29% to 41%, and tillers defoliated twice increased from 4% to 9%. In Texas, Briske and Stuth (1982) found a large percentage of brownseed paspalum (*Paspalum plicatum* Michx.) tillers were not defoliated or were only lightly defoliated even at relatively high stock densities. Gammon and Roberts (1980) found less than 60% of the tillers from the most selected species were defoliated in a single grazing period under rotational grazing. Again, regrazing of an individual tiller was limited within a grazing cycle even as the grazing period lengthened.

Conclusions

Within the grazing systems, stocking rate was the predominant variable influencing grazed height, percentage of tillers defoliated per sampling period and cycle, and number of defoliations within a grazing cycle. In the rotational system, regrazing of an individual tiller within a grazing cycle was limited to 10% even under the heaviest stocking rate and longest grazing period. This result suggests that rotational grazing allows control over frequency of defoliation as stated by Denny and Barnes (1977) and Hinnant and Kothmann (1986). Rotational grazing, however, does not allow control over intensity of defoliation as evidenced by our findings of similar grazed heights between continuous and rotational grazing systems.

Continuous grazing systems result in fewer tillers not defoliated during a grazing season compared to rotational grazing systems at similar stocking rates; correspondingly, frequency distribution of defoliated tillers shift to higher defoliation classes in continuous grazing. Little bluestem plants should not receive multiple defoliations in consecutive years unless the purpose is to weaken large plants so that remaining tillers at the periphery will form new, smaller plants (Mullahey et al. 1990). Fragmentation of individual large plants will result in plant density and plant basal area increases (Butler and Briske 1988).

Grazed heights remain similar between the two systems and are influenced primarily by stocking rate. From this we hypothesize that increased standing crop under rotational grazing (unpublished data, Gillen et al.) may be attributed to reductions in livestock intake (Denny et al. 1977) and less regrazing of individual tillers, especially at light stocking rates. Additional investigations involving livestock intake (unpublished data, McCollum et al.) on the study area support this hypothesis.

Continuous and rotational grazing systems differ little in terms of their effects on range condition in the short-term (Denny et al. 1977, Pitts and Bryant 1987, Hart et al. 1988, O'Reagain and Turner 1992). We hypothesize higher range condition in rotational system pastures will result in the long-term from increased vigor of desirable plants due to fewer defoliations during the grazing season.

Land resource managers in the tallgrass prairie, with the developed prediction equations, can more accurately assess, develop, and implement grazing management strategies to meet desired objectives. Ecosystem vitality and function can be maintained and/or enhanced with livestock grazing through judicial use of the prediction equations.

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APPENDIXES

APPENDIX A

TABLES

Table 1. Coefficients of multiple regression equations for defoliation events in a grazing season, D.E. = defoliation events, YR = year, GRSY = grazing system, SR = stocking rate, R^2 = coefficient of determination. All regression coefficients significant at $P<0.05$.

D.E.	b_o	YR	GRSY	SR	SR^2	SR *YR	GRSY *YR	SR^2 *YR	SR*YR *GRSY	SR^2*YR *GRSY	R^2
0	41.1	42.3	10.7	-89.4		-91.1					0.80
1	40.0		18.1	-66.2			-8.6				0.70
2	24.0	-28.9				64.1			2.4		0.28
3	-4.8			58.9							0.32
4	-1.2		-7.8	41.0							0.48
5	-3.2		-7.1	34.5							0.56
6	2.3		-5.8		25.3		-16.4	-11.3	94.4	-110.6	0.36
>6	2.5		-4.6		14.3						0.42

Table 2. Coefficients of multiple regression equations for continuous grazing system: 1) grazed height and 2) percent of tillers defoliated per sampling period; SR = stocking rate, YR = year, SD = sample date, R^2 = coefficient of determination. All regression coefficients significant at $P<0.05$.

Equation	b_o	SR	YR	SD	SR^2	SR*SD	SD*YR	R^2
Grazed Height	25.1	-31.8		2.0		-4.0		0.46
% defoliated	141.5	872.4	-8.5		-1049.4		-0.3	0.65

Table 3. Coefficients of multiple regression equations for rotational grazing system: 1) grazed height and 2) percent of tillers defoliated per cycle; SR = stocking rate, YR = year, CY = cycle, OBS = observation, R^2 = coefficent of determination. All regression coefficients significant at $P<0.05$.

Equation	b_o	SR	YR	CY	OBS	SR*YR	CY*YR	OBS*YR	SR^2*OBS	SR^2* YR*OBS	R^2
Grazed Height	48.5	-63.0[1]	-12.5	-1.0	-0.5[1]		3.5		-1.2		0.63
% defoliated	-14.9	71.5	-12.3	3.5	6.1	30.5		-5.3		23.3	0.72

[1] Significant at $P<0.10$

Table 4. Coefficients of multiple regression equations for number of defoliation events in a rotational grazing cycle, D.E. = defoliation events, SR = stocking rate, YR = year, R^2 = coefficient of determination. All regression coefficients significant at $P<0.05$.

D.E.	b_o	Cycle	SR	YR	SR*Cycle	SR*YR	SR^2*YR	R^2
0	116.5	-5.5	-116.7	25.0		-59.4		0.77
1	-7.5	4.1	85.2	-18.6		45.5		0.78
2	2.9	-2.5	-0.3[1]	-22.5	10.6	94.4	-96.8	0.60

[1] Significant at $P<0.10$

Table 5. P-values from analysis of variance between continuous and rotational grazing systems, df = degrees of freedom, GRSY = grazing system, SR = stocking rate, YR = year, MSE = mean square error, R^2 = coefficient of determination.

		Grazed	Number of Defoliaton Events in a Grazing Season							
Variables	df	Height	0	1	2	3	4	5	6	>6
GRSY	1	0.1693	0.0112	0.0054	0.3187	0.3097	0.0070	0.0076	0.0320	0.0008
SR	1	0.0066	0.0006	0.0286	0.1249	0.0299	0.0251	0.0355	0.1298	0.0589
SR^2	1	0.6191	0.1923	0.5876	0.1031	0.5795	0.0735	0.2802	0.0352	0.0180
SR*GRSY	1	0.6706	0.2413	0.5959	0.9893	0.1475	0.9106	0.5088	0.8555	0.1513
SR^2*GRSY	1	0.6205	0.4516	0.1184	0.1150	0.6102	0.0630	0.2441	0.0957	0.0560
YR	1	0.0040	0.0086	0.1811	0.0407	0.4179	0.6537	0.7889	0.3669	0.8930
YR*GRSY	1	0.5251	0.0697	0.0085	0.5940	0.2626	0.0547	0.0588	0.0052	0.8441
YR*SR	1	0.1927	0.0264	0.3062	0.0472	0.3306	0.3160	0.6943	0.9166	0.5279
YR*SR*GRSY	1	0.7455	0.2605	0.7894	0.0191	0.4563	0.4150	0.4214	0.0206	0.4717
YR*SR^2	1	0.3779	0.3162	0.5917	0.6901	0.7913	0.9808	0.8895	0.0224	0.4947
YR*SR^2*GRSY	1	0.2909	0.8597	0.6868	0.1480	0.4301	0.6108	0.8842	0.0173	0.5685
MEAN		18.278	16.994	22.101	21.791	17.326	10.264	6.219	3.001	2.305
ROOT MSE		1.2986	5.1827	3.9176	4.2192	5.1719	4.0726	3.4955	0.9104	3.6104
R^2		0.9855	0.9618	0.9646	0.9186	0.8700	0.9120	0.9035	0.9890	0.7584

Table 6. P-values from analysis of variance within continuous grazing system, df = degrees of freedom, SR = stocking rate, YR = year, SD = sample date, MSE = mean square error, R^2 = coefficient of determination.

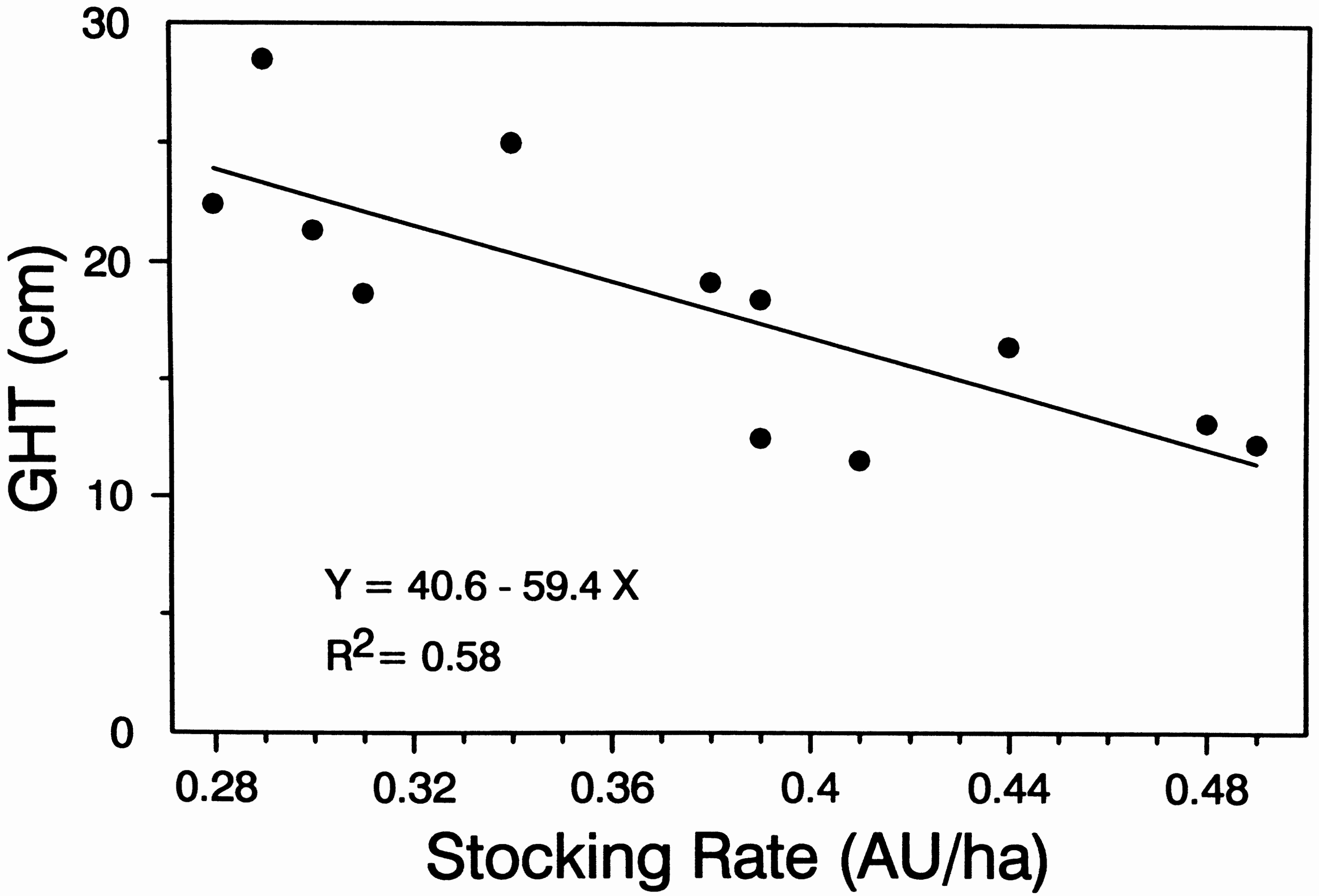
Variables	df	Grazed Height	Percent Defoliated
SR	1	0.0511	0.0199
SR^2	1	0.4211	0.0375
YR	1	0.0570	0.0023
YR*SR	1	0.4331	0.4548
YR*SR^2	1	0.1569	0.2927
SD	10	0.0001	0.1048
SD*YR	9	0.0625	0.0352
SD*SR	10	0.0266	0.8005
SD*SR*YR	9	0.0823	0.3960
SD*SR^2	10	0.1831	0.1403
SD*SR^2*YR	9	0.2877	0.6236
MEAN		16.607	27.820
ROOT MSE		3.2629	6.0576
R^2		0.8765	0.8681

Table 7. P-values from analysis of variance within rotational grazing system, df = degrees of freedom, SR = stocking rate, YR = year, CY = cycle, OBS = observation, MSE = mean square error, R^2 = coefficient of determination.

		Grazed	Percent	Number of Defoliations within a Grazing Cycle		
Variables	df	Height	Defoliated	0	1	2
SR	1	0.0825	0.0330	0.0249	0.0159	0.0853
SR^2	1	0.8959	0.8664	0.8098	0.7288	0.9577
YR	1	0.0185	0.0087	0.0112	0.0213	0.0035
YR*SR	1	0.4682	0.0153	0.0221	0.0267	0.0215
YR*SR^2	1	0.9657	0.3288	0.5694	0.6457	0.0198
CY	3	0.0037	0.0003	0.0001	0.0001	0.0071
CY*SR	3	0.3816	0.3464	0.3930	0.2995	0.0363
CY*YR	2	0.0159	0.9405	0.8333	0.5376	0.7174
CY*SR*YR	2	0.7646	0.5706	0.7111	0.6849	0.1008
CY*SR^2	3	0.7079	0.2896	0.2603	0.2672	0.4127
CY*SR^2*YR	2	0.2943	0.4477	0.4864	0.7205	0.3004
OBS	1	0.0609	0.0001			
OBS*CY	3	0.1884	0.1196			
OBS*SR	1	0.8863	0.0887			
OBS*YR	1	0.4821	0.0530			
OBS*CY*SR	3	0.5236	0.4126			
OBS*CY*YR	2	0.5707	0.8688			
OBS*SR*YR	1	0.3099	0.5543			
OBS*SR^2	1	0.0495	0.2271			
OBS*SR^2*CY	3	0.5815	0.3954			
OBS*SR^2*YR	1	0.3834	0.0411			
OBS*SR^2*CY*YR	2	0.8622	0.4909			
MEAN		19.584	23.514	58.995	34.906	6.099
ROOT MSE		1.5668	3.4117	5.9045	4.4463	2.2440
R^2		0.9848	0.9665	0.9385	0.9352	0.9083

APPENDIX B

FIGURES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20
10
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0.28
0.32
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0.4
0.44
0.48
Stocking Rate (AU/ha)
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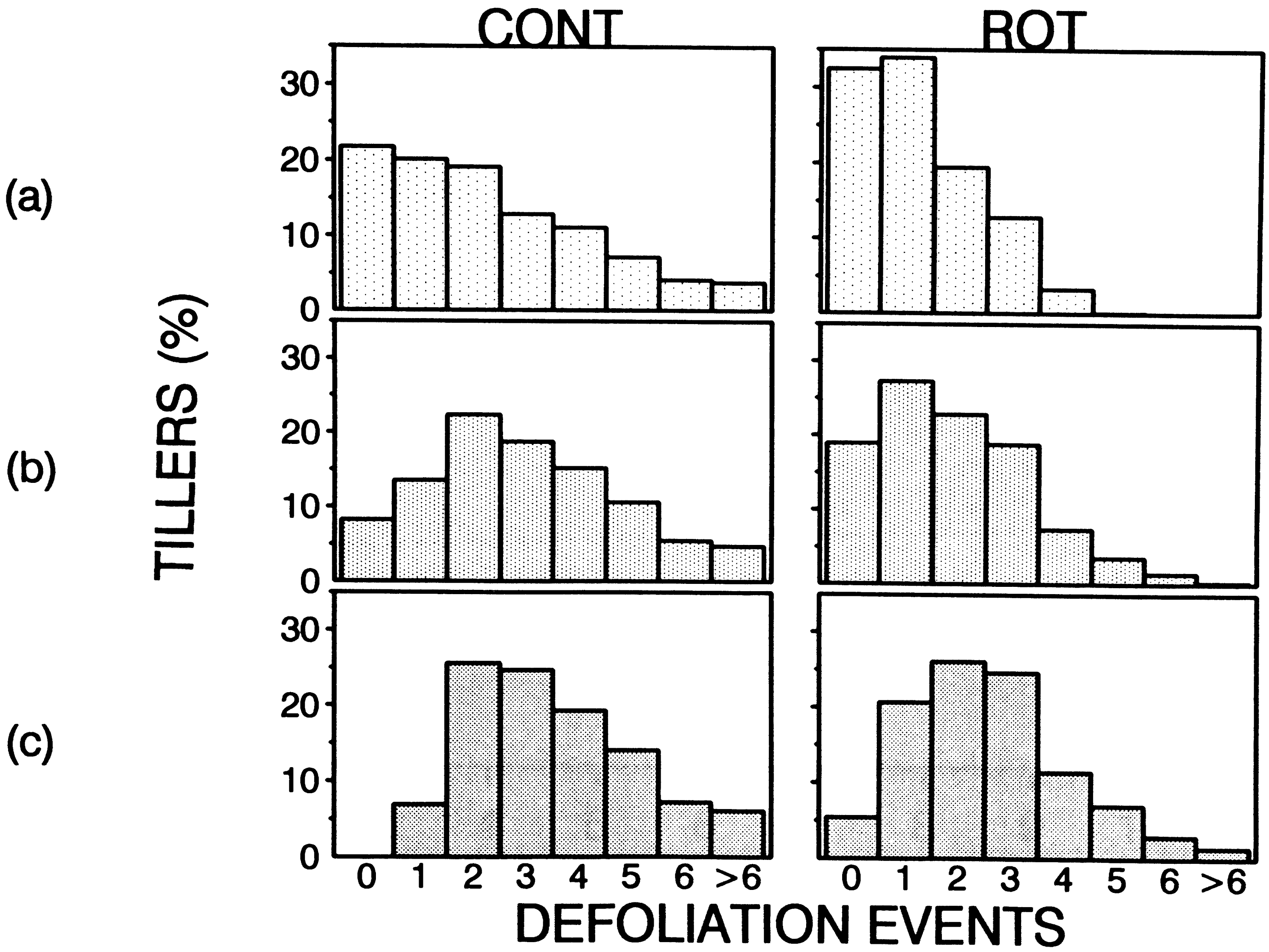
R2= 0.58


CONT
ROT
(a)
(b)
(c)
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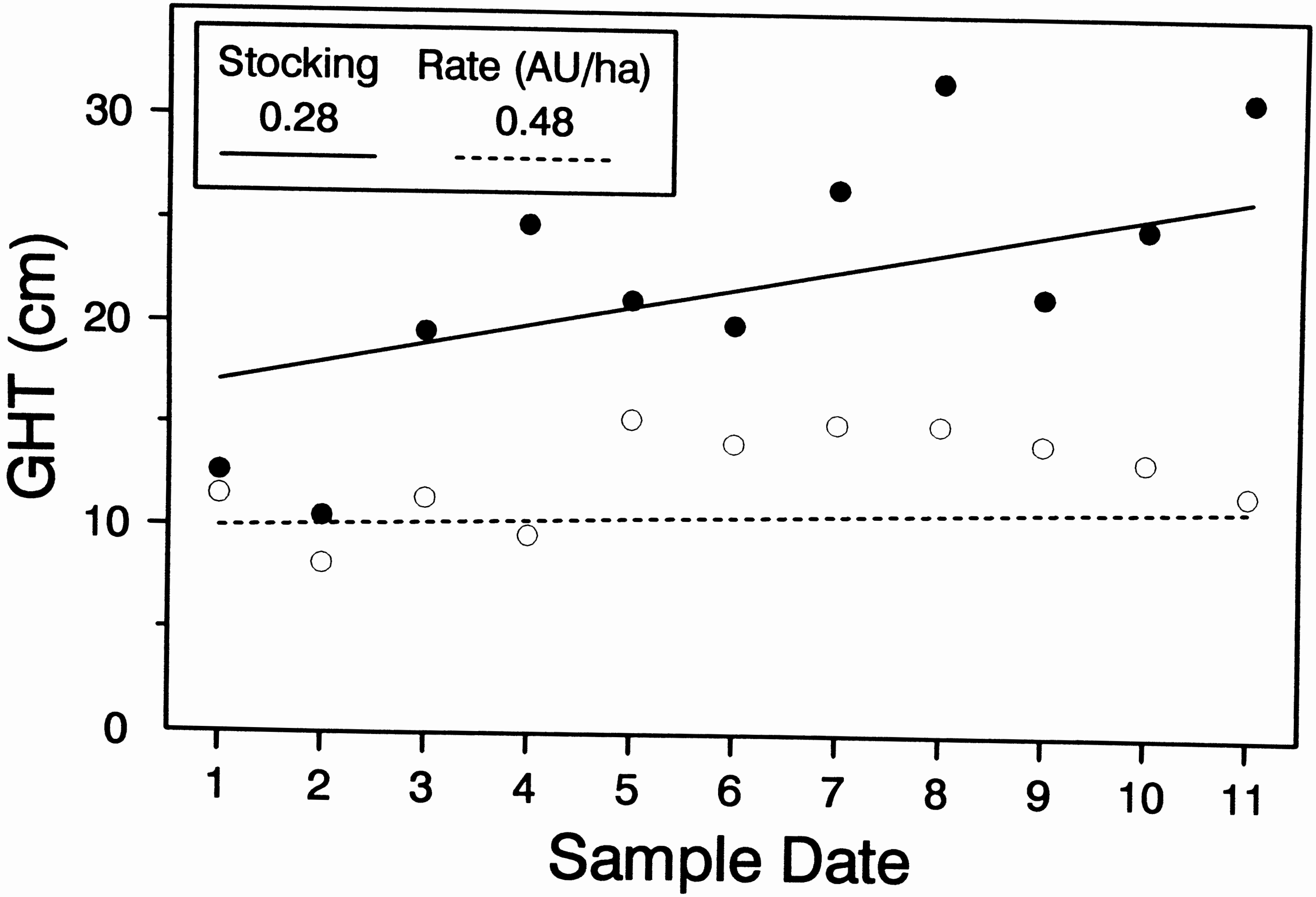
20
30
0
1
2
3
4
5
6
>6
DEFOLIATION EVENTS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0.48
30
20
10
0
GHT (cm)
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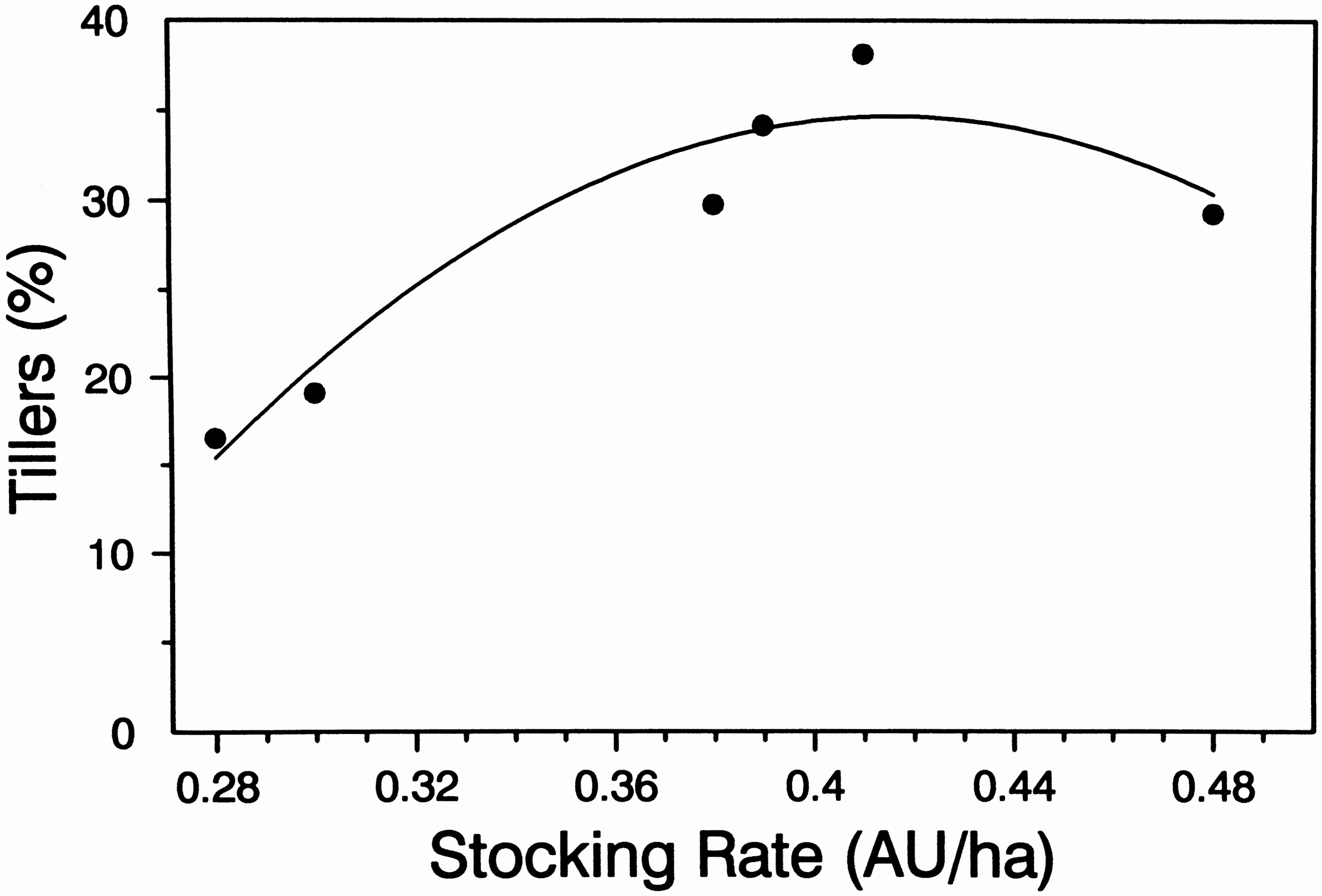
2
3
4
5
6
7
8
9
10
11
Sample Date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20
10
0
Tillers (%)
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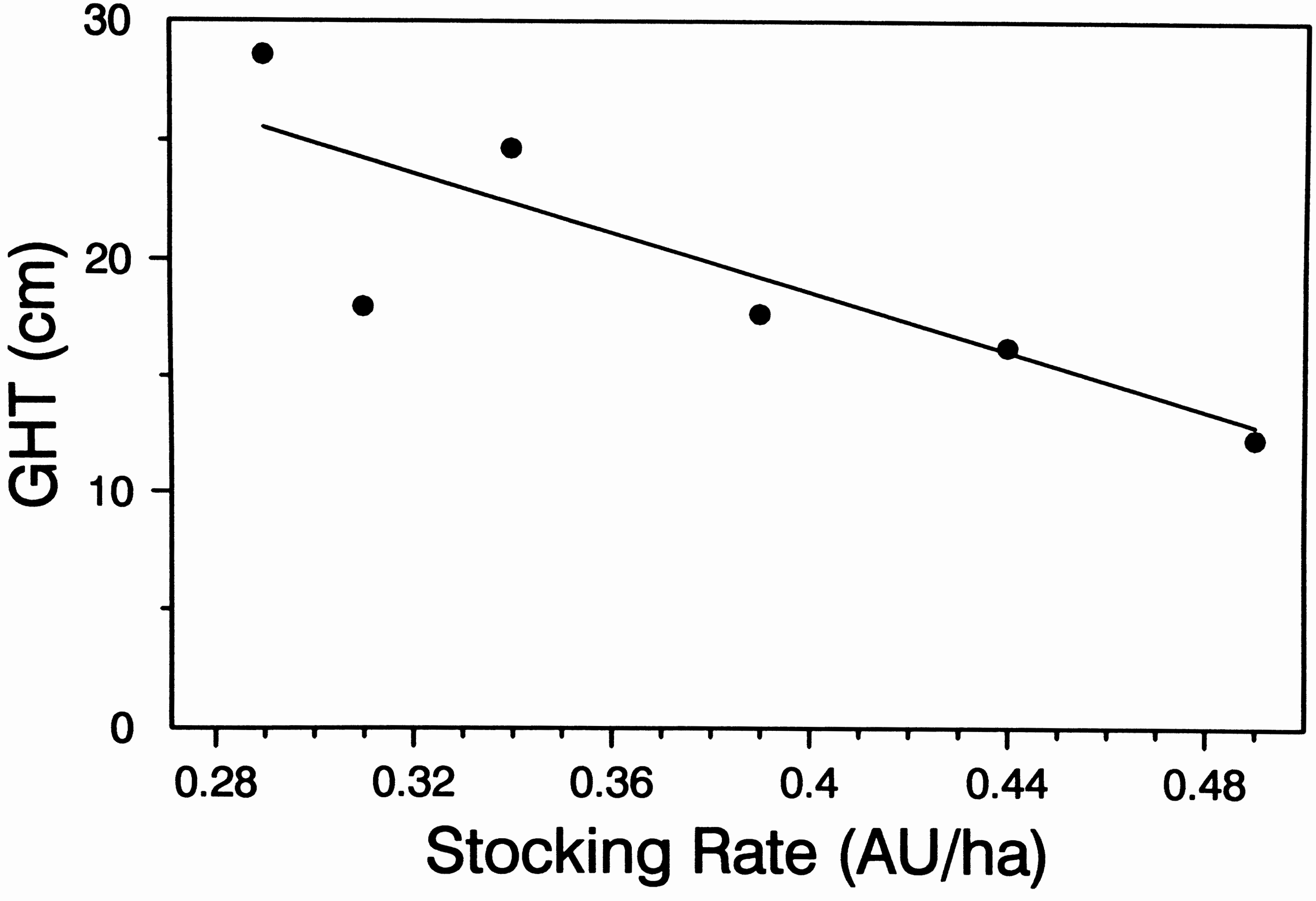
0.32
0.36
0.4
0.44
0.48
Stocking Rate (AU/ha)



GHT (cm)
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10
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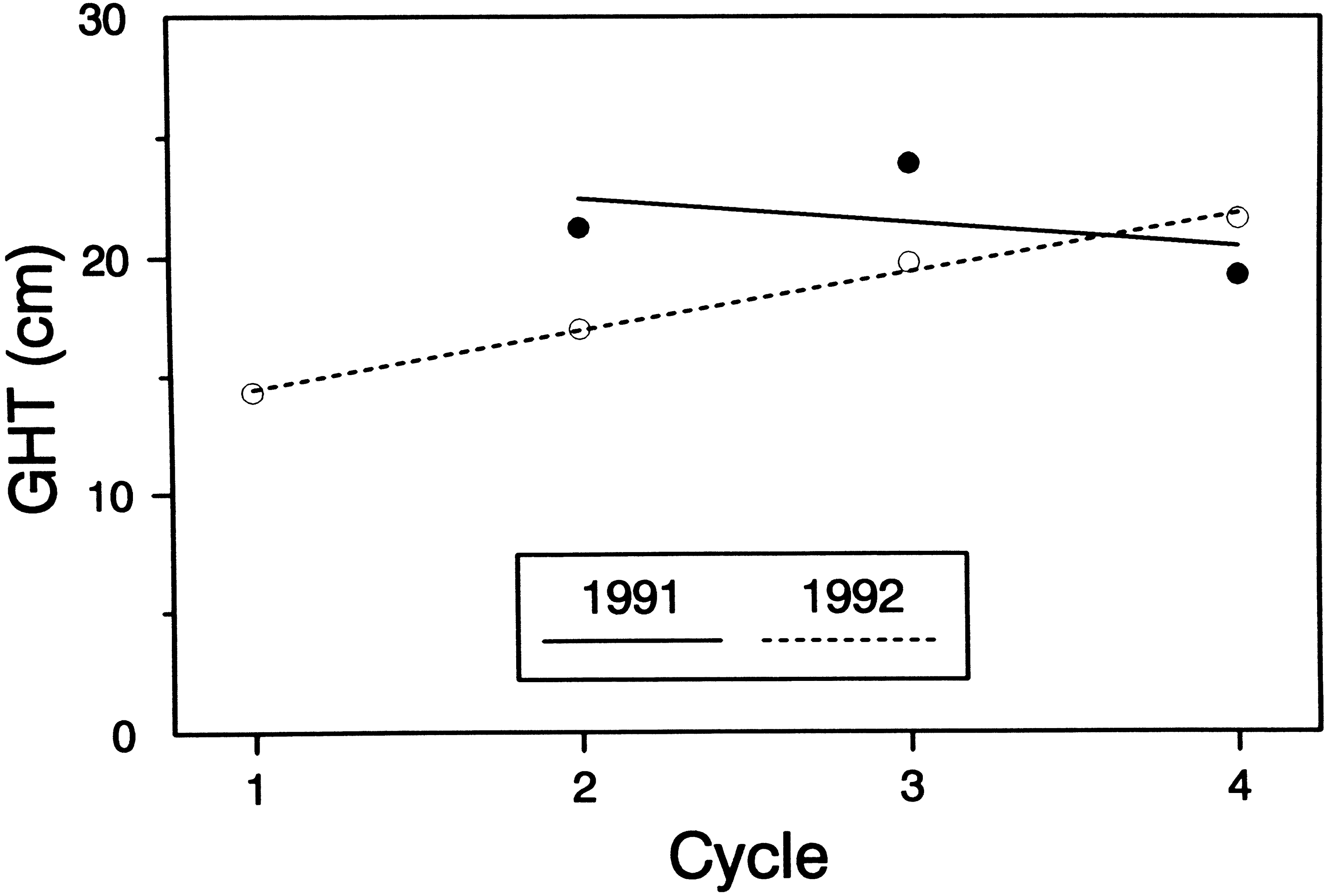
0.28
0.32
0.36
0.4
0.44
0.48
Stocking Rate (AU/ha)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20
10
0
GHT (cm)
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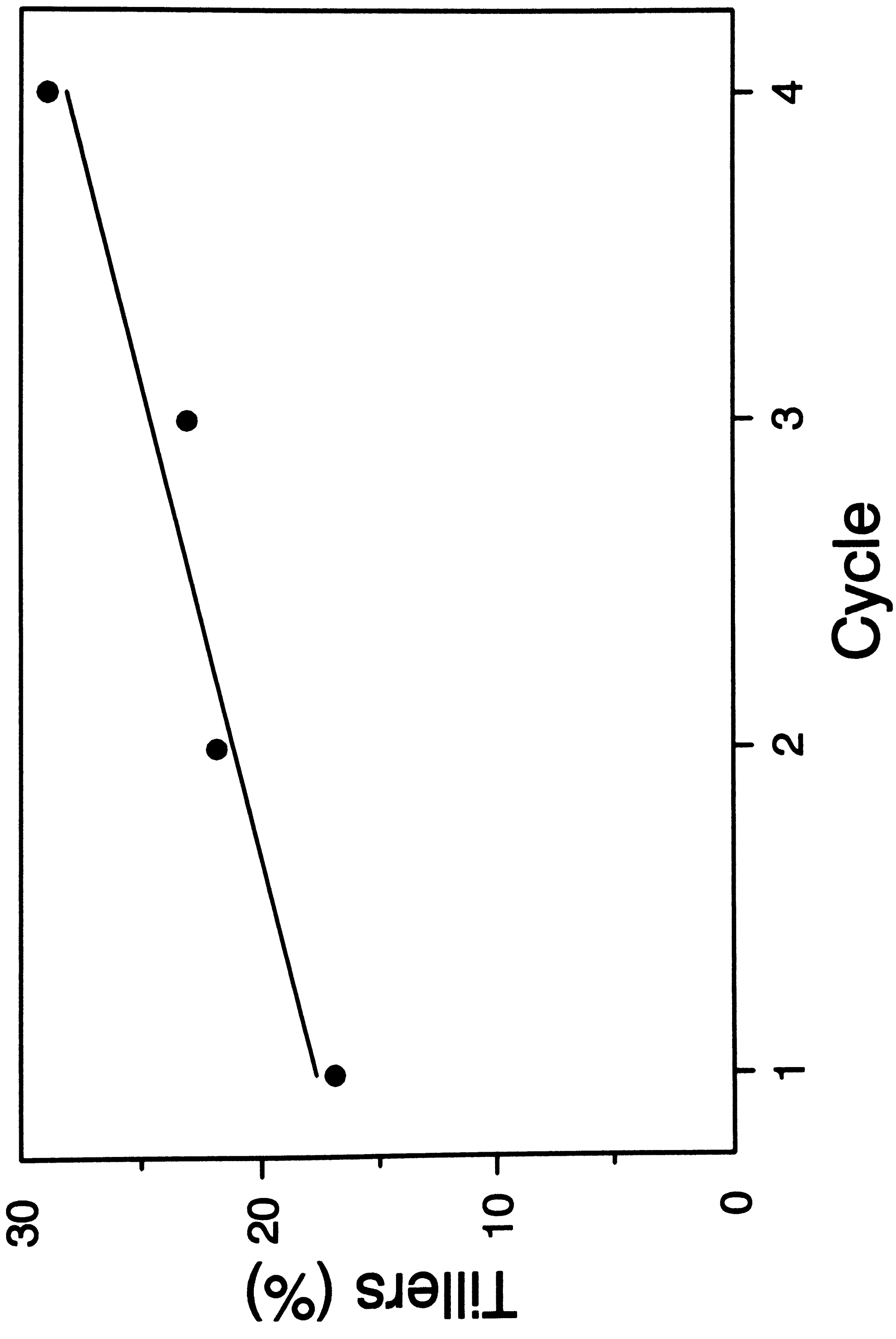
2
3
4
Cycle
1991
1992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10
20
30
Cycle
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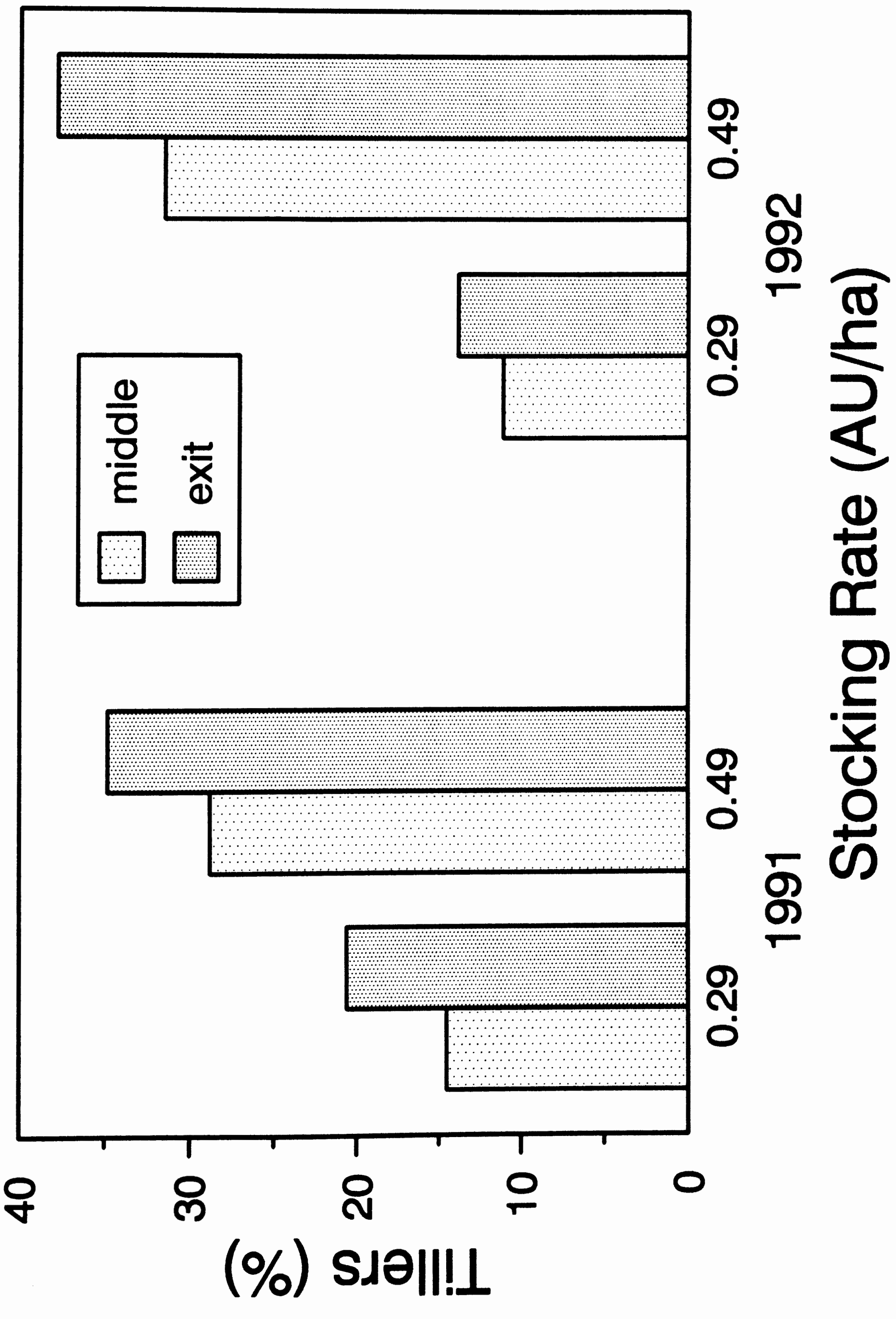
2
3
4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20
30
40
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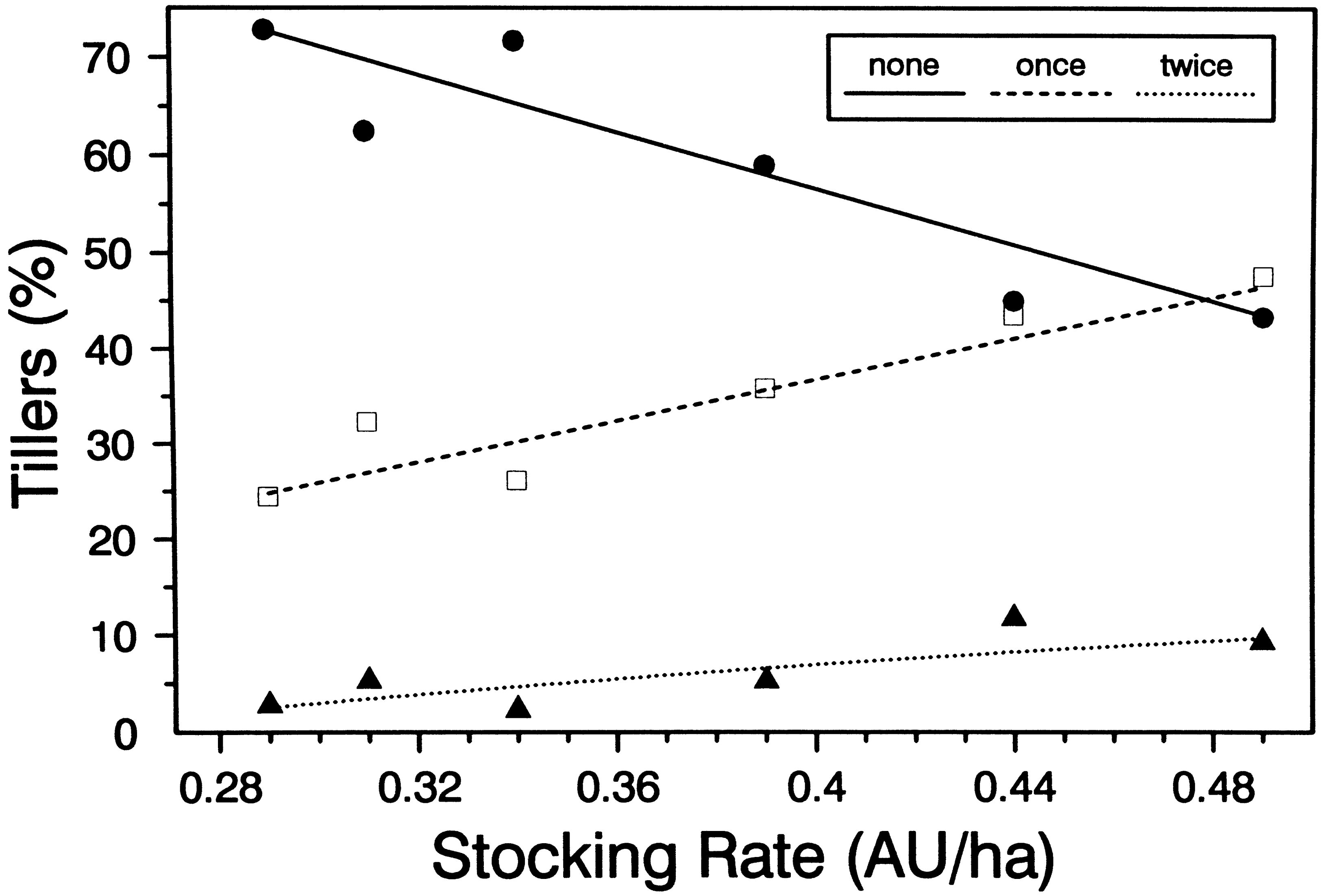
exit
0.29
0.49
1991
0.29
0.49
1992
Stocking Rate (AU/ha)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once
twice
Tillers (%)
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10
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30
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50
60
70
0.28
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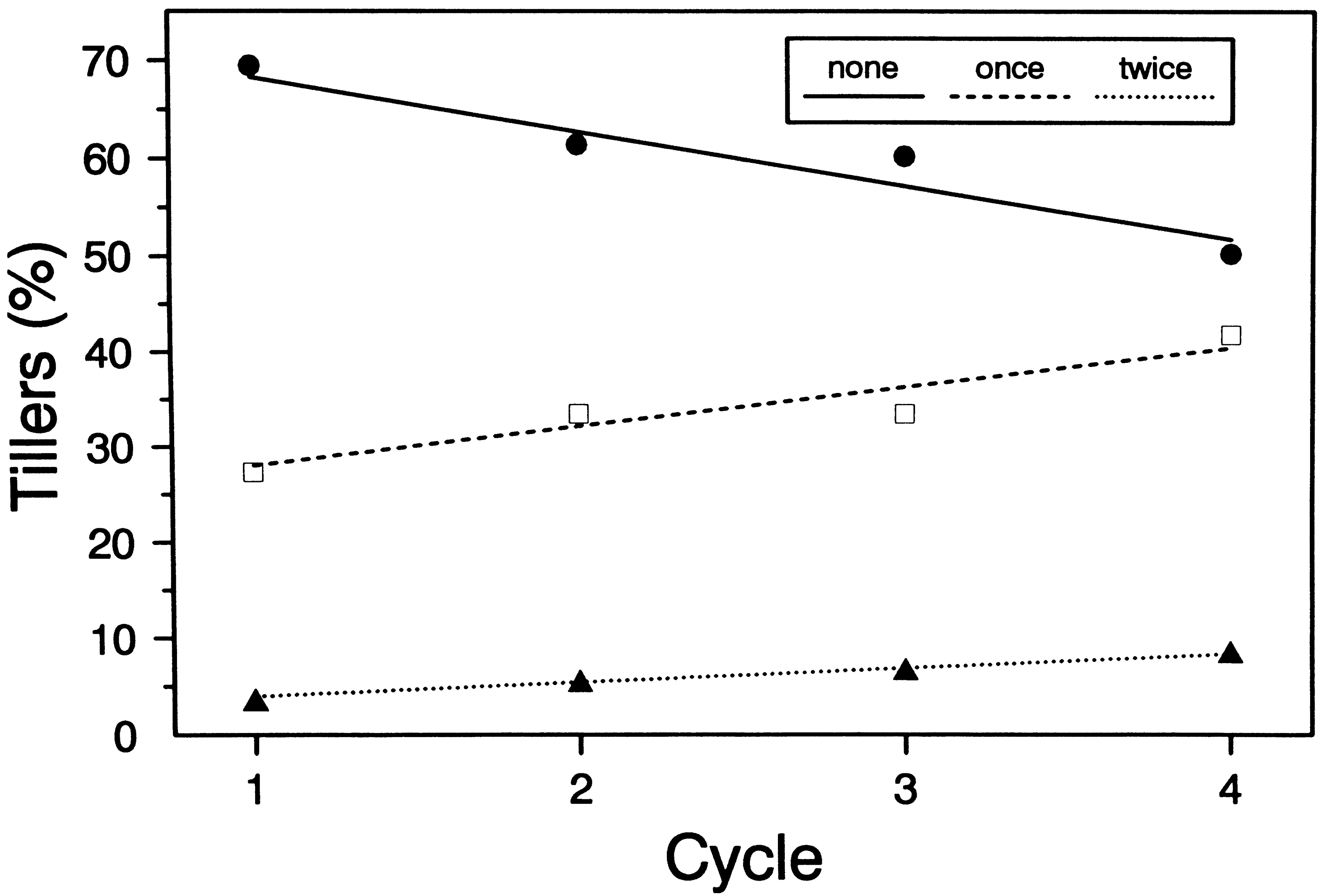
0.4
0.44
0.48
Stocking Rate (AU/ha)



Tillers (%)
70
60
50
40
30
20
10
0
1
2
3
4
Cycle
none
once
twice

VITA

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