STOCKING RATE AND GRAZING SYSTEM EFFECTS ON STANDING CROP DYNAMICS

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PREFACE

Chapter I is a review of current literature concerning the effects of grazing systems and stocking rates on standing crop in native and introduced pastures. Chapter II presents the results of the study and is written in a format suitable for immediate submission to the Journal of Range Management. The appendix contains a supplementary analysis of the data using GLM regression to evaluate Type I sums of squares with respect to linear/quadratic effects and grazing system/stocking rate effects on standing crop.

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CHAPTER I

LITERATURE REVIEW

Short duration grazing has received wide attention in recent years as a method for increasing forage productivity. Short duration grazing (SDG) is a holistic grazing management system based on subdividing large pastures into smaller paddocks, moving the herd from paddock to paddock every 1 to 15 days, and allowing each paddock to rest 20 to 60 days. This grazing technique is claimed to allow key forage species to rest and recover, greatly improve forage production and quality, and dramatically increase stocking rates without range deterioration (Savory 1978).

Models of plant growth responses to SDG and continuous grazing (CG) have been developed to describe several management scenarios. These models have shown standing crop production to be primarily dependent on factors other than grazing system. Noy-Meir's models (1976) indicated moderate rotation had minor effects on plant productivity when compared to continuous grazing; intensive rotation decreased productivity with a moderate stocking rate, initially high standing crop, and absence of ungrazeable plant residual; and intensive rotation increased productivity with a high stocking rate, initially low standing crop, and presence of ungrazeable residual. Morley (1968) developed pasture growth models that predicted the length of time needed to attain maximum plant productivity was not sharply defined in rotational systems. Plant growth rates, which were primarily affected by temperature, light intensity, and photoperiod, were more variable than the optimum length for grazing periods.

Field experiments of SDG and CG systems have had mixed results. Some researchers have reported little or no difference between standing crop yields for the two grazing systems, while others have found SDG to be a superior system for increasing forage biomass.

Gutman et al. (1990) calculated forage consumption by beef cattle maintained at different stocking densities under seasonal and yearlong grazing systems on Mediterranean grasslands. The effect of stocking density or grazing system on forage biomass production was not statistically significant; plants might have been more sensitive to nutrient availability and seasonal distribution of soil moisture.

Long-term effects of moderate continuous grazing, heavy continuous grazing and heavy rotational grazing on the quantity of available forage were studied by Heitschmidt et al. (1989). Aboveground standing crop dynamics in southern mixed grass prairies were not significantly different in both grazing systems, although available forage quantity was generally higher in the moderately stocked pastures.

Seasonal standing crop of tallgrass prairie under short duration grazing with different grazing schedules and stocking rates was studied by Brummer et al. (1988). Three grazing schedules of 2, 3, or 4 rotation cycles per 152-day grazing season and two stocking rates corresponding to 1.3X (light) and 1.8X (heavy) of Soil Conservation Service recommended rates were evaluated. Average seasonal standing crop increased from the 4-cycle to the 2-cycle system at the light stocking rate, but not at the heavy stocking rate. Standing crop was affected by grazing schedule in 1 of 2 years. Grazing schedule had limited and inconsistent effects on standing crop, but the standing crop response might have been attributed to above-average precipitation, which resulted in relatively light utilization.

Hart et al. (1986, 1988) compared continuous grazing (CG), rotationally deferred grazing (RDG), and short duration grazing (SDG) systems on mixed-grass range in Wyoming. Basal cover of vegetation was affected by year, but not by stocking rate or type of grazing system. No significant differences in total herbage production among grazing systems or stocking rates occurred, although differences in production did occur as a result of variation in timing and amount of precipitation.

Cattle, sheep, and goats were used to evaluate moderate and heavy grazing intensities on oak-grassland plant communities in Texas (Thurow et al. 1988). The stocking rates used were (1) 8.1 ha AU^{-1} for the moderate continuous treatment; (2) 4.6 ha AU^{-1} for the heavy continuous treatment; and (3) 4.6 ha AU^{-1} for the heavy rotational treatment. Differences in aboveground biomass for heavily-stocked rotational and continuous systems were not significantly different. The residual forage in the moderately stocked pastures was significantly higher than that of the heavily stocked pastures.

Pitts and Bryant (1987) evaluated vegetation response to year-long short duration grazing and continuous grazing systems. SDG pastures were stocked at a rate equal to the CG pastures in the first year of the study, twice the stocking rate of the CG pastures in the second year, and 1.5 times the CG stocking rate in the third and fourth years. Total standing biomass in the SDG was less than CG after the second year. SDG did not improve forage standing crop over CG when evaluated over the 4-year period.

Kirby et al. (1986) found similar forage disappearance estimates between continuously grazed pastures stocked at 3.5-5.2 ha AU^{-1} and 8-cell rotational pastures stocked at 2.2-3.0 ha AU^{-1}. Rotational systems could sustain 45-50% more cattle than seasonlong continuous grazing systems.

Jung et al. (1985) found although forage availability on smooth bromegrass (Bromus inermis) pastures tended to be higher under SDG than CG, the difference was not significant.

Pitt and Heady (1979) noted annual pastures grazed by sheep at moderate and heavy stocking rates exhibited similar trends in cover and botanical composition. Annual precipitation and possible inherent pasture differences may have been overriding factors. Annual grasslands seemed to be tolerant to a wide range of stocking rates.

While evaluating Tanzanian grasslands, O'Rourke (1978) found that heavy (1.2 ha AU^{-1}) stocking rates resulted in 1000 kg ha^{-1} less forage production than moderate (3.6 ha AU^{-1}) or light (6.1 ha AU^{-1}) rates. Very little difference in vegetation response could be attributed to grazing system. Pratchett and Schrivel (1978) tested several grazing systems in three different ecological and rainfall zones. The systems were (1) continuous; (2) 3 paddocks (graze 1 month/rest 2 months); (3) 9 paddocks (graze 4 days/rest 32 days); and (4) 9 paddocks (graze 7 days/rest 56 days). Stocking rates for all systems were 10 ha AU^{-1} and 8 ha AU^{-1} during the first year and second years, respectively. Little or no difference in dry matter yield or botanical composition occurred between the various treatments.

Computer simulations of standing crop dynamics under SDG and CG with merino sheep suggested that the rest:graze time ratio played an important role in the amount of forage biomass remaining in the pasture at the end of the season (White and O'Connor 1986). Six-paddock and 4-paddock systems were superior to 2-paddock and 1-paddock systems with respect to having higher final standing crops.

Wilson (1986) summarized the major principles governing grazing management systems. Stocking rate was regarded as the major factor impacting animal performance, range resilience, and type of grazing system. Grazing systems were generally less successful in achieving production goals and promoting range condition than continuous grazing. Rotational systems were recommended only if the rest periods in the cycle resulted in improved botanical composition or enhanced reproduction or survival of desirable grass species.

The response of herbage production to grazing systems (18 studies) and stocking intensities (14 studies) was reviewed by Van Poollen and Lacey (1979). For rotation, deferred, and rest rotational grazing systems herbage production was 13% greater than for continuous systems, although herbage response did vary by geographic region. The greatest growth responses occurred in the southwestern U.S. Herbage production consistently increased with reductions in grazing intensity. Mean increases of 35 and 28% occurred when use was reduced from heavy to moderate, and from moderate to light, respectively. Although stocking rate and grazing system both affected herbage growth, livestock numbers had greater impacts on standing crop than type of grazing system.

Principles of grassland management in South Africa enumerated by Booysen and Tainton (1978) included planning for seasonal climatic fluctuations, using stocking rates suited for enhancing desirable species composition, and using rotational grazing systems to maintain sward composition. Continuous grazing systems resulted in deterioration of grasslands and led to severe difficulties in re-establishing productive species.

Pieper et al. (1978) reported that both total forage production and individual grass species production were greater under a 4-pasture, 1-herd rotation system than under continuous grazing. Stocking rates were moderate to heavy for the continuous treatments; the rotational treatment had heavy stocking rates. Confinement in the smaller paddocks may have depressed intake or restricted plant species selectivity, resulting in higher remaining standing crops. During the droughts of 1970, 1971, and 1974, grass production was especially depressed in the heavily-stocked, continuous pastures, and grazing had to be discontinued; grazing was maintained, however, in the rotational systems during this period.

Kothmann et al. (1978) determined that stocking rate and weather influenced standing crop more than type of grazing system. Plant species composition, however, did differ between continuous systems (7.5 and 5.2 ha AU^{-1}), a Merrill system (7.1 ha AU^{-1}), and no grazing. Standing crop was 700 kg ha^{-1} less for the higher-stocked continuous system compared to the lower-stocked one, resulting in 10-15% less forage production.

In summary standing crop biomass has been shown to respond primarily to factors other than grazing system in most studies, however, conflicting conclusions resulting from these studies have not been adequately addressed. Stocking rate has a more clearly defined impact on standing crop dynamics, but the interactions between grazing system and stocking rate are not well understood. Further investigation under a variety of grazing regimes is needed to assess the true impact of these factors.

CHAPTER II

STOCKING RATE AND GRAZING SYSTEM EFFECTS ON STANDING CROP DYNAMICS

Abstract

Grazing system and stocking rate effects on forage standing crop of tallgrass prairies in north-central Oklahoma were evaluated from 1989 to 1991. Twelve experimental units, consisting of pastures dominated by big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), indiangrass (*Sorghastrum nutans* (L.) Nash), and switchgrass (*Panicum virgatum* L.), were arranged in a completely randomized design with either a short duration rotation (SDG) or continuous (CG) grazing system and stocking rates ranging from 0.9 to 2.2 ha hd^{-1}. Standing crop data, collected in June, July, and September, were analyzed using linear regression procedures to generate the best predictive models for total, live, and dead standing crops. Total, live, and dead standing crops did not differ significantly between the two grazing systems during early and mid-summer. In late summer and during 1990, rotational systems had more total and dead biomass than continuous systems, but live herbage

components were not significantly different between SDG and CG. Stocking rates had significant effects on total, live and dead standing crops throughout the study. In nearly every case where stocking rate were significant, standing crop was higher as stocking rate decreased. Stocking rate had more impact on total and live standing crop than on dead herbage. The greatest impact of stocking rate occurred in late summer with rotational systems. Long-term maintainance of high-quality range for forage production could be enhanced by use of appropriate grazing systems and stocking rates to allow more standing crop to remain at the end of the season.

Introduction

In recent years rotational grazing has been suggested as a method for increasing livestock numbers while maintaining range condition and forage quality on a given area of land. However, research results for the superiority of rotational grazing over continuous grazing systems have been contradictory. Numerous studies have shown rotational systems to be quite similar to continuous systems with respect to standing crop dynamics. Gutman et al. (1990) and Kothmann (1978) concluded that standing crop biomass was not significantly affected by grazing system. Similar conclusions were reached by Heitschmidt et al. (1989), Hart et al. (1988), Jung et al. (1985), and O'Rourke (1978).

Pratchett and Schrivel (1978) also found little or no difference in dry matter yield or botanical composition between several grazing systems in three different ecological and rainfall zones.

In contrast to these results, other studies seem to favor short duration grazing over continuous systems. Computer simulations of SDG and CG with merino sheep suggested that the rest:graze time ratio affected standing crop; theoretically, 6- and 4-paddock systems had higher final biomass than 2- and 1-paddock systems (White and O'Connor 1986). Pieper et al. (1978) reported that both total forage production and individual grass species production were greater under SDG than under CG.

Most research indicates that standing crop decreases with increasing stocking rate. Several researchers have suggested that stocking rate affects standing crop more than grazing system (Wilson 1986; Van Poollen and Lacey 1979; Kothmann et al. 1978), while others have noted no significant difference in standing crop among different stocking rates (Gutman et al. 1990; Heitschmidt et al. 1989; Pitt and Heady 1979). Other researchers have affirmed that standing crop increases with decreasing stocking rate (Brummer et al. 1988; Thurow et al. 1988; Van Poollen and Lacey 1979; O'Rourke 1978).

Grazing system and stocking rate effects on standing crop have not been extensively investigated in tallgrass prairie ecosystems. Efficient use of these resources is necessary to maintain good range condition over the long term. Better management decisions based on an understanding of grazing system and stocking rate influences can also result in increased profits for cattle raisers. The purpose of this study was to evaluate the effects of continuous and rotational grazing systems at several stocking rates on standing crop dynamics of tallgrass prairie.

Study Area

The study was conducted from 1989 to 1991 at the Oklahoma State University Research Range, located approximately 21 km southwest of Stillwater, Oklahoma (36°22'N, 99°04'W). The climate is continental with an average frost-free growing period of 204 days, extending from April to October. Average annual precipitation for the area is 831 mm with 65% falling as rain from May to October. The mean annual temperature is 15°C, and ranges from a minimum of -4.3°C in January to a maximum of 34°C in August (Myers 1982). The study area was approximately 40% loamy prairie with Coyle, Coyle-Lucien, Coyle and Zaneis, Mulhall, and Zaneis-Huska soils associations; 35% shallow prairie with Grainola, Grainola-Ashport, and Grainola-Lucien associations; 15% claypan prairie with Masham, and Renfrow-Grainola associations; and 10% sandy or shallow savannah with Stephenville-Darnell associations. Dominant grasses included big bluestem (Andropogon gerardii Vitman), little bluestem (Schizachyrium scoparium (Michx.) Nash), indiangrass (Sorghastrum nutans (L.) Nash). Switchgrass (Panicum virgatum L.) was prominent in localized areas.

Materials and Methods

The experimental design consisted of a completely randomized design with grazing system and stocking rate as treatments. Six of twelve experimental units, ranging in size from 16 to 32 ha, were randomly assigned to a rotational grazing system, and the remaining 6 units were assigned to a continuous grazing system. The rotation units were subdivided into 8 pastures, and cattle in the rotational systems were moved between pastures every 3 to 7 days. Within each grazing system the units were randomly allocated to 1 of 6 levels of stocking rate. The stocking rates ranged from 2.2 to 0.9 ha hd^{-1} to represent moderate to very heavy rates for this range type. The pastures were grazed from early April until late September by mixed-breed yearling beef cattle with average initial weights of 200-225 kg. All units were burned in 1990.

Standing crop was measured in June, July, and September by clipping at ground level the total standing crop in 45, 0.1-m^2 quadrats located systematically in a grid pattern in each pasture. The live:dead herbage ratio was determined according to the technique of Gillen and Tate (1993).

Regression models of the form:

DWT DWL DWD = GRSYS + STRT + (GRSYS*STRT) + $STRT^2$ + ($GRSYS*STRT^2$) were used to describe total, live, and dead standing crop (denoted by DWT, DWL, and DWD, respectively) based on grazing system (GRSYS), stocking rate (STRT), grazing-system-by-stocking-rate interaction (GRSYS*STRT), stocking rate squared ($STRT^2$), and grazing-schedule-by-stocking-rate-squared interaction ($GRSYS*STRT^2$). Two linear regression techniques, STEPWISE and MAXR (SAS 1985), were applied to the models. The best regression models for each month and year were selected based on the following criteria: (1) all variables significant at $\alpha = 0.10$ level; (2) lowest mean square error (MSE); and (3) highest coefficient of determination (R^2).

Results and Discussion

Total Standing Crop. Total standing crop was correlated with growing-season precipitation for the three years (Fig. 1 and 2). Similar correlations between standing crop and precipitation had previously been observed by Gutman et al. (1990), Brummer et al. (1988), Hart et al. (1988), and Pitt and Heady (1979). Growing-season rainfall (April-September) in 1989 was 727 mm, or 31% greater than the average growing-season mean of 556 mm. Unusually low precipitation in April (9 mm, or 75 mm less than average) was offset by abundant precipitation in June and July (71% and 93% above normal).

Mean standing crop over all stocking rates and grazing system combinations increased during this time from 2,490 kg ha^{-1} in June to 4500 kg ha^{-1} in September. June rainfall was only 41 mm, or 38% of normal in 1990. Even though the cumulative growing-season rainfall for 1990 was only slightly less (93%) than average, the 1990 mean standing crop ranged from 1,850 kg ha^{-1} in June to 2,670 kg ha^{-1} in September, or about 60% of the biomass found in 1989 and 1991. Less total biomass in 1990 demonstrated the importance of timing and amount of precipitation during the early growing season. The decreased total standing crop may also have been a reflection of lower-than-normal standing dead herbage in September, 1990, as the burn earlier that year removed standing dead from the previous growing season. In 1991, growing-season rainfall was 90% of normal (500 mm), and total biomass values ranged from 4,440 kg ha^{-1} in June to 4,330 kg ha^{-1} in September.

Regression models providing the best predictions for total standing crop for each of the sampling periods had coefficients of determination ranging from 0.62 to 0.76, indicating good fit between the models and the observed data (Table 1 and Fig. 2). Three models for total standing crop in June and July had the lowest predictive performance. All variables were nonsignificant for June, 1989, so no coefficient of determination was computed for that month.

The rotational grazing system had more ($p \leq 0.10$) total standing crop than the continuous grazing system in 5 of 9 sampling periods (Fig. 3). Heitschmidt et al. (1989) and Van Poollen and Lacey (1979) also found greater total forage in rotational systems. In a review of grazing system literature Booysen and Tainton (1978) also found the rotational systems generally had more end-of-season standing crop than continuous systems. The difference in biomass in response to grazing system was smaller as stocking rate decreased. Possible explanations for this increased biomass in the rotational systems include: (1) enhanced growth due to rest from grazing (Savory 1978); (2) depressed forage intake by cattle as they are moved rapidly through the system (Pieper et al. 1978); or (3) less tiller defoliation (Derner 1993).

Total standing crop was usually higher as stocking rate decreased; these results concurred with those of Brummer et al. (1988), Thurow et al. (1988), Van Poollen and Lacey (1979), and O'Rourke (1978). As more animals per unit area were included, their total dietary dry matter needs increased, so the lower biomass at the heavier stocking rates was an expected result.

No stocking rate effect was observed in June, 1989, but by July, the total biomass for both the rotational and continuous systems was higher with decreasing stocking rates. In September, 1989, forage biomass increased, then decreased over the range of stocking rates in the continuous system. The specific cause for this shift in standing crop was not apparent. Although yields for SDG were 370 to 1870 kg ha^{-1} more than CG during this September, 1989, residual forage for both systems increased, then decreased from very heavy to moderate stocking rates.

SDG stocking rates above 1.25 ha hd^{-1} had more total herbage compared to the continuous system in June 1990; however, at heavier stocking rates total standing crop was lower for the SDG system. This is the only time during the 3-year study that the rotational system had lower total standing crop than the continuous system. Significantly different amounts of total standing crop did occur between the lowest and highest stocking rates for both CG and SDG, however.

Live Standing Crop. Stocking rate and grazing system variables by themselves were usually not adequate to describe live herbage residual trends (Table 2 and Fig. 4). In September, 1989, live biomass peaked at the moderate stocking rates in the continuous system only. Since all units were burned in March, 1990, no standing dead material was present in June, so live standing crop was equal to total standing crop.

Live herbage followed the same general trends as the total biomass results except live standing crop decreased while total standing crop increased with respect to stocking rate in September, 1989, and July, 1990 (Fig. 3 and 4). Less live herbage remained in the continuous grazing system compared to the rotational grazing system whenever a significant ($p \leq 0.10$) difference due to grazing occurred. The amount of live standing crop remaining in the heavily-stocked units was also less than that in the more lightly-stocked units, a result which was also consistent with the total standing crop trends. Since cattle graze selectively for live herbage (McNaughton 1985; Noy-Meir 1976), this component of the total biomass would be affected to a greater extent than dead herbage by grazing system or stocking rate effects.

Dead Standing Crop. Dead standing crop appeared to be inversely related to the amount of live standing crop available. Table 3 and Figure 5 show the best regression models and graphs for estimating standing dead biomass for each sampling period. No dead standing crop was present in June, 1990, because fire had removed all dead biomass from the units.

The difference in dead biomass between grazing systems in September, 1989, may be a result of the higher live standing crop from earlier in the summer reaching maturity. In September, 1990, forage was limited because of low rainfall, so the cattle may have grazed more dead standing crop to meet their nutritional needs.

Conclusions

Grazing system had an impact on total standing crop during in about half of the trials. Whenever a significant difference due to grazing system occurred, rotational systems had higher total standing crop than continuous systems.

Generally speaking, grazing system did not have a major effect on live biomass. In 1990, however, drought may have resulted in low live standing crop; during this time the rotational system had significantly more live residual biomass.

Rotational systems and continuous systems exhibited similar results with respect to their effects on dead herbage. Only in late summer was a detectable difference between the systems observed, possibly the result of higher end-of-season standing dead as the grasses matured.

Stocking rate usually had significant effects on total, live, and dead standing crop. In nearly every case when stocking rate made a difference, total biomass increased as stocking rates decreased. Stocking rate had more impact on total and live forage biomass than on standing dead. Stocking rates had the greatest impact in late summer and with rotational systems.

LITERATURE CITED

Booysen, P.V., and Tainton, N.M. 1978. Grassland management: principles and practice in South Africa. pp. 551-554. In: D.N. Hyder (ed.): Proc. First Int. Rangeland Congr. Denver, CO.

Brummer, J.E., R.L. Gillen, and F.T. McCollum. 1988. Herbage dynamics of tallgrass prairie under short duration grazing. J. Range Manage. 41:264-266.

Derner, J.D. 1993. Little bluestem tiller defoliation patterns under continuous and rotational grazing. M.S. thesis. Oklahoma State Univ. Stillwater, OK.

Gillen, R.L. and K.W. Tate. 1993. An evaluation of the constituent differential method for determining live and dead herbage fractions. J. Range Manage. 46:142-147.

Gutman, M., N.G. Seligman, and I. Noy-Meir. 1990. Herbage production of Mediterranean grassland under seasonal and yearlong grazing systems. J. Range Manage. 43:64-68.

Hart, R.H., M.J. Samuel, P.S. Test, and M.A. Smith. 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. J. Range Manage. 41:282-286.

Hart R.H., P.S. Test, A. Abdel-Magid, G.E. Schuman, and M.A. Smith. 1986. Short-duration rotation grazing: theory vs. practice. In: Rangelands: a resource under siege. Proc. Second Int. Rangeland Congr. Adelaide, S. Australia.

Heitschmidt, R.K., S.L. Dowhower, W.E. Pinchak, and S.K. Cannon. 1989. Effects of stocking rate on quantity and quality of available forage in a southern mixed grass prairie. J. Range Manage. 42:468-473.

Jung, H.G., R.W. Rice, and L.J. Koong. 1985. Comparison of heifer weight gains and forage quality for continuous and short-duration grazing systems. J. Range Manage. 38:144-148.

Kirby, D.R., T. Conlon, D. Landblom, J. Nelson, P. Nyren, and T. Stromberg. 1986. Short duration grazing in North Dakota: preliminary results. North Dakota Farm Res. 44:3-5.

Kothmann, M.M., W.J. Waldrip, and G.W. Mathis. 1978. Rangeland vegetation of the Texas Rolling Plains: response to grazing management and weather. pp. 606-609. In: D.N. Hyder (ed.) Proc. First Int. Rangeland Congr. Denver, CO.

McNaughton, S.J. 1985. Ecology of a grazing ecosystem: the Serengeti. Ecol. Monographs 55:259-294.

Morley, F.H.W. 1968. Pasture growth curves and grazing management. Austr. J. Exp. Agr. and Animal Husbandry 8:40-45.

Myers, H.R. 1982. Climatological data of Stillwater, Oklahoma 1893-1980. Oklahoma Agr. Exp. Sta. Rep. P-821.

Noy-Meir, I. 1976. Rotational grazing in a continuously growing pasture: a simple model. Agr. Systems 1:87-112.

O'Rourke, J.T. 1978. Grazing rate and system trial over 5 years in a medium-height grassland of northern Tanzania. pp. 563-566. In: D.N. Hyder (ed.). Proc. First Int. Rangeland Congr. Denver, CO.

Pieper, R.D., G.B. Donart, E.E. Parker, and J.D. Wallace. 1978. Livestock and vegetational response to continuous and 4-pasture, 1-herd grazing systems in New Mexico. pp. 560-562. In: D.N Hyder (ed.). Proc. First Int. Rangeland Congr. Denver, CO.

Pitt, M.D., and H.F. Heady. 1979. The effects of grazing intensity on annual vegetation. J. Range Manage. 32:109-114.

Pitts, J.S., and F.C. Bryant. 1987. Steer and vegetation response to short duration and continuous grazing. J. Range Manage. 40:386-389.

Pratchett, D., and B. Schirvel. 1978. The testing of grazing systems on semiarid rangeland in Botswana. pp. 567-568. In: D.N. Hyder (ed.). Proc. First Int. Rangeland Congr. Denver, CO.

SAS Institute, Inc. 1985. pp. 270-335. In: Stephanie P. Joyner (ed.). SAS/STAT Guide for Personal Computers, Version 6 Edition. Cary, NC. 378 pp.

Savory, A. 1978. A holistic approach to ranch management using short duration grazing. pp. 555-557. In: D.N. Hyder (ed.). Proc. First Int. Rangeland Congr. Denver, CO.

Thurow, T.L., W.H. Blackburn, and C.H. Taylor, Jr. 1988. Some vegetation responses to selected livestock grazing strategies, Edwards Plateau, Texas. J. Range Manage. 41:108-114.

Van Poollen, H.W., and J.R. Lacey. 1979. Herbage responses to grazing systems and stocking intensities. J. Range Manage. 32:250-253.

White, E.G., and K.F. O'Connor. 1986. Strategies for rotational grazing based on computer simulation of field experiments. pp. 253-254. In: Joss, P.J., P.W. Lynch, and O.B. Williams (eds.). Rangelands: a resource under siege. Proc. Second Int. Rangeland Congr. Adelaide, S. Australia.

Wilson, A.D. 1986. Principles of grazing management systems. pp. 221-225. In: Joss, P.J., P.W. Lynch, and O.B. Williams (eds.). Rangelands: a resource under siege. Proc. Second Int. Rangeland Congr. Adelaide, S. Australia.

Table 1. Regression coefficients for equations predicting total standing crop by month using grazing system (GRSYS) and stocking rate (STRT).[1]

Year	Month	INTERCEPT	GRSYS	STRT	GRSYS*STRT	$STRT^2$	$GRSYS*STRT^2$	R^2	MSE
1989	June	2490						---	---
	July	1800		1230				0.55	136790
	Sept	1890		7730		-2370	360	0.73	174710
1990	June	1540			-990		790	0.37	71660
	July	320		1130				0.45	104550
	Sept	950				480	260	0.62	154720
1991	June	-580	810	2840				0.75	264280
	July	-1560		4610				0.69	645330
	Sept	-1390	590	3340				0.76	298830

[1] All variables significant at $P \leq 0.10$. N=12 for all models. No variables were significant at $P \leq 0.10$ for June, 1989 and June, 1990.

Table 2. Regression coefficients for equations predicting live standing crop by month using grazing system (GRSYS) and stocking rate (STRT).[1]

Year	Month	INTERCEPT	GRSYS	STRT	GRSYS*STRT	$STRT^2$	$GRSYS*STRT^2$	R^2	MSE
1989	June	2035						---	---
	July	1320		860				0.43	107330
	Sept	-1280	230	4300		-1220		0.73	34620
1990	June	1540			-1140		950	0.53	53560
	July	890					320	0.57	66800
	Sept	340				490	230	0.85	34018
1991	June	370		1410				0.61	139300
	July	-740		2510				0.54	579620
	Sept	20		880				0.65	44900

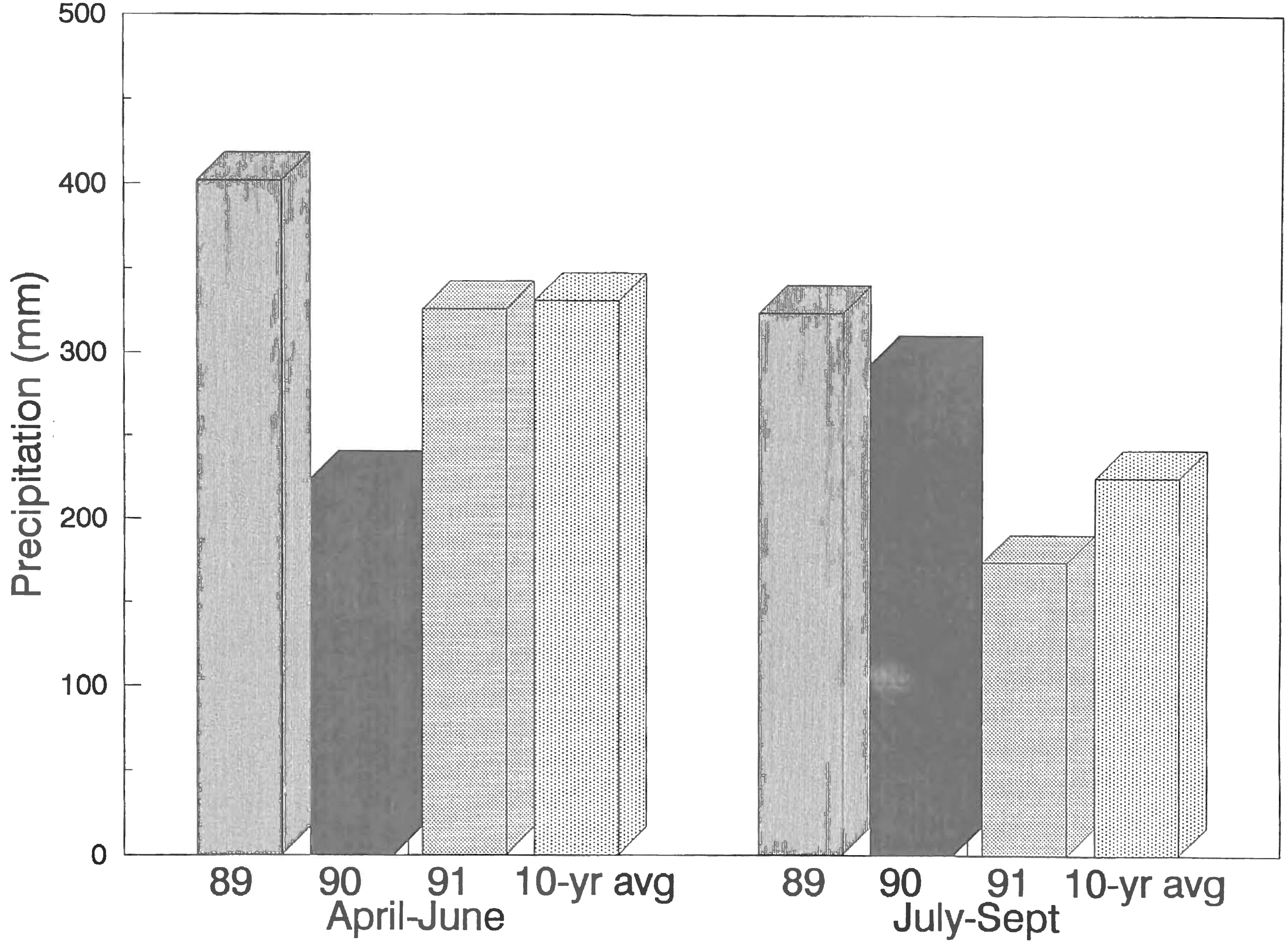
[1] All variables significant at $P \leq 0.10$. N=12 for all models. No variables were significant at $P \leq 0.10$ for June, 1989, and June, 1990.

Table 3. Regression coefficients for equations predicting dead standing crop by month using grazing system (GRSYS) and stocking rate (STRT).[1]

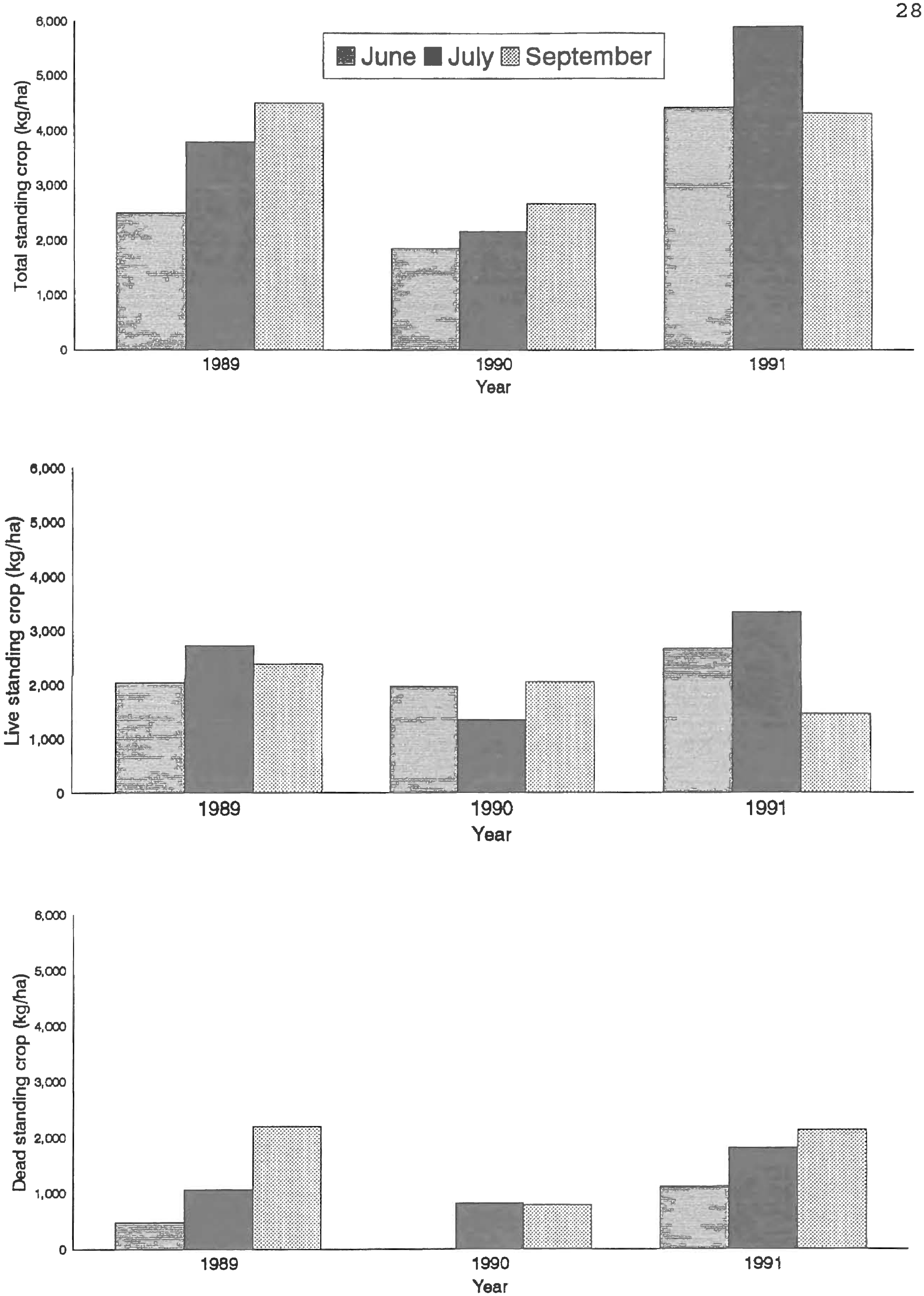
Year	Month	INTERCEPT	GRSYS	STRT	GRSYS*STRT	$STRT^2$	$GRSYS*STRT^2$	R^2	MSE
1989	June	480						---	---
	July	480		360				0.35	27280
	Sept	1860					240	0.47	149710
1990	June	0						---	---
	July	390				150		0.20	38280
	Sept	570					150	0.44	23700
1991	June	-80		880				0.24	267330
	July	-2860		5060		-1260		0.82	38980
	Sept	-250		1580				0.44	352910

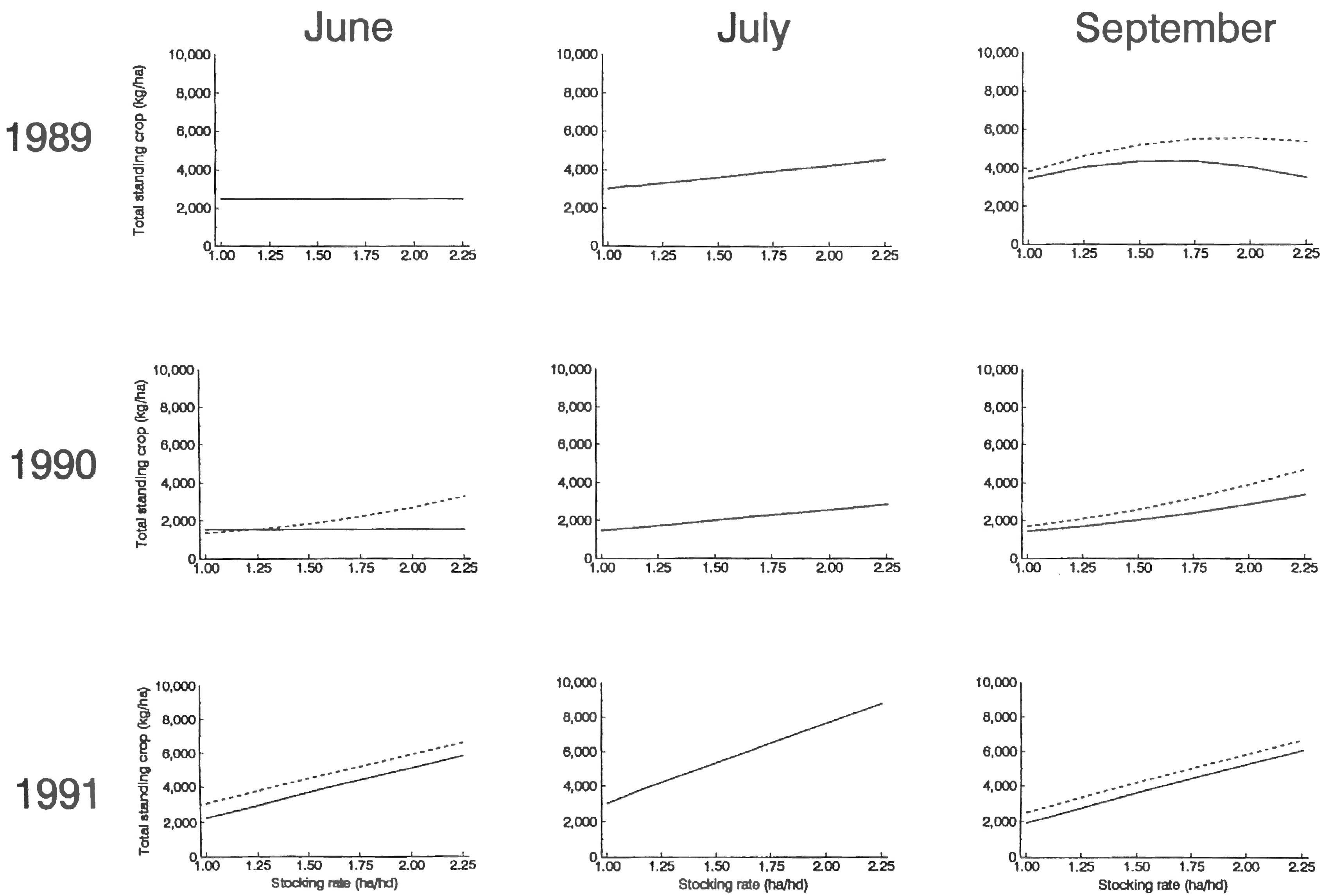
[1] All variables significant at $P \leq 0.10$. N=12 for all models. No variables were significant at $P \leq 0.10$ for June, 1989, and June, 1990.

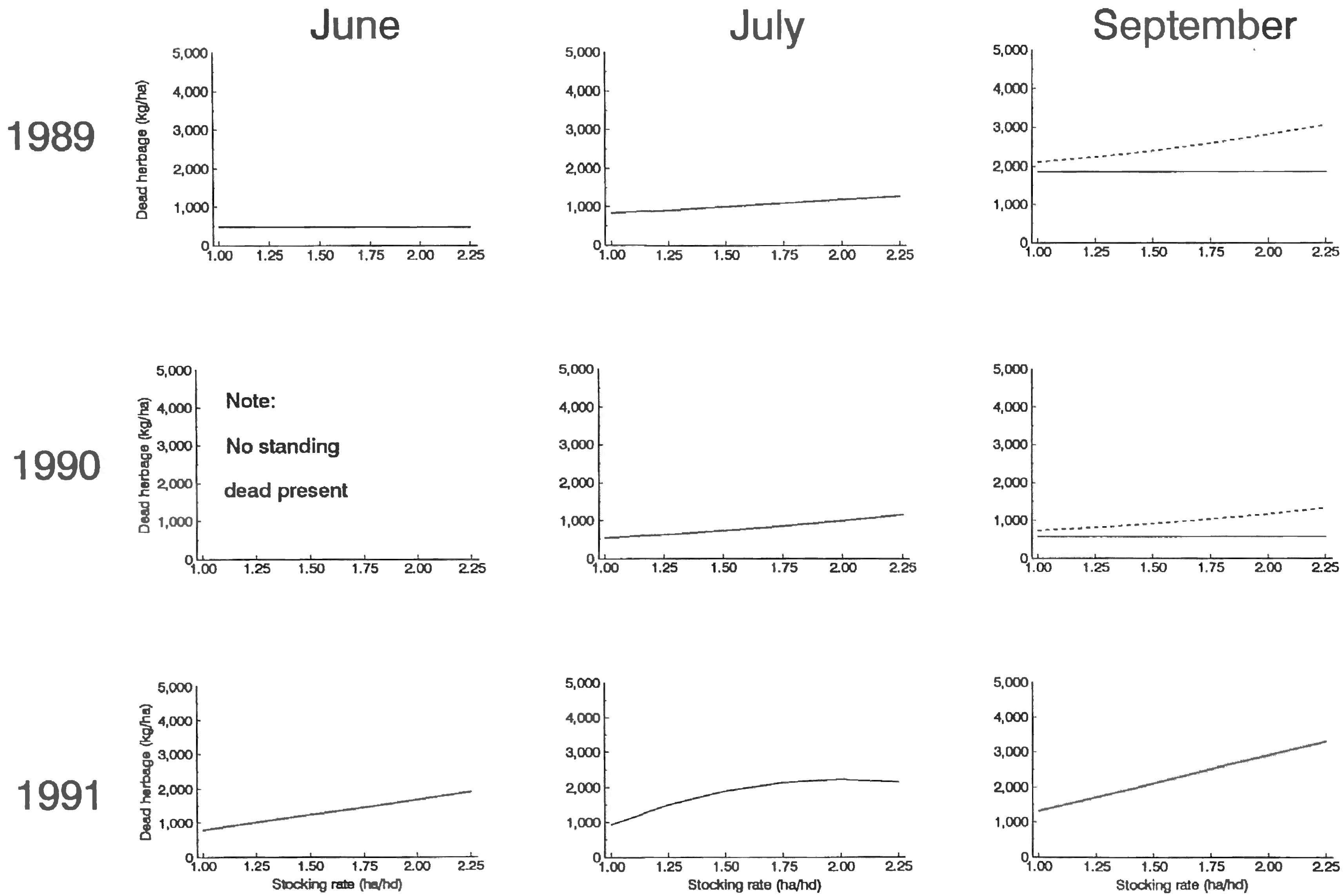
List of Figures

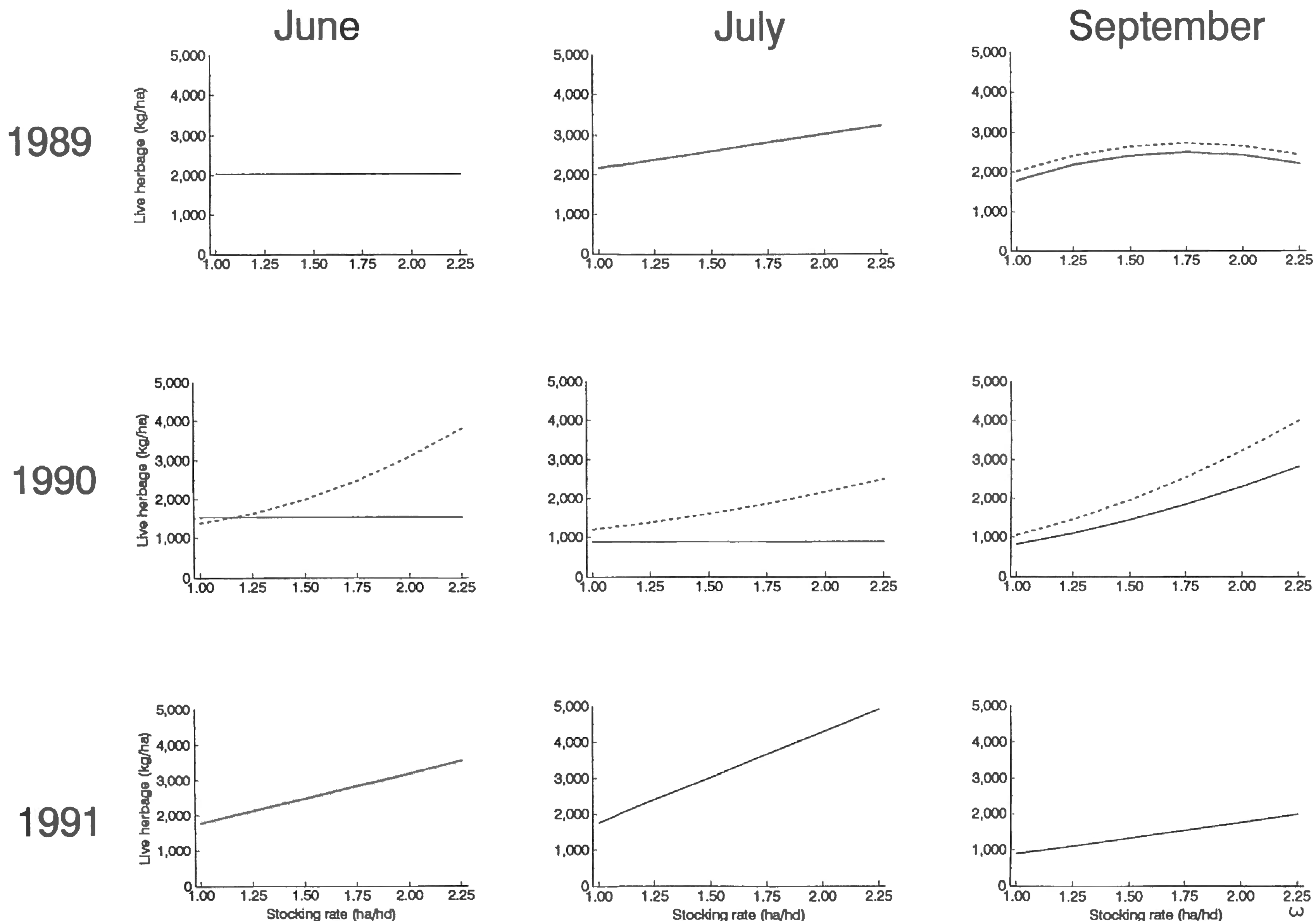


Precipitation (mm)
500
400
300
200
100
0
89
90
91
10-yr avg
April-June
89
90
91
10-yr avg
July-Sept


June
July
September
Total standing crop (kg/ha)
6,000
5,000
4,000
3,000
2,000
1,000
0
1989
1990
1991
Year
Live standing crop (kg/ha)
6,000
5,000
4,000
3,000
2,000
1,000
0
1989
1990
1991
Year
Dead standing crop (kg/ha)
6,000
5,000
4,000
3,000
2,000
1,000
0
1989
1990
1991
Year


June
July
September
1989
1990
1991
Total standing crop (kg/ha)
10,000
8,000
6,000
4,000
2,000
0
1.00
1.25
1.50
1.75
2.00
2.25
Stocking rate (ha/hd)


June
July
September
1989
1990
1991
Dead herbage (kg/ha)
5,000
4,000
3,000
2,000
1,000
0
1.00
1.25
1.50
1.75
2.00
2.25
Note:
No standing
dead present
Stocking rate (ha/hd)


June
July
September
1989
1990
1991
Live herbage (kg/ha)
5,000
4,000
3,000
2,000
1,000
0
1.00
1.25
1.50
1.75
2.00
2.25
Stocking rate (ha/hd)

APPENDIX

GENERAL LINEAR MODEL ANALYSES OF TOTAL, LIVE, AND DEAD STANDING CROP

In addition to using STEPWISE and MAXR to generate predictive equations for DWT, DWTL, and DWTD, complementary GLM analyses (SAS 1985) were conducted to answer several additional questions about the data. The questions were expressed in a format suitable for formal hypothesis testing:

(1) A quadratic trend for stocking rate is present in the data;

(2) Given (1) is true, then the quadratic effects due to grazing system are equal between grazing systems; and

(3) Grazing system has an effect on standing crop.

For convenience in analysis the independent variables in the three models were arranged to facilitate the evaluation of Type I (sequential) sums of squares with respect to the hypothesis of interest. To test hypotheses (1) and (2) the arrangement of terms was:

DWT DWL DWD = GRSYS STRT GRSYS*STRT $STRT^2$ GRSYS*$STRT^2$

The arrangement of terms to test hypothesis (3) was

DWT DWL DWD = STRT $STRT^2$ GRSYS GRSYS*STRT GRSYS*$STRT^2$

The rearrangement of the independent variables did not change the values of variable coefficients, but did change the observed significance levels associated with the Type I sums of squares for the variables. With sequential analysis, values for sums of squares and their associated hypothesis tests are dependent upon the order in which the variables enter the model. A variable which was significant at the 0.10 level under the arrangement of terms for testing hypotheses (1) and (2) may or may not be significant under the arrangement of terms for hypothesis (3).

Results and Discussion

Total Standing Crop. The GLM results to test for quadratic effects due to stocking rate indicated that no variables were significant ($p \leq 0.10$) in June, 1989 or June, 1990 (Table 4). Quadratic effects were nonsignificant ($p > 0.10$) for all sampling periods. The linear interaction GRSYS*STRT was nonsignificant ($p > 0.10$) over all sampling periods. Linear effects for GRSYS and STRT were significant in 2 and 7 periods, respectively. Coefficients of determination for the total standing crop model ranged from 0.34 to 0.79, indicating that the model provided a poor explanation of the variation in the data in the early summer of two years, but otherwise predicted standing crop performance quite well.

Generally, total standing crop was similar at the higher stocking rates; at lower stocking rates residual herbage differences between grazing systems tended to increase (Fig. 6).

Grazing system effects were nonsignificant ($p > 0.10$) in June, 1989, or June, 1990 (Table 5). Grazing system effects were significant ($p \leq 0.10$) in only 2 of the sampling periods, while stocking rate effects were significant in 7 of the periods. $STRT^2$, GRSYS*STRT, and GRSYS*$STRT^2$ were nonsignificant ($p > 0.10$) for all sampling periods. Although the differences were nonsignificant, the rotational systems did have greater total residual biomass than the continuous systems in 6 of 9 periods (Fig. 7).

Live Standing Crop. Quadratic effects ($STRT^2$, GRSYS*$STRT^2$) and the linear interaction term GRSYS*STRT were found to be nonsignificant ($p > 0.10$) in all sampling periods (Table 6). The linear variable GRSYS was significant ($p \leq 0.10$) in September, 1989; July, 1990; and September, 1991. The linear variable STRT was significant in July and September of 1989 and 1990, and in June and July of 1991.

Grazing system did not play a significant ($p \leq 0.10$) role in explaining the trends in the data except in July, 1990 (Table 7). On the other hand, stocking rate had a strong influence in 6 of the sampling periods. Live herbage tended to decrease with decreasing stocking rate for the continuous systems (Fig. 7), but increased with decreasing stocking rate for the rotational systems.

The model did a poor job of identifying sources of variability in the data for June and July, 1989, and June, 1990, but for other sampling periods the model performed well. For all three years, as the growing season progressed, the model's ability to predict standing crop biomass improved.

Dead Standing Crop. Both grazing system and stocking rate effects exhibited significant linear trends in 3 out of 9 sampling periods (Table 8). Significant linear interaction between grazing system and stocking rate occurred only once. Quadratic effects for both grazing system and stocking rate were nonsignificant except in July, 1991, when stocking rate displayed a quadratic trend.

Table 9 indicates that grazing system did not contribute to the trends observed except in September, 1990. Significant stocking rate effects were observed in 2 sampling periods, July and September, 1990 (Fig. 8).

Coefficients of determination were low (0.35 to 0.53) for 5 of the sampling periods, indicating that the model did not perform well in predicting seasonal dead standing crops. In three periods, however, the models performed fairly well (R^2 = 0.64 to 0.87). No trends in R^2 were apparent as the season progressed.

Table 4. GLM regression coefficients and observed significance levels (OSL) of sequential sums of squares to test Hypotheses 1 and 2 for total standing crop. N=12 for all models.

Year	Month	INTERCEPT	GRSYS	STRT	GRSYS*STRT	$STRT^2$	$GRSYS*STRT^2$	R^2	MSE
1989	June	550	5580	1300	-5940	120	1290	0.34	278940
	OSL	0.94	0.76	0.42	0.24	0.51	0.78		
	July	-3900	1210	10170*	-3420	-3370	1740	0.72	142250
	OSL	0.47	0.95	0.01	0.95	0.16	0.60		
	Sept	-2210	-1430*	8570*	1270	-2800	200	0.75	221080
	OSL	0.74	0.03	0.05	0.99	0.13	0.96		
1990	June	90	3270	2190	-6100	-800	2710	0.40	103150
	OSL	0.99	0.76	0.21	0.29	0.79	0.53		
	July	-3100	6740	6520*	-10850	-2130	4370	0.64	115310
	OSL	0.57	0.28	0.03	0.55	0.98	0.35		
	Sept	-2440	8890	5320*	-14280	-1540	5790	0.68	197180
	OSL	0.73	0.16	0.03	0.55	0.64	0.34		
1991	June	1190	-5560*	-50*	10260	1060	-3990	0.76	375800
	OSL	0.90	0.07	0.01	0.98	0.82	0.62		
	July	-13570	18320	22850*	28090	-6870	10760	0.78	774800
	OSL	0.35	0.35	0.01	0.96	0.80	0.37		
	Sept	-4440	-2880	7760*	6480	-1540	-2830	0.79	392340
	OSL	0.66	0.18	0.01	0.70	0.48	0.73		

Table 5. GLM regression coefficients and observed significance levels (OSL) of sequential sums of squares to test Hypothesis 3 for total standing crop. N=12 for all models.

Year	Month	INTERCEPT	STRT	$STRT^2$	GRSYS	GRSYS*STRT	GRSYS*$STRT^2$	R^2	MSE
1989	June	550	1300	120	5580	-5940	1290	0.34	278940
	OSL	0.94	0.40	0.70	0.92	0.21	0.78		
	July	-3900	10170*	-3370	1210	-3420	1740	0.72	142250
	OSL	0.47	0.01	0.29	0.45	0.29	0.60		
	Sept	-2210	8570*	-2800	-1430*	1270	200	0.75	221080
	OSL	0.74	0.02	0.31	0.07	0.27	0.96		
1990	June	90	2190	-800	3270	-6100	2710	0.40	103150
	OSL	0.99	0.22	0.99	0.73	0.27	0.53		
	July	-3100	6520*	-2130	6740	-10850	4370	0.64	115310
	OSL	0.57	0.03	0.96	0.25	0.56	0.35		
	Sept	-2440	5320*	-1540	8890	-14280	5790	0.68	197180
	OSL	0.73	0.03	0.70	0.15	0.49	0.34		
1991	June	1190	50*	1060	-5560*	10260	-3990	0.76	375800
	OSL	0.90	0.01	0.93	0.06	0.93	0.62		
	July	-13570	22850*	-6870	18320	-28090	10760	0.78	774800
	OSL	0.35	0.01	0.84	0.29	0.98	0.37		
	Sept	-4440	7760*	-1540	-2280	6480	-2830	0.79	392340
	OSL	0.66	0.01	0.62	0.14	0.59	0.73		

Table 6. GLM regression coefficients and observed significance levels (OSL) of sequential sums of squares to test Hypotheses 1 and 2 for live standing crop. N=12 for all models.

Year	Month	INTERCEPT	GRSYS	STRT	GRSYS*STRT	$STRT^2$	$GRSYS*STRT^2$	R^2	MSE
1989	June	-5860	11630	10740	-15680	-3530	5090	0.36	358600
	OSL	0.49	0.72	0.40	0.44	0.79	0.36		
	July	-4870	4570	10510*	-7610	-3650	3040	0.57	135330
	OSL	0.36	0.66	0.05	0.98	0.37	0.36		
	Sept	410	-1730*	1630*	3030	-190	-1140	0.74	42850
	OSL	0.89	0.06	0.07	0.10	0.14	0.54		
1990	June	90	3270	2190	-6100	-800	2710	0.40	78240
	OSL	0.99	0.76	0.21	0.29	0.79	0.53		
	July	-1990	1910*	4180*	-3230	-1430	1610	0.70	77700
	OSL	0.66	0.05	0.05	0.20	0.74	0.66		
	Sept	-370	1100	1350*	-2220	-110	1240	0.87	44130
	OSL	0.91	0.15	0.00	0.12	0.70	0.65		
1991	June	-4150	970	8040*	-1860	-2410	930	0.72	168660
	OSL	0.48	0.17	0.02	0.65	0.26	0.80		
	July	-10510	13110	17890*	-19820	-5860	7230	0.60	833976
	OSL	0.42	0.61	0.03	0.92	0.98	0.38		
	Sept	-2040	320*	3820	-560	-1040	290	0.73	58340
	OSL	0.55	0.18	0.01	0.58	0.34	0.89		

Table 7. GLM regression coefficients and observed significance levels (OSL) of sequential sums of squares to test Hypothesis 3 for live standing crop. N=12 for all models.

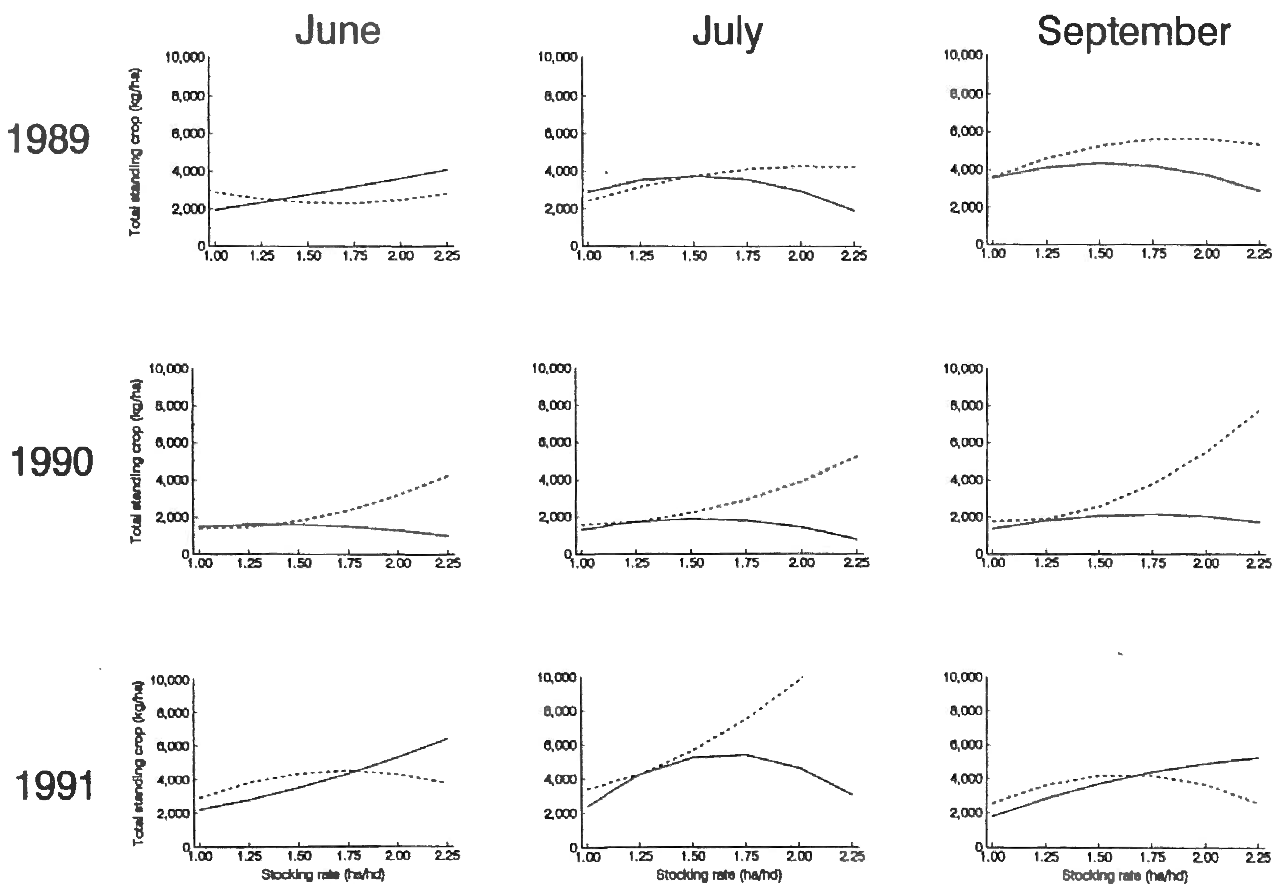
Year	Month	INTERCEPT	STRT	$STRT^2$	GRSYS	GRSYS*STRT	$GRSYS*STRT^2$	R^2	MSE
1989	June	-5860	10740	-3530	11630	-15680	5090	0.36	358600
	OSL	0.49	0.37	0.72	0.87	0.46	0.36		
	July	-4870	10510*	-3650	4570	-7610	3040	0.57	135330
	OSL	0.36	0.05	0.52	0.88	0.52	0.36		
	Sept	410	1630*	-190*	- 1730	3030	-1140	0.74	42850
	OSL	0.89	0.03	0.05	0.11	0.86	0.54		
1990	June	90	2190	-800	3270	-6100	2710	0.40	78240
	OSL	0.99	0.22	0.99	0.73	0.27	0.53		
	July	-1990	4180*	-1430	1910*	-3330	1610	0.70	77700
	OSL	0.66	0.09	0.69	0.03	0.22	0.66		
	Sept	-370	1350*	-110	1100	-2220	1240	0.87	44130
	OSL	0.91	0.00	0.83	0.04	0.11	0.65		
1991	June	-4150	8040*	-2410	970	-1860	930	0.72	168660
	OSL	0.48	0.01	0.28	0.50	0.61	0.80		
	July	-10510	17890*	-5860	13110	-19820	7230	0.60	833970
	OSL	0.42	0.03	0.94	0.82	0.96	0.38		
	Sept	-2040	3820*	-1040	320	-560	290	0.73	58340
	OSL	0.55	0.01	0.31	0.57	0.77	0.89		

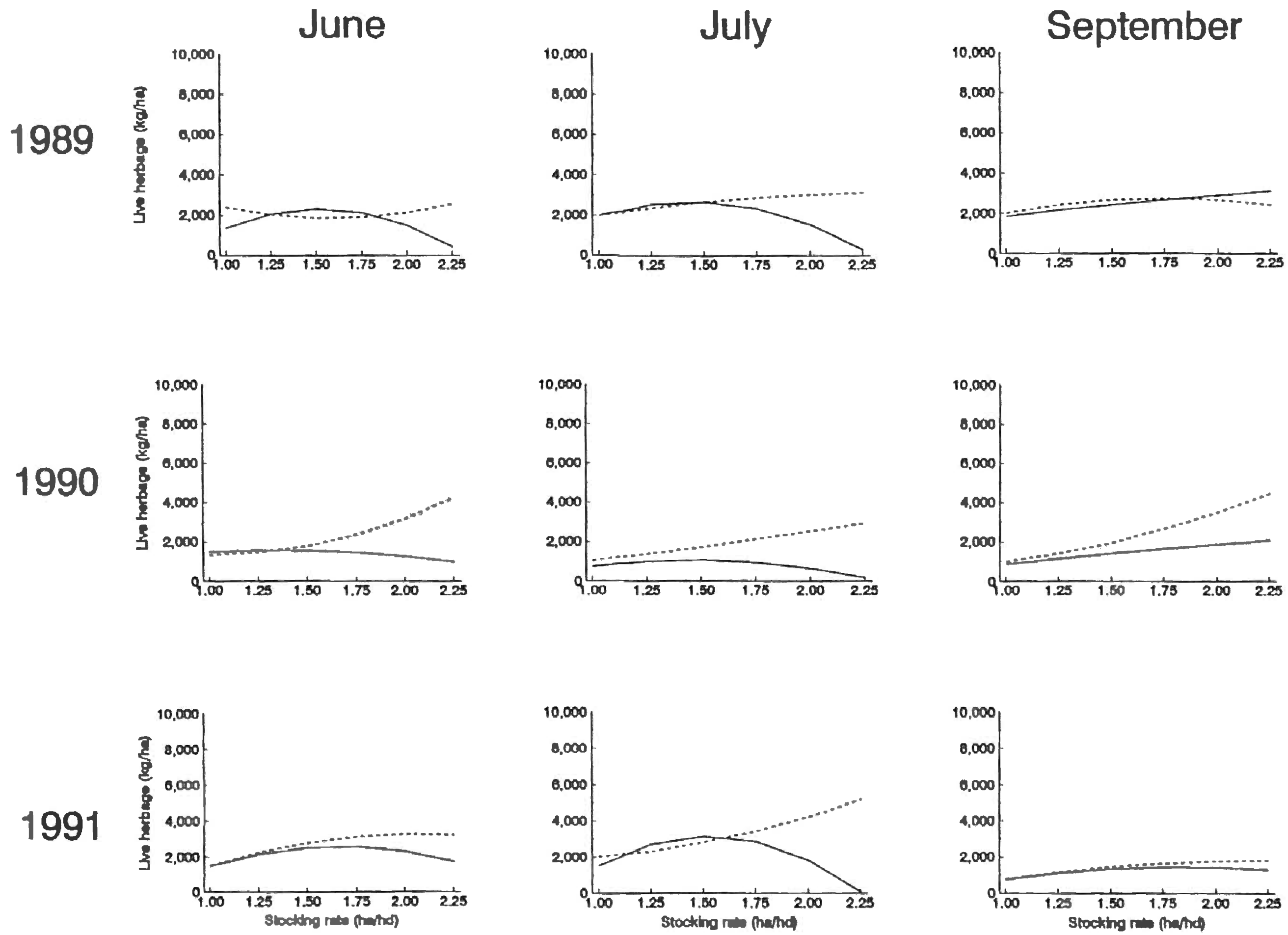
Table 8. GLM regression coefficients and observed significance levels (OSL) of sequential sums of squares to test Hypotheses 1 and 2 for total standing crop. N=12 for all models.

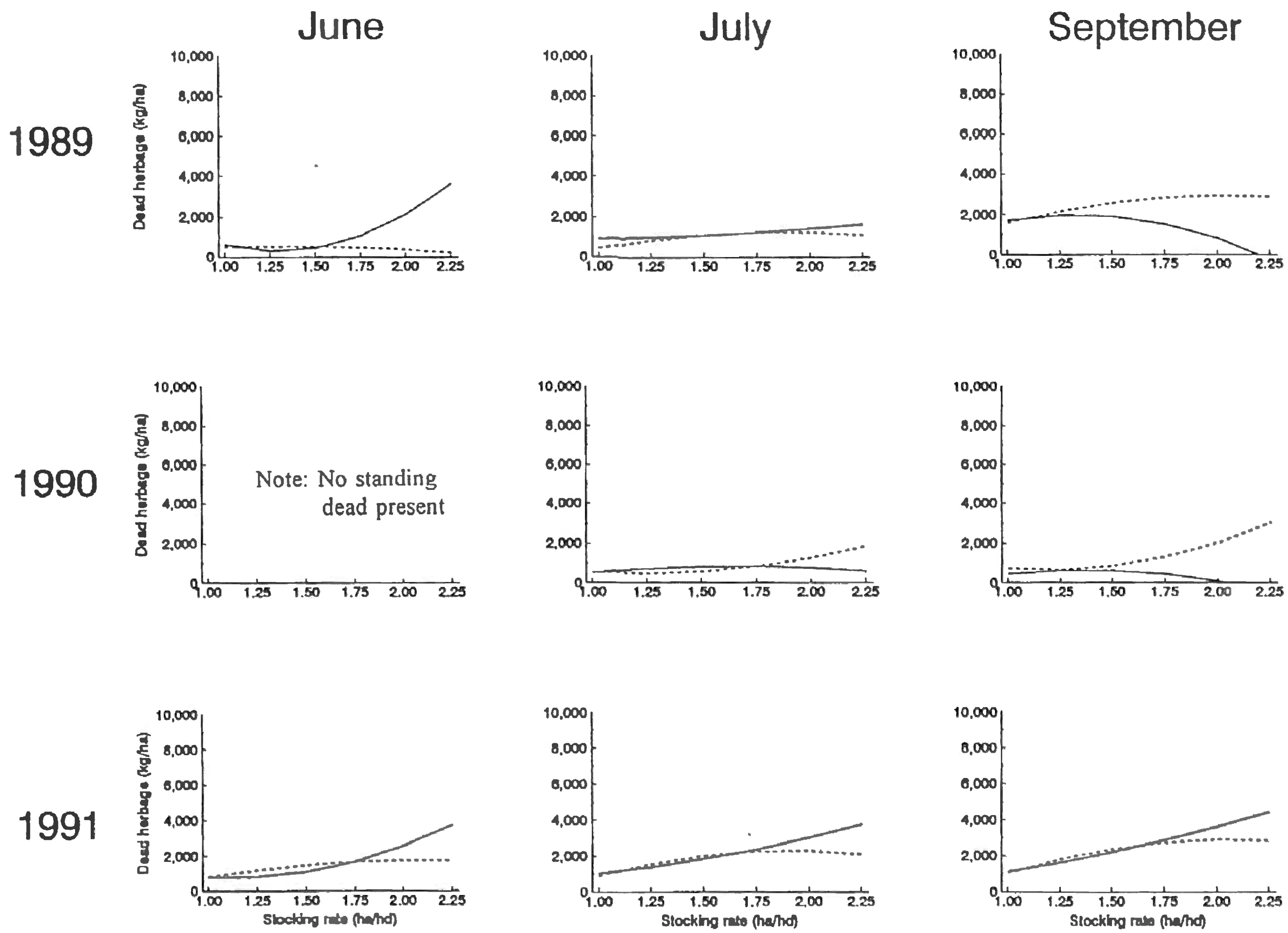
Year	Month	INTERCEPT	GRSYS	STRT	GRSYS*STRT	$STRT^2$	$GRSYS*STRT^2$	R^2	MSE
1989	June	6410*	-6630	-9440	10560	3650	-4060	0.53	52220
	OSL	0.09	0.92	0.62	0.43	0.64	0.09		
	July	970	-3350	-330*	4180	280	-1300	0.71	20230
	OSL	0.63	0.34	0.02	0.90	0.13	0.32		
	Sept	-2620	310*	6940	-1770	-2610	1340	0.59	19610
	OSL	0.67	0.10	0.15	0.40	0.33	0.73		
1990	June	0	0	0	0	0	0	---	---
	OSL	0.00	0.00	0.00	0.00	0.00	0.00		
	July	-1110	3530	2340	-5510	-700	2000	0.38	49850
	OSL	0.76	0.29	0.27	0.62	0.83	0.50		
	Sept	-2080	5840*	3970	-9120	-1440	3590	0.64	25120
	OSL	0.43	0.06	0.24	0.59	0.71	0.12		
1991	June	3620	-5360	-5140	8474	2310	-3100	0.35	384070
	OSL	0.68	0.31	0.26	0.86	0.91	0.58		
	July	560	-4530*	-270*	6840*	750*	-2470	0.87	40850
	OSL	0.84	0.09	0.00	0.10	0.10	0.20		
	Sept	20	-4070	450*	6280	670	-2300	0.50	321470
	OSL	0.99	0.45	0.07	0.60	0.62	0.72		

Table 9. GLM regression coefficients and observed significance levels (OSL) of sequential sums of squares to test Hypothesis 3 for dead standing crop. N=12 for all models.

Year	Month	INTERCEPT	STRT	$STRT^2$	GRSYS	GRSYS*STRT	$GRSYS*STRT^2$	R^2	MSE
1989	June	6410*	-9440	3650	-6630	10560	-4060	0.53	52220
	OSL	0.09	0.65	0.83	0.78	0.38	0.09		
	July	970	-330*	280	-3350	4180	-1300	0.71	20230
	OSL	0.63	0.04	0.25	0.13	0.24	0.32		
	Sept	-2620	6940*	-2610	310	-1770	1340	0.59	19610
	OSL	0.67	0.08	0.97	0.20	0.22	0.73		
1990	June	0	0	0	0	0	0	---	---
	OSL	0.00	0.00	0.00	0.00	0.00	0.00		
	July	-1110	2340	-700	3530	-5510	2000	0.38	49850
	OSL	0.76	0.21	0.81	0.38	0.65	0.50		
	Sept	-2080	3970	-1440	5840*	-9120	3590	0.64	25120
	OSL	0.43	0.41	0.66	0.05	0.55	0.12		
1991	June	3620	-5140	-2310	-5360	8470	-3100	0.35	384070
	OSL	0.68	0.19	0.87	0.48	0.96	0.58		
	July	560	-270	750	-4530	6840	-2470	0.87	40850
	OSL	0.84	0.00	0.04	0.51	0.99	0.20		
	Sept	20	450	670	-4070	6280	-2300	0.50	321470
	OSL	0.99	0.06	0.48	0.81	0.98	0.72		


June
July
September
1989
1990
1991
Total standing crop (kg/ha)
10,000
8,000
6,000
4,000
2,000
0
1.00
1.25
1.50
1.75
2.00
2.25
Stocking rate (ha/hd)


June
July
September
1989
1990
1991
Live herbage (kg/ha)
10,000
8,000
6,000
4,000
2,000
0
1.00
1.25
1.50
1.75
2.00
2.25
Stocking rate (ha/hd)


June
July
September
1989
1990
1991
Dead herbage (kg/ha)
Note: No standing dead present
Stocking rate (ha/hd)
10,000
8,000
6,000
4,000
2,000
0
1.00
1.25
1.50
1.75
2.00
2.25

VITA

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