PROGRESS REPORT

CENTRAL PLAINS EXPERIMENTAL RANGE LTER PROJECT

I. SUMMARY AND OVERVIEW

A. Introduction

The Central Plains Experimental Range Shortgrass Steppe Long Term Ecological Research Project (BSR-9011659 LTER) had a successful year in 1991-92. We have continued to collect data regarding long term patterns in ecosystem structure and function, while initiating important new studies to further our understanding of the shortgrass steppe. The project produced 20 papers in refereed journals during the last 2 years (1990 and 1991). We supported a large number of graduate, undergraduate, and high school students for research at the site. Scientists from our project are involved in LTER network activities, through comparative modeling studies, database management, and development of new cross-site experiments.

Below, we provide a summary of the new activities and products from our site during 1991-1992, and our plans for 1992-93. A more detailed description of our scientific activities, organized by core area, follows.

B. New Studies

Exclosure Study

We initiated a new long-term study this year that will be a major focus of activity for our project. Grazing is the most common management of shortgrass steppe, and may have been a key component of its evolutionary history (Milchunas et al. 1988). We developed a study in our proposal to address new questions regarding grazing by taking advantage of long-term exclosures on the Central Plains Experimental Range (CPER). Much of the current understanding of grazing effects is based upon exclosures and the traditional interpretation that they represent a relatively steady-state, undisturbed condition for grasslands. We hypothesize that areas removed from grazing undergo aggradation, increasing soil organic matter and potentially changing productivity and plant community structure. We are initiating our study to test these ideas by examining transient and long-term responses to grazing and removal from grazing.

During summer of 1991, we collected baseline data on 7 long-term (50 years old) exclosures on the CPER, on soil texture, soil organic matter, plant species composition, and net primary productivity, to test for differences between long-term grazed and long-term ungrazed (manuscripts in preparation). This summer (1992), we invested significant resources to move exclosure boundaries to both exclude new areas and to open previously excluded areas to grazing. Each of the 7 exclosure areas now has 4 treatments: long-term grazed, long-term ungrazed, long-term grazed and recently excluded, and long-term ungrazed and recently grazed. In following years, we will test for the response of major components of ecosystem structure and function to these treatment.

Ecosystem Recovery:

Large areas of the shortgrass steppe are currently being returned to native grasses after long periods of cultivation. While the effects of cultivation are relatively well studied, recovery dynamics are not well-understood. During the summer of 1990, we conducted a large-scale study of abandoned fields to examine long-term recovery of short-grass steppe ecosystems after cultivation (Coffin et al. submitted, Burke et al. submitted). All of the fields sampled at that time had undergone grazing since the time of abandonment. Last year, through a study of historical aerial photographs of the site, we determined that several of the abandoned fields on the CPER have had exclosures in them for at least the past 30 years.

This year, we have initiated a new study of the role of grazing in recovery of the shortgrass steppe from cultivation. We are studying plant community structure and soil organic matter dynamics in 3 areas on the site, each of which has 3 treatments, native, abandoned/grazed, and abandoned/ungrazed.

C. Highlights From Ongoing Work

Time Domain Reflectometry

Soil water is often the most important resource limiting ecosystem activity at the CPER. Because it is so important we have focused a considerable amount of attention on obtaining estimates of soil water availability. For the first nine years of the project we used a neutron moisture gage to estimate soil water availability. This instrument works well and is very reliable. The major problem with the neutron moisture gage is that it does not work for the soil layers near the soil surface. Unfortunately for us these are also the layers that are the most important for ecosystem dynamics in semiarid regions. In 1991 we acquired a new technology for soil water estimates, time domain reflectometry. Our initial work with it during the 1991 field season made us very enthusiastic about its potential to provide reliable estimates of soil water both in the surface layers as well as in deep layers. These results will be part of a PhD dissertation by Paul Hook (Range Science Department) as well as a manuscript to be submitted to Ecology this fall.

Population-Ecosystem Interactions

During the summer of 1991, Mary Ann Vinton. a PhD student (Forest Science Department) initiated a study of the influence of the interactions of plant species and ecosystem processes such as soil organic matter dynamics. She based her study on a long-term nutrient addition experiment at the CPER (Vinton and Burke, in prep.). Her results showed significant effects of species composition and individual plant location on total soil organic matter, the availability of nitrogen, and microbial activity. Based upon these results, she submitted a Dissertation Proposal to NSF to further develop such studies at the CPER, and to extend them to a regional gradient from the CPER to Konza Prairie LTER. She was awarded the grant this spring.

New Soil Survey and Map for the CPER

Researchers at the CPER contacted the Soil Conservation Service (SCS) in 1989 about obtaining a new and increased detail survey of the site. The SCS agreed to provide a new detailed survey. In 1991 Gene Kelly and Caroline Yonker from the CPER-LTER project worked with SCS personnel to collect the data for a new soil map. The map is now available and being used to design field studies.

^{14}C Turnover as an Estimate of Belowground Production

Daniel Milchunas and Bill Lauenroth had a paper published in *Ecology* in 1992 describing the use of ^{14}C to estimate belowground production at the CPER (Milchunas and Lauenroth 1992). The new estimates resulted in a revision in our thinking about the importance of belowground production. Instead of aboveground to belowground production ratios of 5 to 10 as was published during the IBP project, new estimates suggest the ratio is very near to 1.

Predicting Evapotranspiration

Romel Lapitan and Bill Parton have developed a method of predicting daily evapotranspiration from air and soil temperature. The difference between the air and soil temperature at 11 AM (EDT) was found to be significantly related to evapotranspiration from the LTER weighing lysimeter. This result provides a basis for remotely sensing evapotranspiration and is being initially investigated during the 1992 growing season using a black-body radiometer in conjunction with the lysimeter.

D. Network Activities

Cross-site assessment of climate change on ecosystem dynamics

Bill Parton is leading a group of investigators and site participants in a simulation experiment to evaluate potential responses of North American terrestrial ecosystems to climate change. The LTER network provides and ideal context for this work because the parameter and initial conditions needed to run the CENTURY model are available at all of sites. All 17 of the North American LTER sites will participate in the experiment. An important product from this work will be a directly comparable indication of the relative sensitivity of North American ecosystems to climate change.

Papers from the All-Scientist meeting

We were invited to prepare two papers for a special issue of Ecological Modelling, as a result of our participating in the All-Scientists meeting (Lauenroth et al. 1992, Burke et al. 1992). The special issue will focus on regional aspects of LTER research.

Participation in New Cross-Site Experiments

Our site (Indy Burke) hosted the organizing workshop for a new project that focuses on development of a cross-LTER-site experiment. We (6 LTER sites) have submitted a proposal to NSF-Ecosystems to undertake a long-term study of soil organic matter formation and degradation across forest, grassland, and tundra ecosystems. The project will involve manipulation of litter inputs and A horizons, and will provide critical new process information on soil organic matter that is highly relevant to global carbon studies.

Clowes Workshop

Our site (Indy Burke) hosted a Clowes Workshop for training graduate students in spatial modeling in January 1992. The workshop was funded and organized through the Woods Hole MBL Ecosystem Center. PI's from 4 LTER sites participated, including CPER, Harvard Forest, Arctic, and Virginia Coast Reserve, as well as scientists from Oak Ridge National Laboratory. Each group brought 2 graduate students to participate in the workshop.

Intersite Electronic Database

Tom Kirchner is participating in the development of technology to set up and use a multisite database that can be accessed over the Internet.

E. Modeling & Synthesis

SCOPE Grassland Project

Bill Parton is the leader of a project to compare 17 temperate and tropical grasslands world-wide using the CENTURY model.

SCOPE Workshop on Climate Change and Coniferous Forests and Grasslands

Indy Burke, Osvaldo Sala, Bill Parton, and Bill Lauenroth will participate in the workshop which will bring researchers together to evaluate the potential responses of coniferous forests and grasslands to predicted climate change. Drs Burke, Sala, Parton, and Lauenroth will be authors and coauthors of papers that will be published in the proceedings of the workshop.

New Version of the STEPPE Model

Debra Coffin and Bill Lauenroth are nearing completion of a new individual-plant-based simulation model for grasslands. The key features of the new model are improved representations of roots, canopies, and the effects of water and nitrogen on recruitment, growth, and death. The new model will allow us to explicitly consider aboveground (light) and belowground (water and nitrogen) competition for resources as well as interface with existing soil water (SOILWAT) and soil process (CENTURY) models.

F. Education

The CPER-LTER has supported and involved a large number of graduate, undergraduate and high school students in the project this year. Graduate students this year worked in the areas of plant population dynamics (Manuel

Aguilera, Range Science Department), grazing effects on primary production (Menwyelet Atsedu, Range Science Department), plant competition (Martin Aguiar, Range Science Department), plant population - ecosystem interactions (Mary Ann Vinton, Forest Science Department), soil water and root dynamics (Paul Hook, Range Science Department),remote sensing (Stella Todd, Forest Science Department), bird populations (Kimberly With, Biology Department), and small mammal population dynamics (Paul Stapp, Biology Department). We have supported 9 undergraduates who are assisting in field and laboratory work. This summer we participated in the NSF-sponsored Young Scholars Program for high school students in plant science. We sponsored 4 students, who collected plant species composition data and soils for our old field study, described above. These students presented preliminary results of their analyses in a formal meeting at the end of their program.

This year, we began to interact more closely with courses at the University. We sponsored two fieldtrips to the site, one for interested undergraduates, and another for the major graduate course for the Program for Ecological Studies (Synecology).

G. Site Operation

The Agricultural Research Service (ARS) is changing their mode of operation of the CPER. The change is partly the result of a change in the demand by researchers to work at the site and partly the result of a change in personnel. The Scientist-in-Charge of the CPER died during 1991. The ARS has chosen to not replace him in the short-term and is deliberating about replacing him at all. This has substantially changed their activities at the site. It has had a minor impact on our collaborative work with ARS researchers. The ARS has also instituted a formal procedure for researchers to follow to gain access to the site for research. There is now a Scientific Advisory Committee consisting of members from the research community in the Fort Collins area. Most are from Colorado State University and the LTER has a representative. This new procedure has worked very well in its first year of operation and we consider it to be a very positive step for the site.

H. Plans for Next Year

^{13}C-^{15}N Labeling Experiment

In 1993 we plan to begin installing the labeling experiment in conjunction with our new long-term research project (see New Studies) as described in our proposal. The objective is to be able to evaluate the incorporation of C and N into various plant and soil fractions under conditions of steady state, agrading, and degrading systems. The C portion of the experiment will represent our first attempt to estimate belowground production using the carbon turnover technique that we have been working on for the past 7 years.

Minirhizotrons

In 1993 we plan to acquire and begin using a video camera in minirhizotrons. This work will initially be done in conjunction with the ^{13}C-^{15}N labeling experiment on our new long-term experiment. In later years we will expand to the grazing intensity pastures with the objective of trying to understand the effects of a gradient in grazing intensity on intra and inter-annual root dynamics.

Collaboration with University of Buenos Aires

We have a long-term continuing collaboration with Dr. Osvaldo Sala at the University of Buenos Aires. In 1993 we plan to begin working on a formal method of making this collaboration part of the LTER network. NSF's current interest in 'partnerships' makes this a feasible activity at this time.

Project Meetings

For the past several years our regular project meeting have been biweekly seminars at which an LTER scientist or someone conducting work closely related to the LTER research presented his/her findings. In 1993 we plan to modify this schedule such that for the fall semester we have group discussions of issues relevant to the CPER-LTER project and in the spring we have biweekly seminars.

II. DETAILED REPORT

A. New Studies

Effects of Grazing and Exclosure on Shortgrass Steppe Ecosystems: Disturbance and Recover

Baseline Studies

We have initiated a new study to examine the transient and long-term responses of shortgrass steppe ecosystems to grazing. During summer 1991, we sampled 7 long-term exclosures on the CPER in order to establish initial conditions for long-term grazed and ungrazed conditions. Baseline data were collected in 1991 for 2 separate reasons, 1) to characterize sites in order to allow us to identify the best long-term exclosures for our study (soil texture, grazing utilization, and site heterogeneity), and 2) to produce interesting data on differences between long-term grazed and ungrazed treatments (soil C and N pools, N and C mineralization rates and microbial biomass, plant species density and basal cover, aboveground biomass and nitrogen, and belowground microarthropods, nematodes, and protozoa). Additional baseline data collected this summer (1992) are root biomass and low-level aerial photograph surveys to census small scale disturbances (mammal and arthropod), density of shrub and cactus clumps, and spatial patterns of individual species.

We hypothesize that responses to grazing are likely to interact with soil texture, given the importance of soil texture in controlling shortgrass steppe ecosystem structure and function. Baseline data on soil texture were thus important to characterize our sites, as well to use as a covariate for examining grazing effects. Average soil textures for the sites indicated that two sites were distinctly different from five other sites which were similar (Fig. 1). All sampling was conducted by randomly subsampling a grid thereby allowing us to map texture isopleths for each site (Fig. 2 and Fig. 3). eThis will allow us to make contour maps of texture for each site to aid in both sample selection and interpretation of results. Texture gradients within sites were as great as that between sites. We had initially planned to identify texture classes that these exclosures could represent, however, a reasonable range in soil texture using site as the unit of replication could not be achieved. Therefore, we decided to use plot-specific-texture in regression and covariate analyses. This approach will entail additional sampling for soil texture until maps are developed to an acceptable level of precision.

Relative grazing intensity is also likely to influence responses of each site to grazing or exclosure. Although all pastures (half-sections) are stocked to achieve overall moderate levels of utilization, grazing intensities in the vicinity of a particular exclosure can vary due to a complex array of factors governing foraging behavior. Relative intensities of grazing estimated by fecal-pat densities show significant differences in utilization of the sites (Fig. 4). End-of-season biomass in grazed and temporary caged plots will provide estimates of utilization averaged across all sites, and will verify fecal-pat estimates of relative differences in utilization after several years of data are compiled.

Species dissimilarities were calculated for one half of an ungrazed exclosure versus the other half and for each half versus the grazed treatment at each site. Species populations in ungrazed versus grazed treatments were usually more dissimilar than the two halves of the exclosure that would become different treatments in 1992 (Fig. 5). Average soil texture for sites, grazing intensity, or their interaction did not explain differences between sites or differences between treatments between sites.

Effects of Long-term Grazing and Exclosure

Basal cover of the dominant species (*B. gracilis* + *B. dactyloides*) showed no relationship along the soil texture (site averages) or grazing intensity (recent intensity) gradients. Grazed treatments had greater basal cover of the dominant species than did ungrazed. Ungrazed treatments generally had greater density of exotics and litter cover than did grazed treatments (Fig. 6 and Fig. 7). Similar results were also observed for end of season standing biomass along the soil texture and grazing intensity gradients Fig. 8 and Fig. 9).

Liang et al. (1989) found greater aboveground net primary production in sandy sites that was not attributable to the *Bouteloua-Buchloe-Opuntia-Sphaeralcea* matrix which is common across all plant communities at the CPER. Heavy grazing smoothed the distributions of species populations (Milchunas et al. 1989) and above- and belowground plant biomass (Milchunas and Lauenroth 1989) across topographic environmental gradients compared with that in ungrazed grassland. Initial analyses from this study suggest that grazing may be affecting the 'secondary layer' of plant species that provide the additional productivity found in sandy soils. On the other hand, exotics and native 'weed' species are more abundant (Milchunas et al. 1990) and establishment and invasion is potentially greater (Milchunas et al. 1992) in grazed compared with ungrazed grassland in non-sandy soils. Major invasions of economically undesirable exotics have occurred in the relatively more mesic front-range habitats in Colorado and along roadsides in shortgrass steppe, but invasions into native grassland have been patchy and appear more prevalent in sandy sites. Preliminary analyses from this study suggests that spatially fine-grained heterogeneity in soil texture may contribute to the diversity of shortgrass steppe, but may also be important in the potential for invasions.

Data from the soil organic matter studies and soil fauna studies are still being analyzed. We hope to submit 3 separate papers on these results within the next year.

New Experiment: Aggradation and Degradation of Shortgrass Steppe Ecosystems

This summer (1992), we moved long-term exclosure boundaries at 6 of the sites to form 4 treatments at each site, long-term grazed/grazing continued (gz/gz), previously grazed/newly ungrazed (gz/un), long-term ungrazed/no grazing continued (un/un), long-term ungrazed/newly grazed (un/gz). We are collecting data this year on primary production, N-yield and utilization (consumption or herbivory), nutrient availability, and individual plant location in permanent plots. We intend for these plots to be studied intensively over the long-term to evaluate short and long-term responses of the system to grazing following exclosure, and exclosure following grazing.

2. Recovery of Shortgrass Steppe Ecosystems from Cultivation

Major portions of the shortgrass steppe region have been subjected to cultivation management over the past 100 years. Large areas have been historically returned to native grassland following cultivation; recently, the Conservation Reserve Program (CRP) has provided economic incentives for farmers to turn previously cultivated land back into native grassland. Little is known about the potential long-term implications of the CRP. Through analysis of historical photographs, we recently learned that a significant proportion of the CPER consists of historically abandoned fields. These fields provide an exceptional opportunity to examine the long-term recovery of grasslands following cultivation, and to provide critical information about the potential effects of the CRP.

In 1990, we initiated a study to evaluate the recovery of shortgrass ecosystems on agricultural fields abandoned in the 1930's on the CPER and the adjacent Pawnee National Grasslands (see Core Area Disturbances, below). This summer (1992), we initiated a new study to address the interaction of recovery with grazing management. Historical aerial photographs of the site indicated that 3 of the long-term exclosures (1939) on the site were located in abandoned fields. One of these was located on the middle of the boundary between native steppe and an abandoned field. Vegetation and soils were sampled for up to four combinations of grazing and disturbance: grazed old field, ungrazed old field, grazed unplowed, and ungrazed unplowed. Sampling was conducted with the help of four high school students participating in the Young Scholars Program at CSU.

The recovery of B. gracilis and total cover on these sites 53 years after abandonment and initiation of grazing treatment is indicated by the similar cover on old fields and unplowed areas for both grazed and ungrazed locations (Fig. 10).

Grazing by cattle also had little effect on cover; although cover was higher on grazed than ungrazed areas, the differences are likely not significant. Cover of B. gracilis relative to total cover was similar to or larger on the grazed than the ungrazed areas (Fig. 10c). Soils are still being analyzed.

B. Core Areas

Primary Production

Monitoring of aboveground primary production (ANPP) has been expanded to include the range in soil textures encountered at the CPER (Fig. 11). Production in the relatively sandy-lowland site was significantly greater than the more loamy-lowland site, and both were more productive than the clay-loam-lowland. Grasses contributed nearly 100% of the production in the clay-loam-lowland, and shrubs and forbs were a relatively greater proportion of the production in ungrazed uplands compared to grazed uplands. In addition, nitrogen concentrations and yields are determined for all long-term ANPP sites.

We are continuing to evaluate belowground production at a single site using a radioisotope technique (see Section C). We plan to expand this work to other sites in 1993 (see Section H).

In 1991-2 Bill Lauenroth and Osvaldo Sala completed an analysis of a data set collected by the Agricultural Research Service. The data represented aboveground forage production and spanned the time period 1939-1990. A manuscript based upon this analysis will be published in 1992 in *Ecological Applications* (Lauenroth and Sala 1992). Several interesting points were illustrated by these results. Forage production was positively and significantly related to ANPP therefore the results are discussed in terms of ANPP. ANPP over the past 52 years was significantly related to but more variable than its key driving variable, precipitation. Furthermore, the relationship between ANPP and precipitation was different from the one we found in the analysis of a regionally extensive data set (Sala et al 1988) suggesting that spatial and temporal relationships between ANPP and precipitation are not interchangeable. ANPP was not related to annual temperature but annual temperature itself showed a very interesting pattern. Annual temperature has been increasing at the CPER since 1967 and has been above the mean in each year since 1974.

Population Dynamics

Bouteloua gracilis

In 1991 we initiated a field study to evaluate the response of individual *B. gracilis* plants to small (0.1 to 0.3 m-diameter) disturbances. We selected six sites at the CPER to represent three soil textures (clay loam, silt loam, and sandy loam). At each site, a total of 100 *B. gracilis* plants were selected, half of which were protected from grazing by cattle and half were unprotected. Effects of small disturbances were simulated either by shading portions of each plant to represent cattle fecal pats or by removing above- and belowground parts of each plant to represent digging and removal by small animals. Ten plants in each grazing treatment were randomly assigned to five mortality treatments: 0, 50, 75, 90, and 100% of each plant either shaded or removed. Treatments began in July (1991) when plant size and number of live tillers in the undisturbed part of each plant were recorded. Survival of each plant based on remaining number of live tillers were recorded in June (1992) and will be recorded again in August (1992). In 1992 we will also establish permanent plots at each site for demographic analyses. Plots will also be established at the sites representing the old and new grazing treatments.

We are continuing our study of the effects of soil texture and grazing by cattle on the production of *B. gracilis* seeds. Spatial and temporal variability in seed production is being evaluated by collecting seeds and reproductive structures for 96 plants at each of ten sites chosen to represent the variability in soils and grazing intensity at the CPER. Data have been collected annually since 1989. In the first year of the study, grazing was found to be important in mediating the effects of soil texture. Density of viable seeds produced was negatively related to clay content of the soil. Inter-annual variability in seed production was found to not have a simple relationship with mean annual or growing season precipitation, but rather is more related to the timing of precipitation relative to when inflorescences and seeds are produced.

Song Birds

We are continuing to do frequent roadside censuses along a permanent transect to evaluate seasonal and interannual fluctuations in populations. The PhD student (Biology Department), Kimberly With, who is currently conducting the roadside censuses is also investigating nesting behavior of the Horned Lark, McCown's Longspur, and Lark Bunting as well as movement patterns of McCown's Longspur and their important prey item, grasshoppers.

Small Mammals

Paul Stapp a PhD student in the Biology Department is working with two small mammal species at the CPER, the grasshopper mouse (*Onychomys leucogaster*) and the deer mouse (*Peromyscus maniculatus*). His work is focusing on habitat use and activity using radiotelemetry methods.

Nutrients

Spatial Heterogeneity

During 1990, we conducted a study on the small-scale spatial heterogeneity in soil nutrients associated with the presence of B. gracilis individuals (Hook et al. 1991). Field and laboratory analysis suggest that 1) plant-associated C and N are distributed concomitantly with the presence of B. gracilis individuals (Fig. 12), 2) total soil C and N are higher under individual B. gracilis plants than between (Fig. 13), and 3) available and potentially mineralizable C and N are higher under than between individual B. gracilis plants (Fig. 14). These results have a great deal of significance for our understanding of shortgrass steppe ecosystems, suggesting that semi-arid grasslands are subject to the same kind of plant-induced heterogeneity that is often recognized as occurring in semi-arid shrublands.

Effects of Grazing/exclosure

As a part of our new field study on the influence of grazing and exclosure, we have sampled soils in longterm grazed and longterm exclosed areas on the CPER. We stratified our sampling by plant-interplant location, since earlier work has suggested that 1) spatial distribution of biomass is influenced by grazing (Milchunas and Lauenroth 1989) and 2) that nutrient pools are strongly influenced by location of individual plants (Hook et al. 1991). We are analyzing soils for total carbon and nitrogen, microbial biomass, and potential and *in situ* N mineralization. In addition, next summer we plan to sample the newly exclosed and opened areas for microbial biomass and N mineralization potential, in order to test for rapid responses to the new treatments.

Recovery Dynamics

We conducted a large-scale analysis of recovering old fields at the CPER and on the adjacent Pawnee National Grasslands in 1990 (see also Large-Scale Disturbances, below), sampling both plant communities and soils. Our results suggested that after 50 years of abandonment, soils still had significantly lower total carbon and nitrogen (Fig. 15), but had recovered microbial biomass and N mineralization potential to the same levels as native fields (Fig. 16 and Fig. 17). In addition, our results suggested that the small-scale heterogeneity associated with individual B. gracilis plants also recovered after 50 years of abandonment. These results provide corroboration of two key hypotheses about the sturucture and function of shortgrass steppe ecosystems. First, total soil organic matter pools have relatively long turnover times and do not recover rapidly, while soil organic matter pools responsivle for nutrient supply have relatively rapid turnover rate and may recover over time periods as short as 50 years. Second, population dynamics of B. gracilis have important implications for the recovery of soil organic matter and heterogeneity of shortgrass steppe ecosystems.

As described above, we have initiated a new study this year on the CPER that evaluates the influence of grazing on recovery patterns. We sampled soils for total and active soil organic matter pools. Samples are currently being analyzed.

Microclimatic Interactions

This summer (1992), we have initiated a new study to evaluate the interaction of substrate quality and microclimate in controlling in situ N mineralization. Soil organic matter is strongly patterned with soil texture, landscape position, and land management history at the CPER, and potential N mineralization has been demonstrated to vary with spatial location (Schimel et al.

1985). In addition, we hypothesize that the pulsed nature of precipitation in the shortgrass steppe may play a large role in determining the amount of N made available through mineralization each year. We have installed a large number soil cores with TDR rods adjacent to them across a large spatial gradient in soil organic matter at the CPER. A set of soil cores will be extracted once per month for the next year, allowing us to estimate net N mineralized per month at each site, with excellent soil moisture data. Next summer, we plan to conduct further experiments including the effects of moisture exclusion and addition on N mineralization dynamics.

Long-Term Dynamics of N in Grazed and Ungrazed Systems:

In 1989, we initiated a long-term ^{15}N tracer study on the CPER, to evaluate the impacts of longterm grazing and exclosure on N storage and partitioning in shortgrass steppe ecosystems. We amended 3 - 1 m^2 plots with 2 g of ^{15}N at each of 2 landscape positions (summit and toeslope) in each of two grazing treatments (ungrazed, grazed) at teh CPER. In 1989, we sampled for initial conditions by estimating the amount of tracer N in plant biomass, total soil pools, microbial biomass, and mineralizable N. This summer, we are resampling the plots to determine the effects of 3 years of grazing on N conservation and partitioning. The results of this study will be critical for our udnerstanding of the influence of grazing on soil organic matter. Results of plant community studies thus far have suggested that there is minimal effect of long-term grazing on shortgrass ecosystem structure, but initial sampling has suggested that there are significant losses soil C and N as a result of grazing. This study will allow us to assess the amount and sources of those losses.

Soil Water

We are continuing to evaluate soil texture-landscape effects on the spatial and temporal distribution of soil water. Our plans for the next several years in this area call for expanding our use of time domain reflectometry (see Section C) and decreasing our use of the neutron moisture gage. We plan to take several years to accomplish this so that we will have a substantial period of overlap between the two techniques to allow us to be able to compare information from one method with that collected by the other.

Disturbances

Grazing

ANPP, rain-use efficiency, forage quality concentrations and yields were assessed in treatments that had been ungrazed, lightly, or heavily grazed for 50 years, not defoliated or defoliated based upon removals observed in naturally-grazed reference plots, in a year of average precipitation or with supplemental water to simulate a wet year (Varnamkhasti et al. submitted, Milchunas et al. submitted). ANPP of non-defoliated vegetation was greatest in long-term ungrazed treatment when supplemented with water, but was least among the three grazing treatments when not supplemented with additional water (Fig. 18). ANPP was greater in long-term lightly than heavily grazed treatments only when defoliated under conditions of relatively greater water stress. The only instance where less precipitation did not result in less ANPP was in lightly grazed treatment with current defoliation; suggesting a water conservation mechanism due to defoliation under water stress conditions. However, water treatment generally had the greatest effect among the three treatments on ANPP. Rain-use efficiency of non-defoliated grassland differed between water treatments only in long-term ungrazed grassland, and differed between lightly and heavily grazed treatment only when defoliated.

In general, defoliation had positive effects, and long-term grazing and water had negative effects, on forage nitrogen concentrations and digestibilities (Fig. 19 and Fig. 20). However, defoliation interacted with grazing in determining forage nitrogen concentrations, and with grazing and with watering in determining digestibilities. Nitrogen and digestibility increased with defoliation in lightly, but not in heavily, grazed treatments. The dilution effect of watering on digestibilities through increased plant growth was offset by defoliation. The negative effects of long-term grazing on forage quality were small, equally or more than compensated for by defoliation under relatively dry conditions, but more pronounced with increased precipitation.

Nitrogen yields and digestible forage production were usually increased by defoliation, but this depended upon grazing and watering treatments (Fig. 21 and Fig. 22). Increased yields and concentrations in response to defoliation were greater than the ANPP response in lightly grazed grassland. Quality yields were greater in grazed than ungrazed treatments in the year of average precipitation, but less in the simulated wet year. Optimizing quantity and year-to-year stability of nitrogen and digestible forage yield may best be achieved with light grazing rather than no or heavy grazing.

Defoliations were conducted in a manner closely resembling the natural pattern and intensity, and confirm the potential for a positive feedback-loop of increased forage quality with defoliation observed in pot experiments. Long-term heavy grazing can diminish this response. Quantity (ANPP), quantity of quality (digestible and N yields), and quality (concentrations) do not necessarily respond similarly in interactions between defoliation, long-term grazing and precipitation; implications for non-selective versus selective consumers co-inhabiting the range may be different.

Long-term Forage Production

Estimates of forage production since 1939 for long-term ungrazed, lightly, moderately, and heavily grazed treatments (0, 20, 40, 60% removal) were subjected to multiple regression analyses to assess long-term temporal trends due to grazing and short-term sensitivities to abiotic factors (Milchunas et al. submitted). Variability in forage production was explained mostly by cool-season precipitation, and quantities of forage production were more sensitive to annual fluctuations in precipitation than to long-term grazing treatments (Fig. 23). Production per unit increase of cool-season precipitation was greater than for warm-season precipitation, but only when cool-season precipitation was greater than average (Fig. 24). This was attributed to differences in evaporative demand of the atmosphere and potentially different utilization of small and large rainfall events in the two seasons.

Forage production was not affected by grazing at 20 to 35 % consumption. For pastures of average relative productivity, grazing at 60 % level of consumption for 25 yrs resulted in a 3 % decrease in forage production in wet years to a 12 % decrease in dry years. Estimates of productivity after 50 yrs of treatment were -5 and -18 % for wet and average years of precipitation, respectively, for 60 versus 20 % levels of consumption. Average production based upon all data from 1939-1990 was 75, 71, 68, and 57 $g/m^2/yr$ for ungrazed, lightly, moderately, and heavily grazed treatments, respectively. Standard deviations for production of all four treatments suggest a similar degree of stability.

Small-scale Disturbances

In 1990, we resampled areas where the vegetation had been killed by the larvae of June beetles (white grubs) in 1977. These 32 areas were originally sampled in 1977 by the USDA-Agricultural Research Service and have been resampled five times (1978, 1979, 1980, 1982, 1990). For each grub-killed area, cover, density, and biomass by species were obtained in permanent plots both in the killed area (patch) and outside the area (undisturbed). In four pastures (sites 7W, 7E, 19NW, and 8NC), paired areas were found inside and outside exclosures that allow us to evaluate the effects of grazing by cattle on plant recovery; therefore our analysis has focused on the areas in these pastures.

For undisturbed areas surrounding patches killed by white grubs, cover was dominated by *B. gracilis* for both grazed and ungrazed areas with values ranging from 18 to >60% (Fig. 25a, b). Total cover ranged from 21% in 1978 for grazed areas to >70% in 1982 on ungrazed areas. C3 perennial grasses, perennial forbs and shrubs, and cactus were small, but important components of cover for both grazed and ungrazed areas. For patches killed by white grubs, total cover and cover of *B. gracilis* were smaller than for the undisturbed areas for each year of sampling. Both total cover and cover of *B. gracilis* increased from 1977 to 1982 then decreased with a similar magnitude as the decrease in cover on undisturbed areas for the same time period. Perennial forbs and shrubs were important components of cover for both grazed and ungrazed patches in the early stages of recovery (1977-1980) whereas cactus and perennial grasses other than *B. gracilis* increased in importance with time. Grazing was important to the recovery of *B. gracilis* for three of the four sites (Fig. 26). Cover of *B. gracilis* on the disturbed areas as a proportion of *B. gracilis* cover in the undisturbed areas increased from 1977 to 1982 for all sites with a faster rate of increase on the ungrazed than the grazed areas for all sites except 8NC (Fig. 26d). At this site, the application of nitrogen fertilizer during this time period may have reduced differences in plant recovery as affected by grazing. A similar analysis using degree of patchiness as a covariate indicated no difference between ungrazed and grazed areas in their rate of recovery, and indicated that grazing had important affects on the patchiness of each area. For all sites, the patchiness or amount of area with dead *B. gracilis* decreased with time, and for three sites patchiness was larger for grazed than ungrazed areas from 1977 to at least 1979 (Fig. 27). No differences in patchiness were found between grazed and ungrazed areas for site 8NC (Fig. 27d).

We continued our study of the effects of interactions among disturbance characteristics for small disturbances (0.5 to 1.5 m-diameter) by comparing plant recovery on naturally-occurring and artificially-produced disturbances of different types, seasonality, size, and location by soil texture. Species composition data have been collected annually since 1985. Recently our efforts have included sampling the area immediately surrounding each disturbance to determine the importance of nearby seed source and vegetative propagules to plant recovery. A large amount of variability has been observed between disturbed areas that is likely related to variability in vegetation surrounding each area.

Large-scale Disturbances

In 1990, we initiated a study to evaluate the recovery of shortgrass ecosystems on agricultural fields abandoned in the 1930's. Most successional studies in the shortgrass steppe have focused on plant recovery on old fields with the important conclusion that the dominant species, *B. gracilis*, either fails to recover or recovers very slowly after disturbances. Because this conclusion is in conflict with our simulation modeling results, we designed a study to evaluate the recovery of plants and soils on old fields in the Pawnee National Grasslands (PNG) and CPER of northeastern Colorado. Aerial photos from 1937 were used to select thirteen fields on similar soils that had recently been abandoned. Because wind direction during the time of seed dispersal is primarily from the west, fields were selected with a west edge bordering unplowed vegetation, the primary source of propagules for recovery. The fields were selected to represent the precipitation and temperature gradients of the PNG and CPER. Photos from 1988 were then used to find the fields on the ground. Because our simulation results indicated the importance of distance from the west edge to plant recovery, spatial sampling was used for both vegetation and soils. Sampling was conducted on transects placed perpendicular to the west edge, and at 3-m intervals for distances up to 99m from the edge. Sampling was conducted with the help of thirteen volunteers from the Earthwatch Foundation. Plant community results are reported below and the soil organic matter and nutrient results are reported in the nutrient section (page 9).

In contrast to previous successional studies on old fields, *B. gracilis* was found on all fields sampled 53 years after abandonment and dominated the cover on two of the fields. We classified the fields into four groups based on the relationship between *B. gracilis* cover and distance from the edge for the first 42 m (Fig. 28). Because the unplowed cover varied among fields, we used the magnitude of the slope to determine the groups. For two groups, the slope was negative and significantly different from 0 (Fig. 28a,b). The remaining two groups have insignificant regressions with either a uniformly large cover or uniformly small cover with distance (Fig. 28d). Although cover of *B. gracilis* is one index of recovery, indices based on community measures indicated none of the fields had recovered to the unplowed state. Similarity in species composition decreased with distance for all fields (Fig. 29a) and the number of species either decreased or increased with distance (Fig. 29b). A comparison of our results with two traditional models of succession for shortgrass communities indicated that few fields fit either model. These models use another index of recovery, percentage of vegetation attributed to shortgrasses (*B. gracilis*, the co-dominant Buchloe dactyloides, and Carex species). For the traditional Clementsian model, only two fields had the expected high shortgrass cover (Fig. 30a) and for the model modified for northeastern Colorado, only two fields had low shortgrass cover expected of the model (Fig. 30b). The large variability in cover, density, and species composition found on these fields may be related to differences among fields in the timing of precipitation and temperature, or historical events, such as grazing intensity and length of cultivation. We plan to evaluate the importance of these factors to the recovery of plants and soils using our linked STEPPE-CENTURY-SOILWAT models.

C. Data Management

CPER Bibliography

The CPER Bibliography was updated and distributed in January. It contains listings of publications relevant to the CPER classified by journal articles, technical reports, chapters in books and symposium proceedings, theses, dissertations, and abstracts. The entries are indexed by authors and keywords.

Interactive Data Access Program

The interactive data access program, ltermenu, that we are developing has been converted to run under the X windowing system, and will soon run on personal computers under MS-DOS.The program previously ran only under Sunview. Ltermenu enables one to examine the CPER data sets by accessing the data and data descriptions using the Internet. The program uses menus to select and display data or data descriptions. The data can be displayed in tabular form, or as graphs. Data files can be downloaded to the local machine and saved, and data items selected by the investigator can be extracted from the data file and saved.

As part of a supplement through the University of Michigan we are developing a library of functions which can be used to transfer data between computers attached to the Internet. The routines can be compiled to use either BSD Unix stream sockets, or to use the X/Open Transport Interface(XTI). XTI is a transport layer independent interface compatible with ATT's Transport Layer Interface(TLI). These routines can be used to transfer entire files, to transfer records of data, and to pass messages between concurrently executing programs. The functions can be accessed from either Fortran or C, and provide a base on which distributed data management tools easily can be built.

Attribute-Value Syntax for Describing Data

We are in the process of converting our data descriptions to a new format(Fig. 31). The new format provides considerably more flexibility in describing data files than the previous format. It is based on a C-style description of data structures. The structures can be simple variables, such as FileName, or more complicated structures, such as Column_format (Fig. 32). Structures can be nested with structures. The complex structures use {} to delimit the beginning and end of the structure. A structure consists of an optional type specifier, an attribute label or "tag", and a simple or complex data item.

By default, the data "values" are character strings. The special types INTEGER, REAL, TEXT, and LIST (perhaps more later) can also be used to identify the type of a data element. A TEXT item has one or more character strings enclosed by {} braces. INTEGER and REAL flag numeric types. A LIST is one of more character strings, and is handled much like TEXT. TEXT is differentiated from LIST to help in the process of reformatting the metadata for printing.

We have written a parser that will return the values of items that match an attribute or, for complex structures, the specific value for an attribute. The parser assumes nothing about the names of attributes, nor about the complexity of the structures, so one can add new structures at anytime. One can also include an item in one structure, such as "Units" within the Item structure, without including a Units record in all Item structures in the file.

The general syntax for a data description is <TYPE_DECLARATION> Attribute (value | value (). Things enclosed in brackets <> are optional and | denotes alternative selections. The default type for an attribute is STRING, which is a string of characters beginning with anon-whitespace character and ending with a newline.

SYNTAX RULES:

1. Complex attributes are structures and are identified by having { as their last character.
2. Names of attributes can contain no whitespace characters
3. The value for a simple attribute starts with the first non-whitespace character following the attribute and ends with a newline character. The interpretation of newline characters as the end of a value can be overridden by "escaping" them with a \. The definition of a complex attribute ends with a }.
4. The brackets {} enclose a value that is itself made up of 1 or more attribute-value pairs or, for fundamental types such as TEXT, embedded newline characters.
5. The $ character flags the start of an attribute name that is defined within the file. For example, the EXTERNAL_FUNCTION named DisplayData takes as its argument the name of the data file, which is declared elsewhere in this file.
6. All possible elements within a complex attribute do not need to be defined. For example, Missing_codes is defined only for the Item called NUMBER. The parser returns a flag indicating that an attribute is not defined if the attribute is omitted from an instance of a complex attribute.

The value of a complex attribute can be thought of as the tag for a structure. A generic parser for such a description can look up and return the values for specific attributes, such as Column_format.[ID].Start_column or

Column_format.[NUMBER].Missing_codes.BMDPwith. used to separate hierarchical levels within the data structures. The parser would look up the data by matching the elements of the string (ID, etc.) against the attributes and values. The specification for a value within a particular structure uses brackets ([]) to identify the value of the structure, as in: Column_format.[Item]ID.Start_column. This additional specification could be used to allow the label ID to be associated with more than 1 attribute within Column_format, as long as the ID attributes were of different types. It would also allow one to formulate a request for all values of Variables using the wildcard character *, as in: Column_format.*.Variable. Such a request could be used to generate a menu of data items that could be selected from the data file. The fundamental types would be INTEGER, REAL, TEXT, LIST, EXTERNAL_FUNCTION and perhaps some other types we would agree upon as a group to facilitate data exchange. EXTERNAL_FUNCTION is included as a fundamental type to facilitate using the data description as a class in an object oriented data access system. Such a system would be able to handle non-ASCII data in a logical fashion. For example, if the data were a bit map for an image, the DisplayData function could be a program to display the image on a workstation. If the data were stored as binary values, the DisplayData function could be a program to convert the data to ASCII and then display them. If a site frequently exported data to spreadsheet programs then a function like CreateDIF could identify the appropriate program to call to convert the data to a DIFformat. This new syntax was developed specifically to facilitate the management of non-ASCII data, such as map images, and to facilitate the exchange of data with other sites. The interactive data access program we are developing, ltermenu, is being converted to use the new format for data descriptions. We have been cooperating with the VCR site to enable them to use the metadata tools that we develop. The ltermenu program and data description software that we develop will be made publically available.

Spatial Data

In the past year, we have made significant progress in our CPER Geographic Information System. We hired a new 1/2 time LTER GIS research associate who has a great deal of expertise. Her activities this year have included the following:

- Imported CPER GIS data into the ARC/INFO 6.0 data format;

- Updated a number of our spatial layers for the CPER, including:
    - A new 1991 soil survey of the CPER,
    - a corrected Digital Elevation Model (DEM) for the CPER and surrounding area,
    - regenerated slope and aspect maps for the site using improved algorithms and the new DEM,

- Developed and completed a new data description format for the CPER GIS data library layers.

- Generated maps at 1:24,000 scale for the CPER including vegetation, streams/roads/public land surveys, soils, slope, landform, and aspect.

In addition, we have used the CPER GIS as a resource for locating experiments. First, we input soil sample data from the new exclosure experiment to generate soil texture maps for each exclosure (Figs. 2,3). We are using these maps to characterize the spatial heterogeneity of each site and develop adequate sampling designs for this longterm experiment. Second, we used the GIS to locate new experimental sites for the nutrient cycling - microclimate work described above.

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FIGURE LEGENDS

Fig. 1. Particle size distribution for soils (0-10 cm and 10-30 cm) collected from the new long-term exclosure experiment.

Fig. 2. Contour map of sand content (%) of soils inside (long-term protected) and outside (long-term moderate grazed) of exclosure 24c. This is a site with a relatively complex spatial distribution of soil texture.

Fig. 3. Contour map of sand content (%) of soils inside (long-term protected) and outside (long-term moderate grazed) of exclosure 5a. This is a site with a relatively simple spatial distribution of soil texture.

Fig. 4. Density of cattle fecal pats around the seven exclosures evaluated for the new long-term experiment. Fecal pat density is an index of grazing intensity.

Fig. 5. Species dissimilarity as a function of sand content (%), grazing intensity, and their interaction for the seven exclosures evaluated for the new long-term experiment.

Fig. 6. Density of exotic species as a function of sand content (%), grazing intensity, and their interaction for the seven exclosures evaluated for the new long-term experiment.

Fig. 7. Cover (%) of litter as a function of sand content (%), grazing intensity, and their interaction for the seven exclosures evaluated for the new long-term experiment.

Fig. 8. Standing crop biomass (g/m^2) as a function of sand content (%) and grazing intensity for the seven exclosures evaluated for the new long-term experiment.

Fig. 9. Standing crop biomass (g/m^2) of minor species as a function of sand content (%) for the seven exclosures evaluated for the new long-term experiment.

Fig. 10. Total cover and cover of *B. gracilis* on and off old fields abandoned for 53 years that were either grazed or not grazed by cattle for two sites: (a) site 10 (b) site 8 (c) relative cover of *B. gracilis* for both sites.

Fig. 13. Standing stocks of soil organic carbon (TOC) (a) and total nitrogen (TN) (b) and mass ratio of C to N in the top 0.05 m of soil (c) at two sites at the Central Plains Experimental Range. Site and microsite codes are: CL, clay loam site; SL, sandy loam site; P, plant-covered microsite; O, opening. Error bars represent ±1 standard error of the mean.

Fig. 12. Standing stocks of plant biomass (a) and N (b) at two sites at the Central Plains Experimental Range. Aboveground biomass and biomass in the top 0.05 m of soil were sampled at microsites with *Bouteloua gracilis* plants and in small

openings between plants. Site and microsite codes are: CL, clay loam site; SL, sandy loam site; P, plant-covered microsite; O, opening. Error bars represent ±1 standard error of the means of total biomass and N.

Fig. 14. N mineralized and C respired during 30-d, aerobic incubations of soil from 0 to 0.05 m depth at sandy loam site and clay loam site at the Central Plains Experimental Range: net N mineralized (a) and CO_2-C produced (b) during incubations; ratios of net N mineralized to total N (c), CO_2-C produced to total organic carbon (d), and CO_2-C produced to net N mineralized (e). Microsite codes are : P, plant-covered microsite; O, opening. "L" indicates subsamples amended with additional belowground litter. Error bars represent ±1 standard error of the means of total biomass and N.

Fig 15. Carbon and nitrogen from under and betweenplants in soils from 12 native and abandoned fields and 5 cultivated fields in northeastern Colorado. C and N were significantly affected by both management practice and sample location with respect to *B. gracilis* at $p < 0.05$. Shaded bars represent standard error of the mean.

Fig. 16. and b. Microbial biomass C and N from under and between *Bouteloua gracilis* plants in soils from 12 native and abandoned fields and 5 cultivated fields in northeastern Colorado. Microbial biomass C and N were significantly higher under plants than between, and significantly lower in cultivated fields than native or abandoned at $p < 0.05$. Shaded bars represent standard error of the mean.

Fig. 17. Potentially mineralizable C and N from under and between *Bouteloua gracilis* plants in soils from 12 native and abandoned fields and 5 cultivated fields in northeastern Colorado. There were no significant differences among management practices, but both C and N mineralization were higher under than between plants. Shaded bars represent standard error of the mean.

Fig. 18. Aboveground net primary production (g/m^2) in long-term lightly (L) and heavily (H) grazed treatments that were not defoliated or defoliated and not watered (control) or watered (addition) to simulate a wet year for northern shortgrass steppe. B) Aboveground net primary production (g/m^2) in long-term ungrazed, lightly, and heavily grazed treatments (all nondefoliated) in three different lowlands (locations 1,2,3), and without (control) and with water addition. The half-bar of ungrazed treatment that is starred (*) and solid does not include, and the other half-bar does include, location-2 (see text for explanation).

Fig. 19. Nitrogen concentration (% dry weight) of forage in long-term lightly (L) and heavily (H) grazed treatments that were not defoliated or defoliated and not watered (control) or watered (addition) to simulate a wet year for northern shortgrass steppe. B) Nitrogen concentrations of forage in long-term ungrazed (U), lightly (L), and heavily (H) grazed treatments (all nondefoliated) without (control) and with water addition.

Fig. 20. Digestibility (*% in vitro* dry matter) of forage in long-term lightly (L) and heavily (H) grazed treatments that were not defoliated or defoliated and not watered (C=control) or watered (W=addition) to simulate a wet year for northern shortgrass steppe. B) Digestibility of forage in long-term ungrazed (U), lightly (L), and heavily (H) grazed treatments (all nondefoliated) without (control) and with water addition.

Fig. 21. Nitrogen yield (g/m^2) of forage in long-term lightly (L) and heavily (H) grazed treatments that were not defoliated or defoliated and not watered (control) or watered (addition) to simulate a wet year for northern shortgrass steppe. B) Nitrogen yield of forage in long-term ungrazed (U), lightly (L), and heavily (H) grazed treatments (all nondefoliated) without (control) and with water addition.

Fig. 22. Digestible forage production (*in vitro* digestible dry matter/m^2) of forage in long-term lightly (L) and heavily (H) grazed treatments that were not defoliated or defoliated and not watered (control) or watered (addition) to simulate a wet year for northern shortgrass steppe. B) Nitrogen yield of forage in long-term ungrazed (U), lightly (L), and heavily (H) grazed treatments (all nondefoliated) without (control) and with water addition.

Fig. 23. Sensitivity of change in the regression model of forage production (aboveground g/m^2/yr) to changes in A) cool-season and B) warm-season precipitation. Ranges for precipitation were chosen to provide examples of reasonable low-high values; other variables in the regression model were held constant at average values.

Fig. 24. Sensitivity of change in the regression model of forage production (aboveground g/m^2/yr) to changes in grazing intensity, years of treatment, and cool- and warm-season precipitation. Ranges for precipitation were chosen to provide examples of reasonable low-high values. Decreased production with increasing years of treatment is not considered a grazing effect, because cool-season precipitation declined over the years of measurement.

Fig. 25. Cover of five species or functional groups of species on grazed or ungrazed patches killed by white grubs or the surrounding undisturbed area for six dates: (a) grazed undisturbed (b) ungrazed undisturbed (c) grazed patch (d) ungrazed patch.

Fig. 26. Cover of *B. gracilis* on each grub-killed patch as a proportion of cover of this species on the surrounding undisturbed area through time for two grazing intensities (ungrazed, grazed) and four sites: (a) site 7W (b) site 7E (c) site 19NW (d) site 8NC.

Fig 27. Area of each grub-killed patch containing dead *B. gracilis* through time for two grazing intensities (ungrazed, grazed) and four sites: (a) site 7W (b) site 7E (c) site 19NW (d) site 8NC.

Fig. 28. Cover of *B. gracilis* on abandoned fields 53 years after abandonment with distance for the first 45 m from the edge for four groups of fields based on slopes and intercepts of regressions between cover and distance: (a) fields with small negative slopes (b) fields with large negative slopes (c) fields with slopes not different from zero; groups differ in the intercept.

Fig. 29. (a) Similarity in cover between abandoned fields and unplowed vegetation with distance for the first 45 m from the edge for four groups of fields based on slopes and intercepts of regressions between similarity and distance. (b) Species richness on abandoned fields with distance for the first 45 m from the edge for two groups of fields based on slopes and intercepts of regressions between number of species and distance.

Fig. 30. Clementsian models of succession for shortgrass communities of North America and relative shortgrass cover for the thirteen sites sampled 53 years after abandonment. (a) traditional model adapted from Judd and Jackson (1940) (b) conventional or modified oldfield model for northeastern Colorado adapted from Costello (1944), Hyder and Everson (1968), Hyder et al. (1971), and Laycock (1989; 1991).

Fig. 31. An example data description form.

Fig. 32. An item in a data description consists of an optional type specifier, and attribute label, and a value. Values can be simple or complex structures containing other attributes and values.

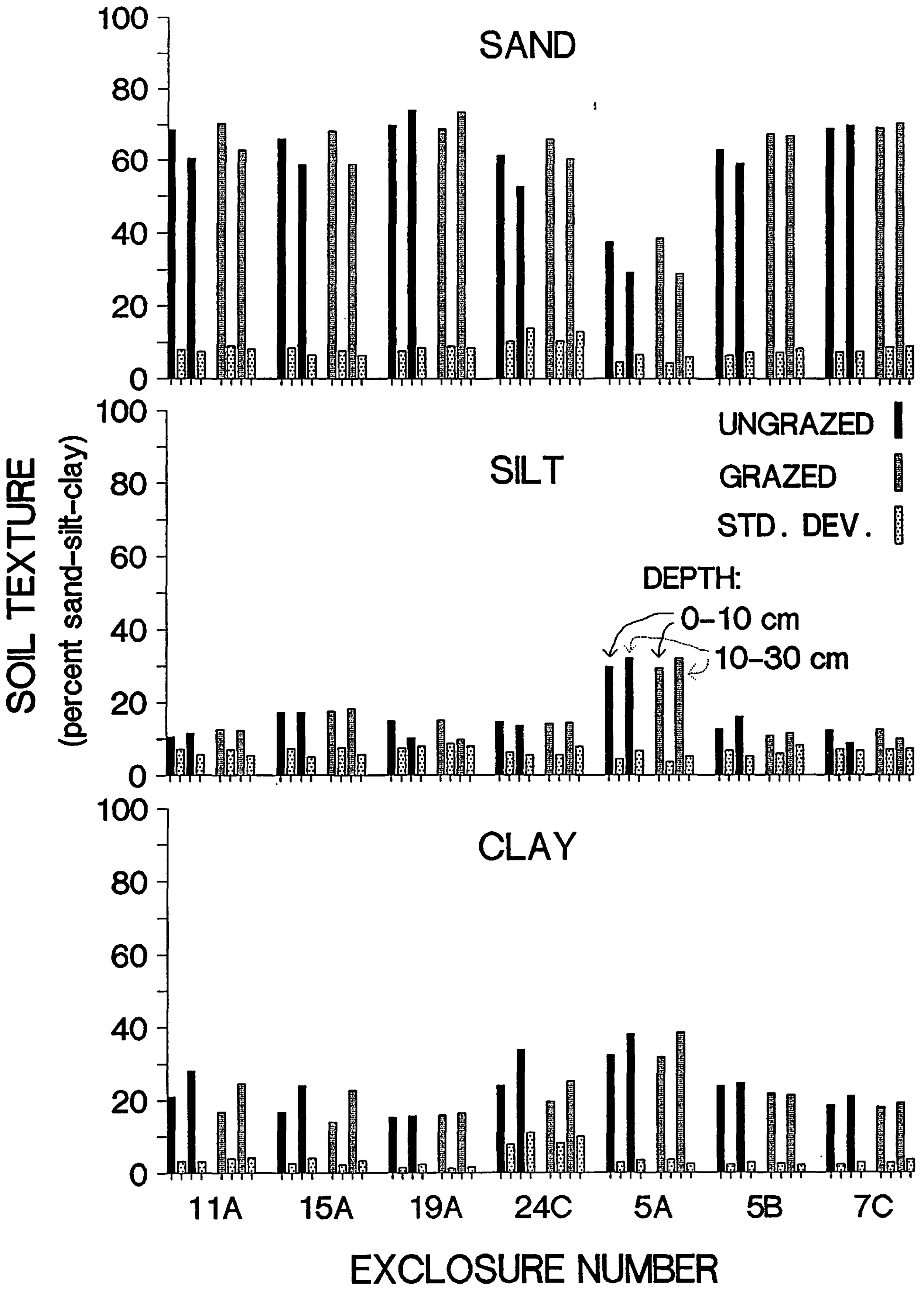

SAND
SILT
CLAY
UNGRAZED
GRAZED
STD. DEV.
DEPTH:
0-10 cm
10-30 cm
SOIL TEXTURE
(percent sand-silt-clay)
0
20
40
60
80
100
11A
15A
19A
24C
5A
5B
7C
EXCLOSURE NUMBER

Figure 1.

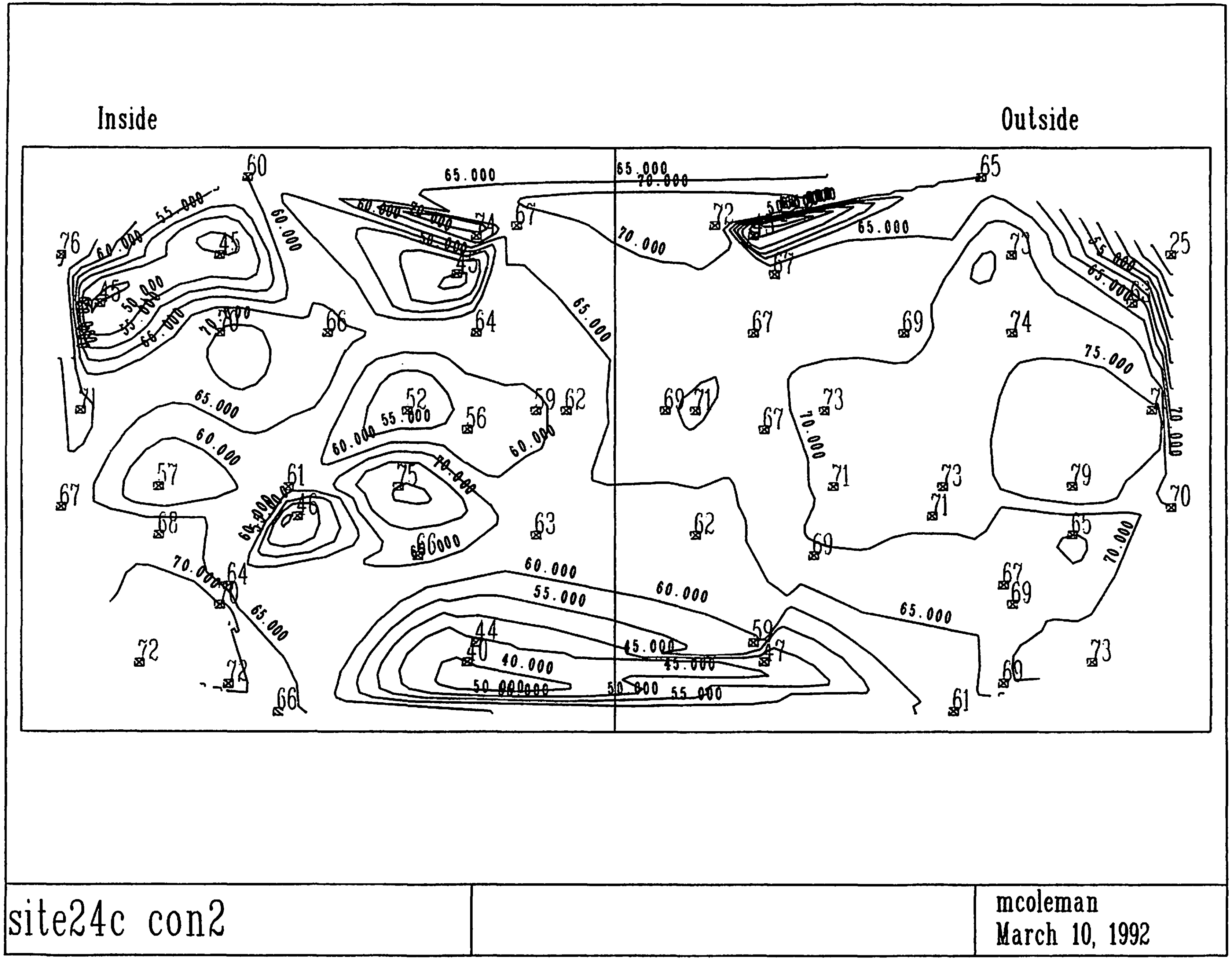

Inside
Outside
60
65.000
65.000
70.000
65
55.000
60.000
60.000
50.000
74
67
72
70.000
65.000
76
45
45
50.000
73
25
55.000
65.000
45
64
66
70.00
67
69
74
75.000
65.000
65.000
71
52
55.000
56
59
62
69
71
67
73
70.000
60.000
60.000
60.000
70.000
57
61
75
71
73
79
67
46
71
70
68
63
62
69
65
66000
60.000
55.000
60.000
70.000
64
70
65.000
65.000
67
69
72
44
40
40.000
45.000
45.000
59
47
73
72
50.000
50.000
55.000
60
66
61
site24c con2
mcoleman
March 10, 1992

Figure 2.

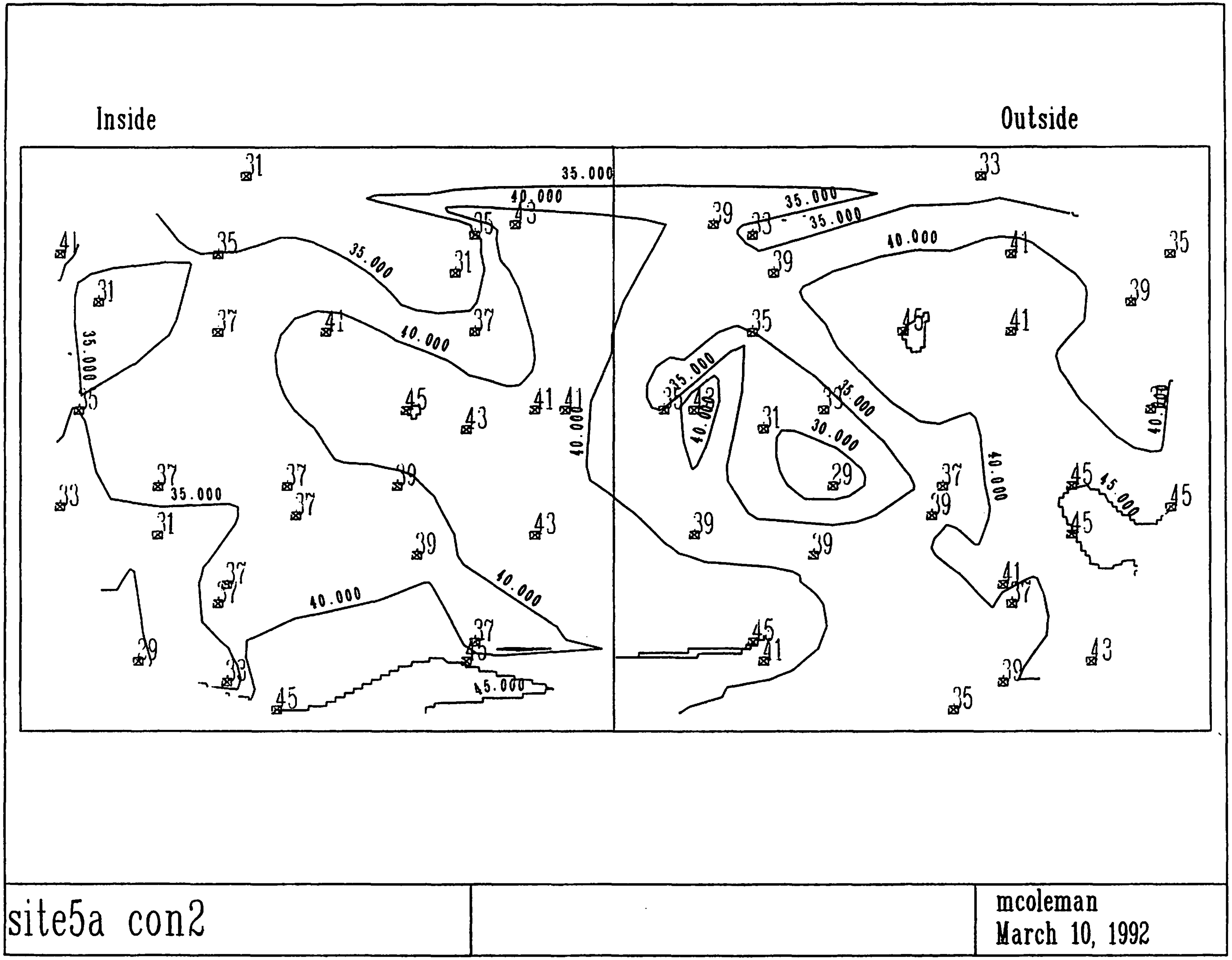
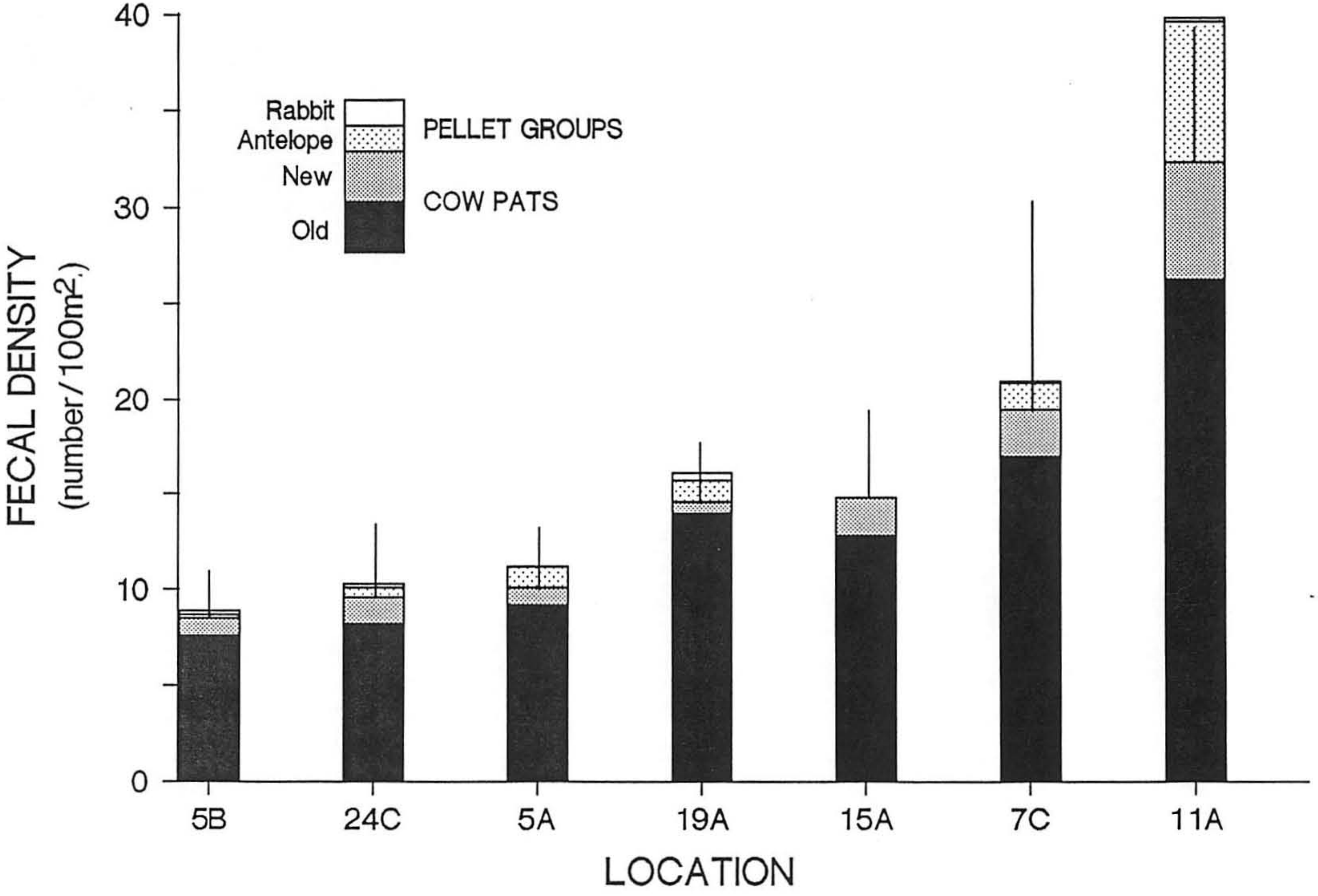

Inside
Outside
35.000
40.000
30.000
45.000
site5a con2
mcoleman
March 10, 1992

Figure 3.



40
30
20
10
0
FECAL DENSITY
(number/100m²)
Rabbit
Antelope
PELLET GROUPS
New
Old
COW PATS
5B
24C
5A
19A
15A
7C
11A
LOCATION

Figure 4.

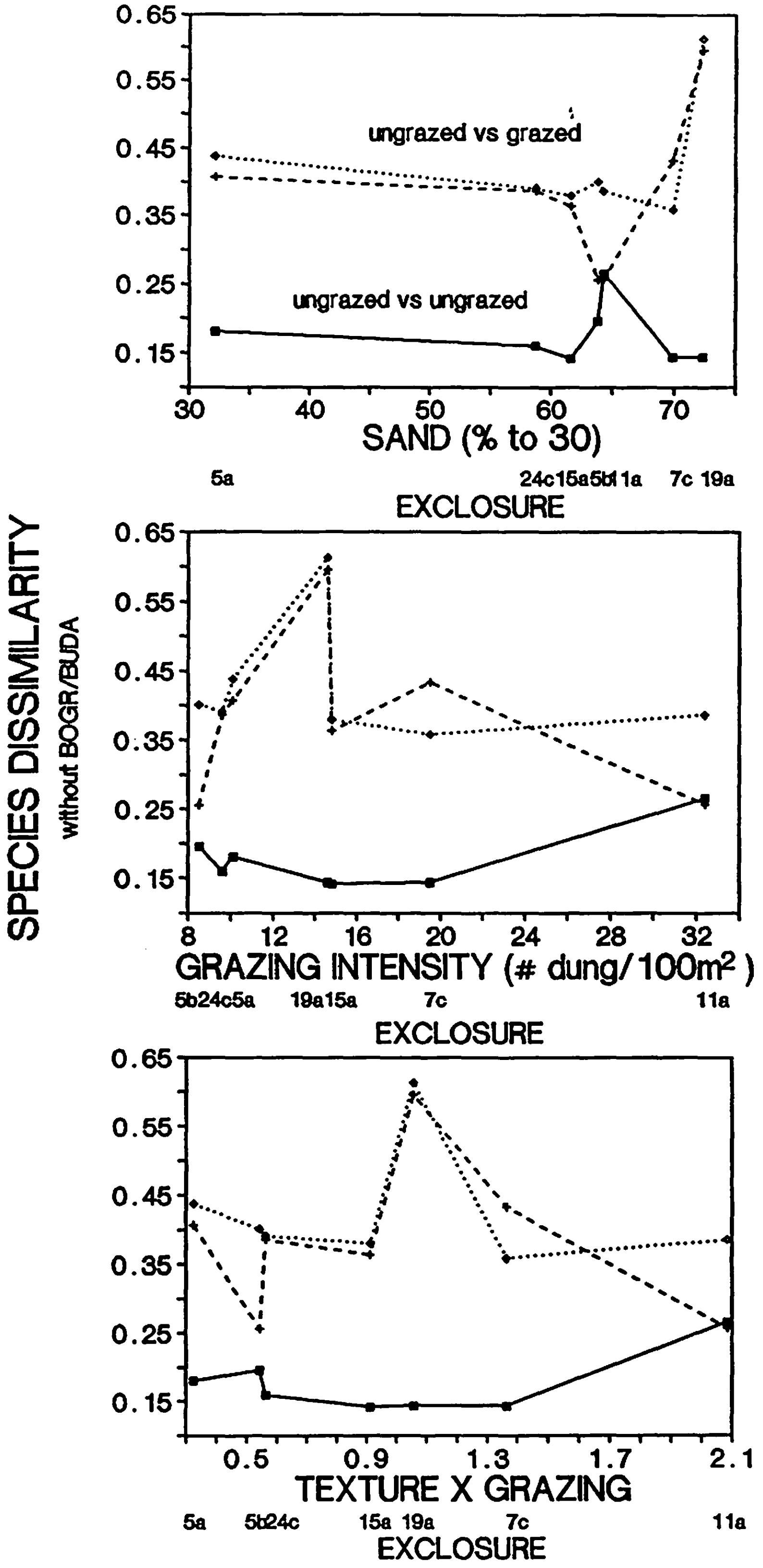
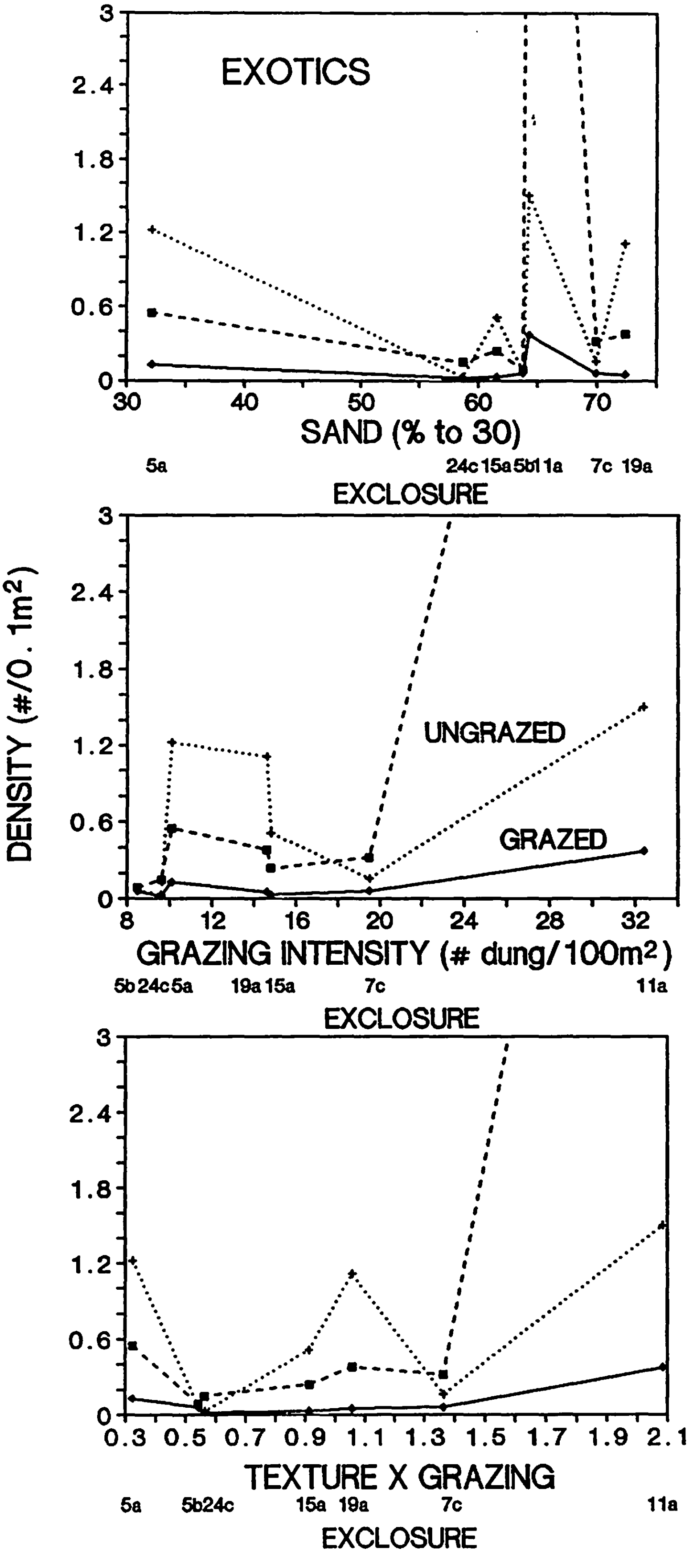

SPECIES DISSIMILARITY
without BOGR/BUDA
0.65
0.55
0.45
0.35
0.25
0.15
ungrazed vs grazed
ungrazed vs ungrazed
30
40
50
60
70
SAND (% to 30)
5a
24c15a5b11a
7c 19a
EXCLOSURE
8
12
16
20
24
28
32
GRAZING INTENSITY (# dung/100m²)
5b24c5a
19a15a
7c
11a
EXCLOSURE
0.5
0.9
1.3
1.7
2.1
TEXTURE X GRAZING
5a
5b24c
15a 19a
7c
11a
EXCLOSURE

Figure 5.



EXOTICS
DENSITY (#/0. 1m2)
3
2.4
1.8
1.2
0.6
0
30
40
50
60
70
SAND (% to 30)
5a
24c 15a 5b 11a
7c 19a
EXCLOSURE
UNGRAZED
GRAZED
8
12
16
20
24
28
32
GRAZING INTENSITY (# dung/100m2)
5b 24c 5a
19a 15a
7c
11a
EXCLOSURE
0.3 0.5 0.7 0.9 1.1 1.3 1.5 1.7 1.9 2.1
TEXTURE X GRAZING
5a
5b 24c
15a 19a
7c
11a
EXCLOSURE

Figure 6.

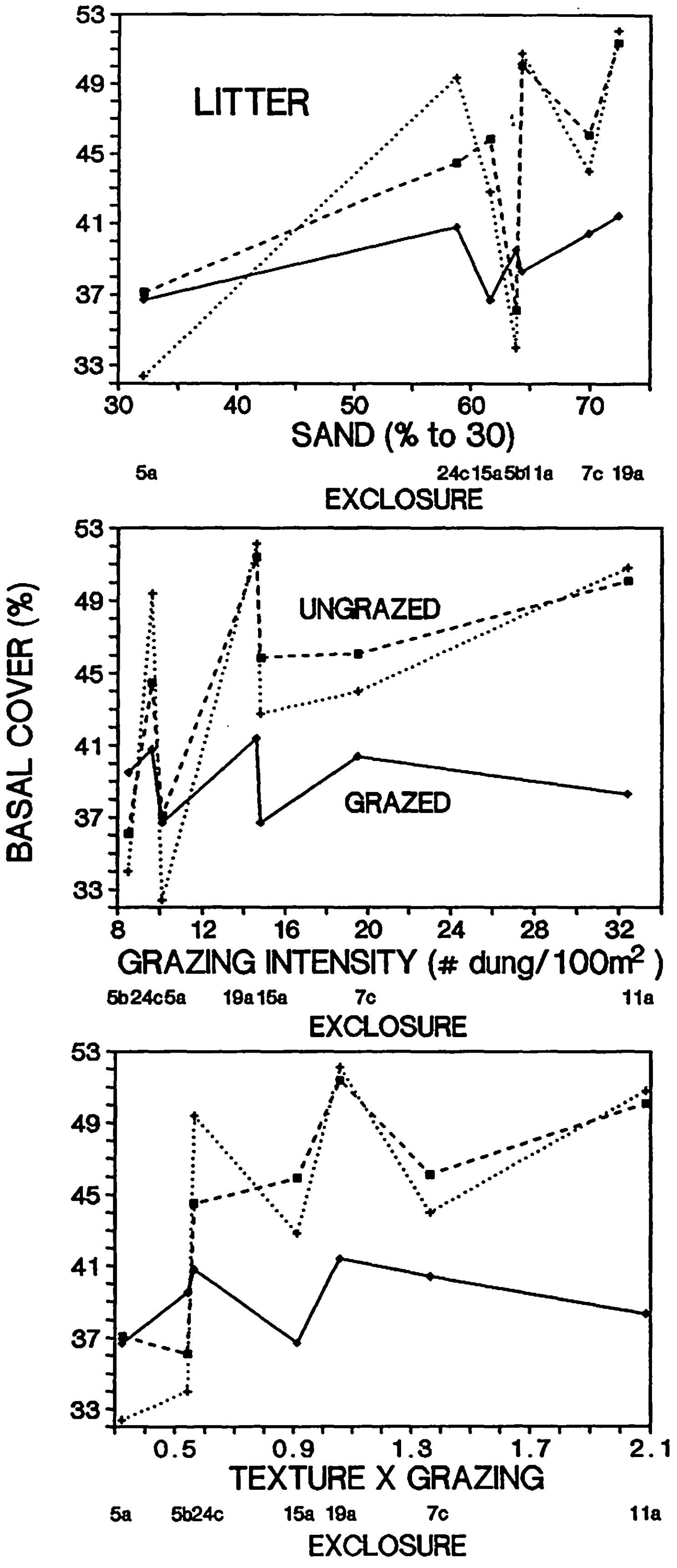

LITTER
UNGRAZED
GRAZED
BASAL COVER (%)
53
49
45
41
37
33
30
40
50
60
70
SAND (% to 30)
5a
24c 15a 5b 11a
7c 19a
EXCLOSURE
8
12
16
20
24
28
32
GRAZING INTENSITY (# dung/100m²)
5b 24c 5a
19a 15a
7c
11a
EXCLOSURE
0.5
0.9
1.3
1.7
2.1
TEXTURE X GRAZING
5a
5b 24c
15a 19a
7c
11a
EXCLOSURE

Figure 7.

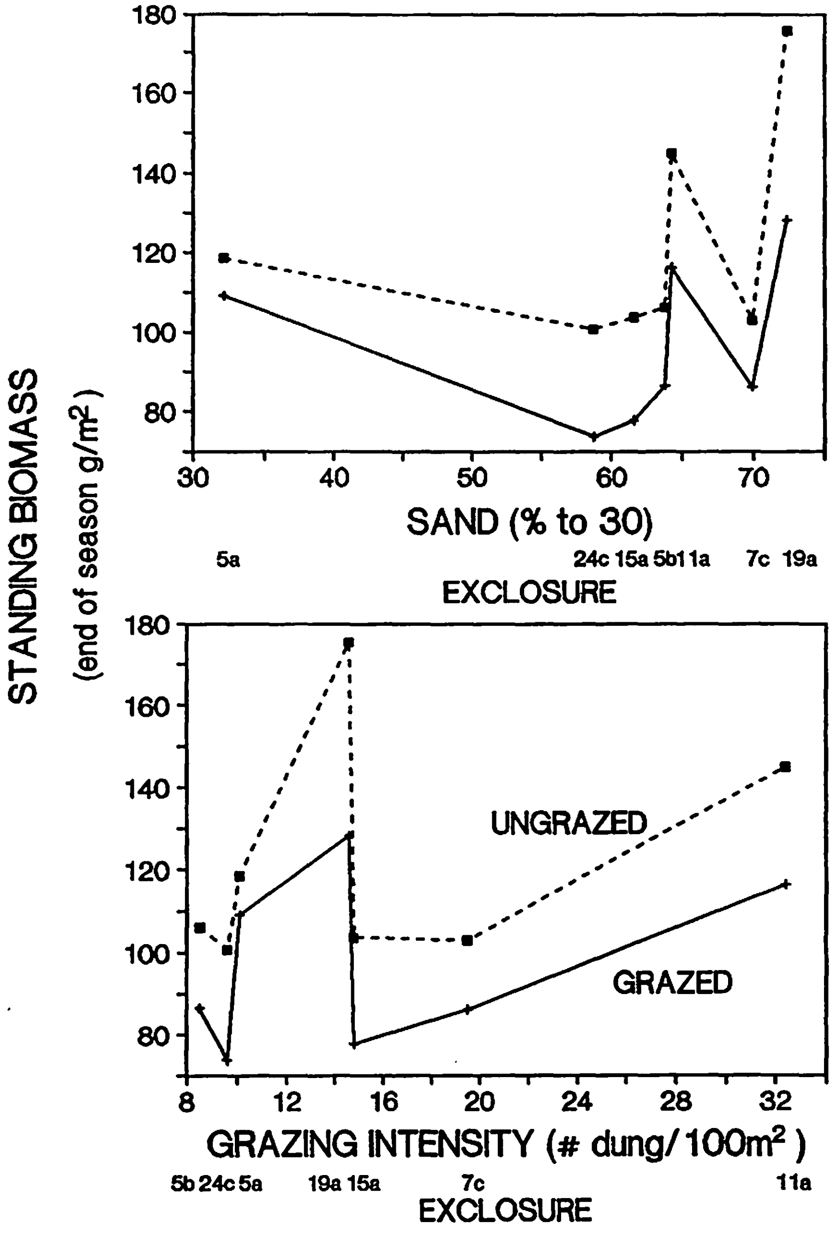

STANDING BIOMASS
(end of season g/m²)
180
160
140
120
100
80
30
40
50
60
70
SAND (% to 30)
5a
24c 15a 5b 11a
7c 19a
EXCLOSURE
UNGRAZED
GRAZED
8
12
16
20
24
28
32
GRAZING INTENSITY (# dung/100m²)
5b 24c 5a
19a 15a
7c
11a
EXCLOSURE

Figure 8.

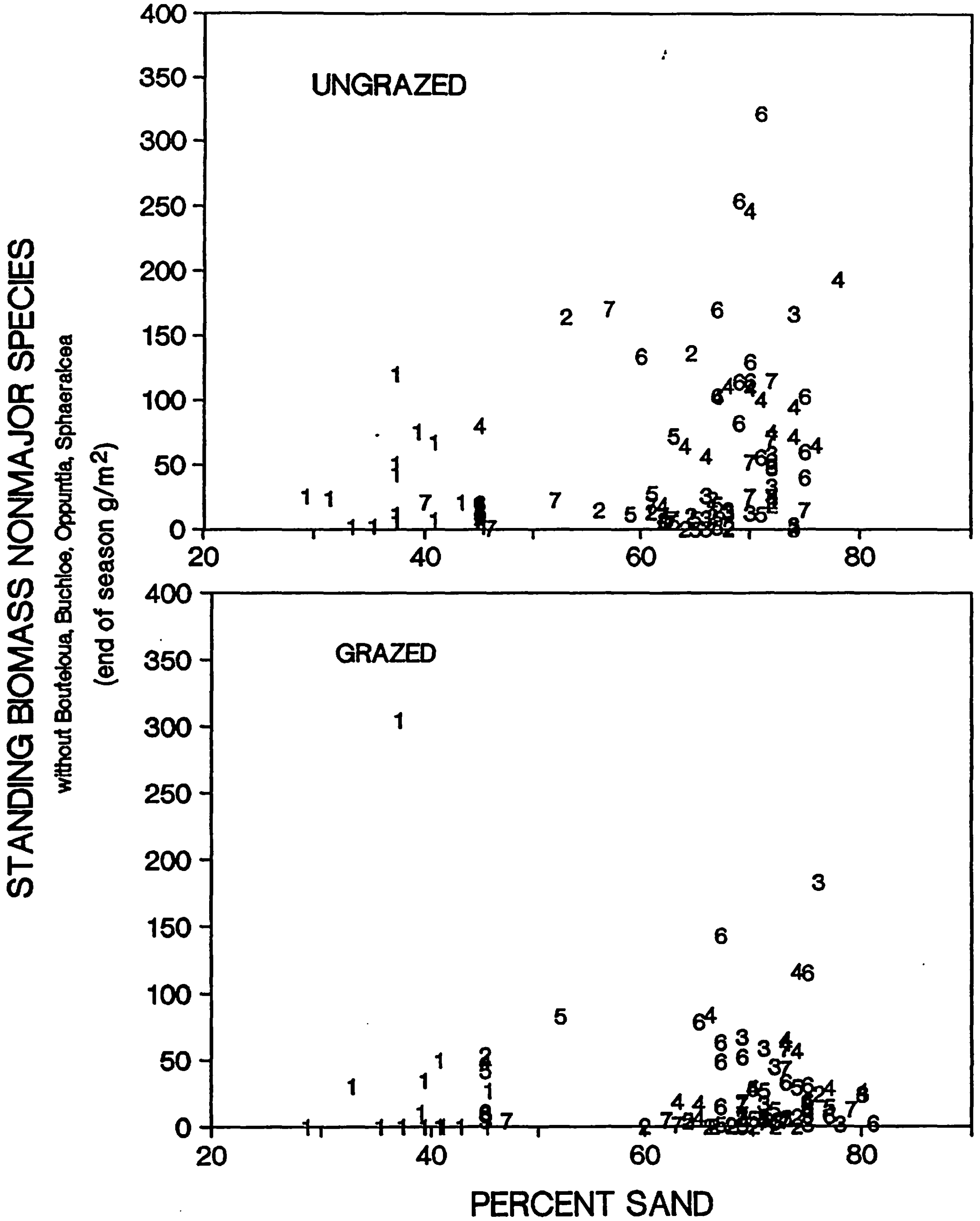

UNGRAZED
GRAZED
STANDING BIOMASS NONMAJOR SPECIES
without Bouteloua, Buchloe, Oppuntia, Sphaeralcea
(end of season g/m2)
PERCENT SAND
0
50
100
150
200
250
300
350
400
20
40
60
80

Figure 9.

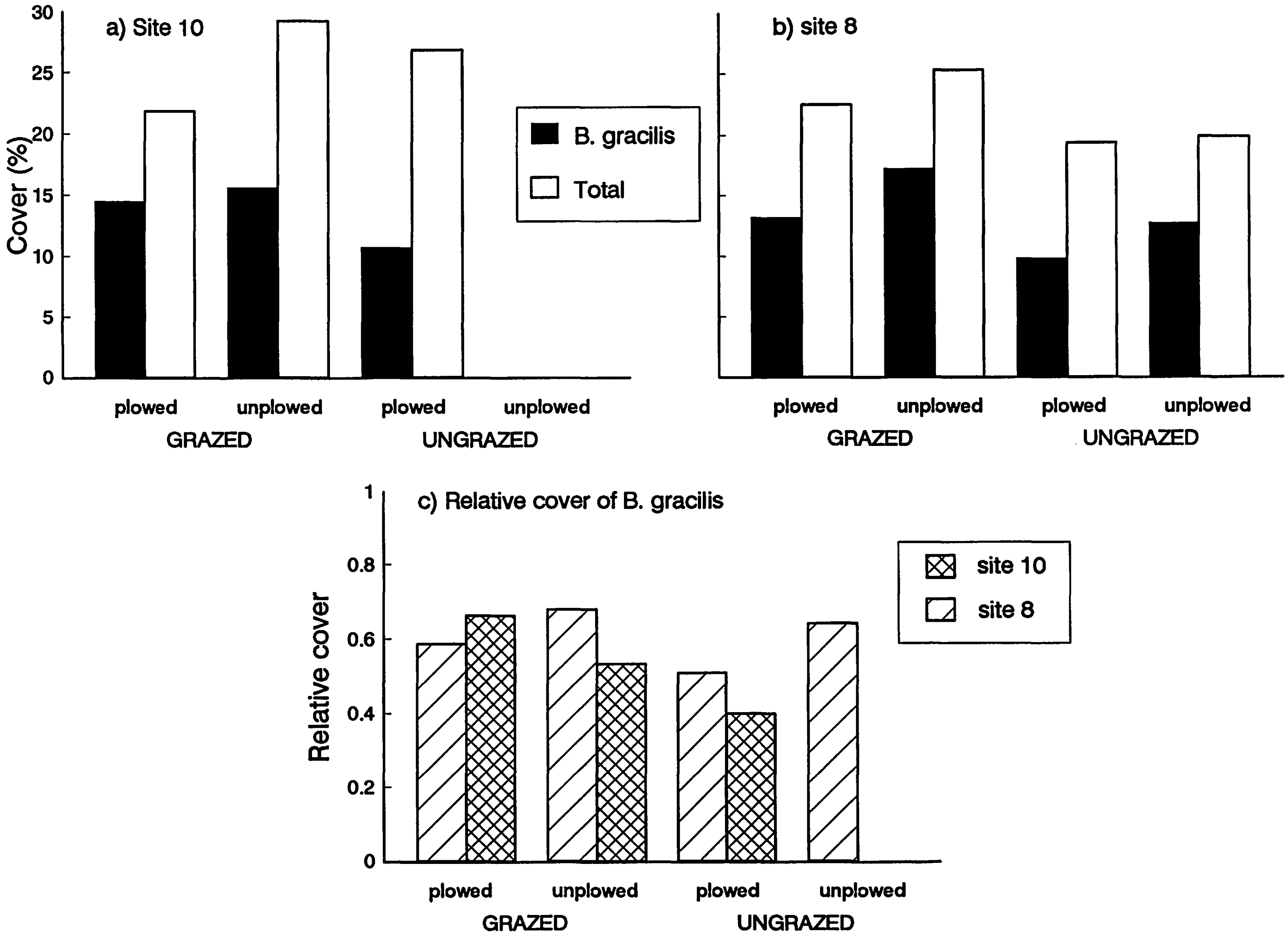

a) Site 10
Cover (%)
30
25
20
15
10
5
0
B. gracilis
Total
plowed
unplowed
plowed
unplowed
GRAZED
UNGRAZED
b) site 8
plowed
unplowed
plowed
unplowed
GRAZED
UNGRAZED
c) Relative cover of B. gracilis
Relative cover
1
0.8
0.6
0.4
0.2
0
site 10
site 8
plowed
unplowed
plowed
unplowed
GRAZED
UNGRAZED

Figure 10.

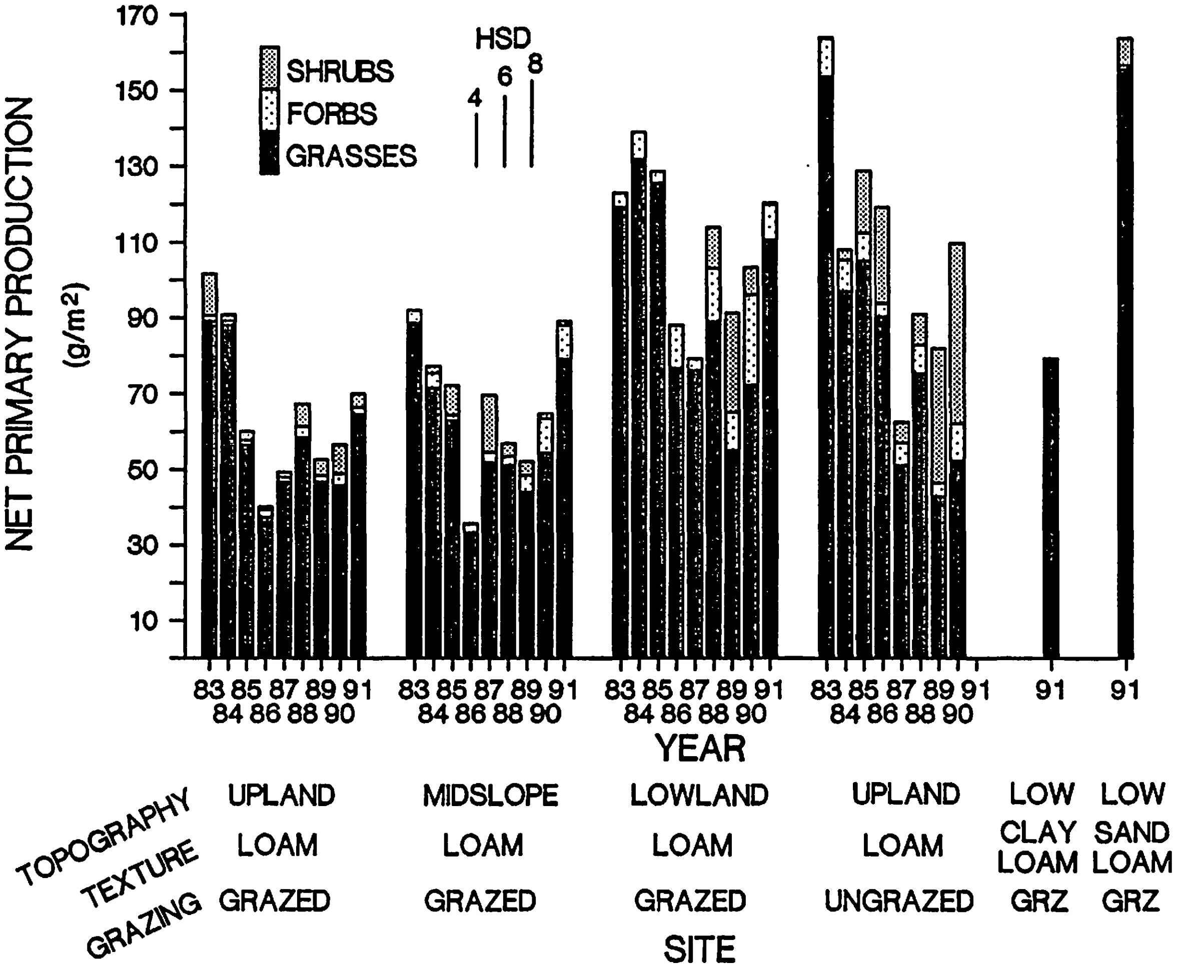
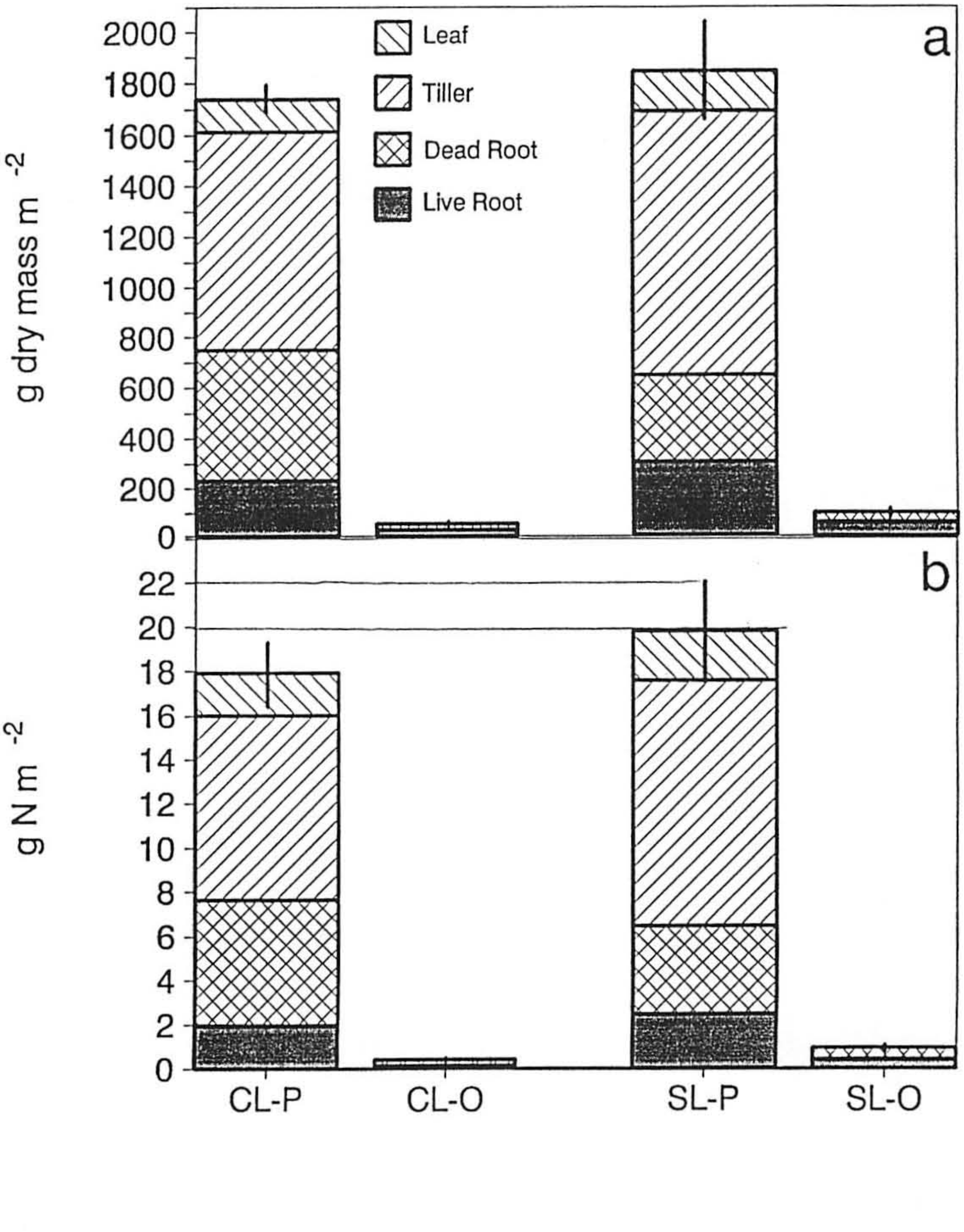

NET PRIMARY PRODUCTION
(g/m²)
170
150
130
110
90
70
50
30
10
SHRUBS
FORBS
GRASSES
HSD
4
6
8
83 85 87 89 91
84 86 88 90
83 85 87 89 91
84 86 88 90
83 85 87 89 91
84 86 88 90
83 85 87 89 91
84 86 88 90
91
91
YEAR
TOPOGRAPHY
TEXTURE
GRAZING
UPLAND
LOAM
GRAZED
MIDSLOPE
LOAM
GRAZED
LOWLAND
LOAM
GRAZED
UPLAND
LOAM
UNGRAZED
LOW
CLAY LOAM
GRZ
LOW
SAND LOAM
GRZ
SITE

Figure 11.



a
b
Leaf
Tiller
Dead Root
Live Root
g dry mass m -2
g N m -2
2000
1800
1600
1400
1200
1000
800
600
400
200
0
22
20
18
16
14
12
10
8
6
4
2
0
CL-P
CL-O
SL-P
SL-O

Figure 12.

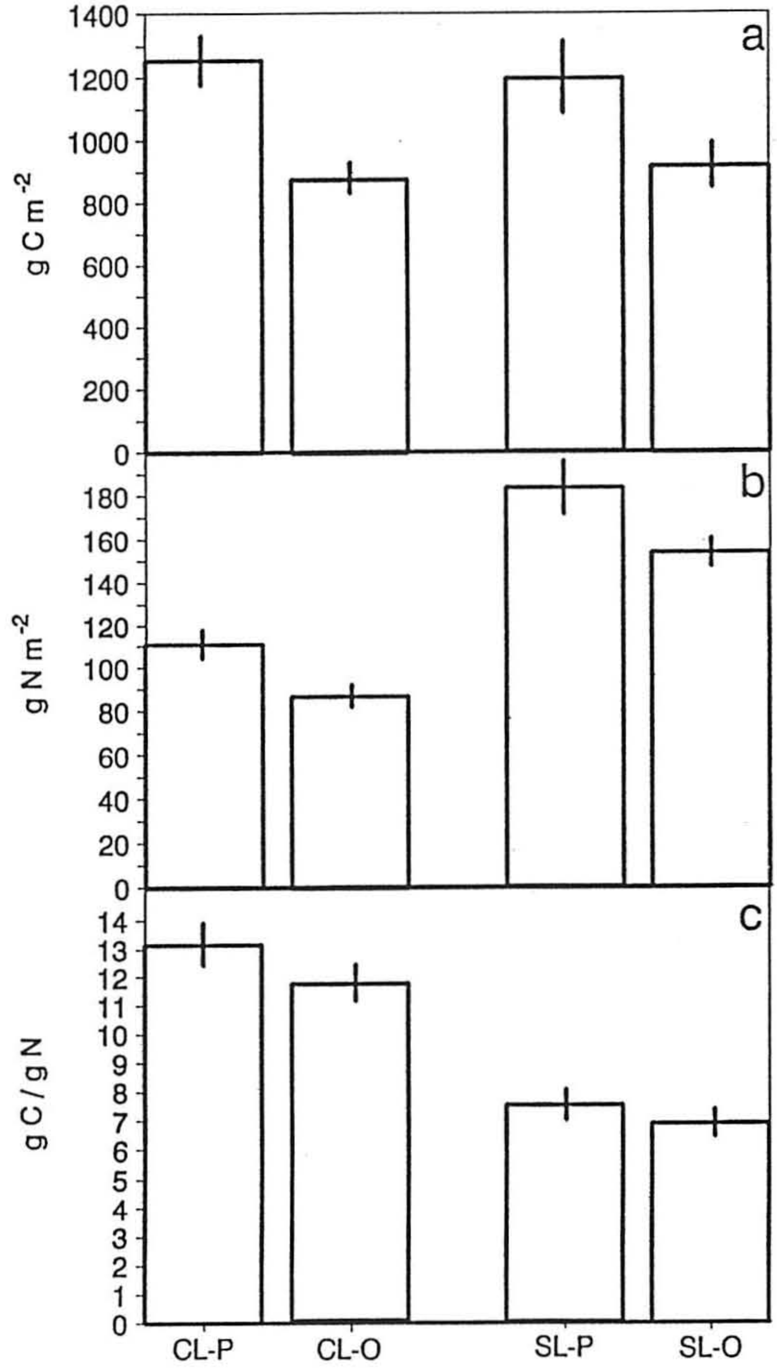

1400
1200
1000
800
600
400
200
0
g C m^{-2}
a
180
160
140
120
100
80
60
40
20
0
g N m^{-2}
b
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
g C / g N
c
CL-P
CL-O
SL-P
SL-O

Figure 13.

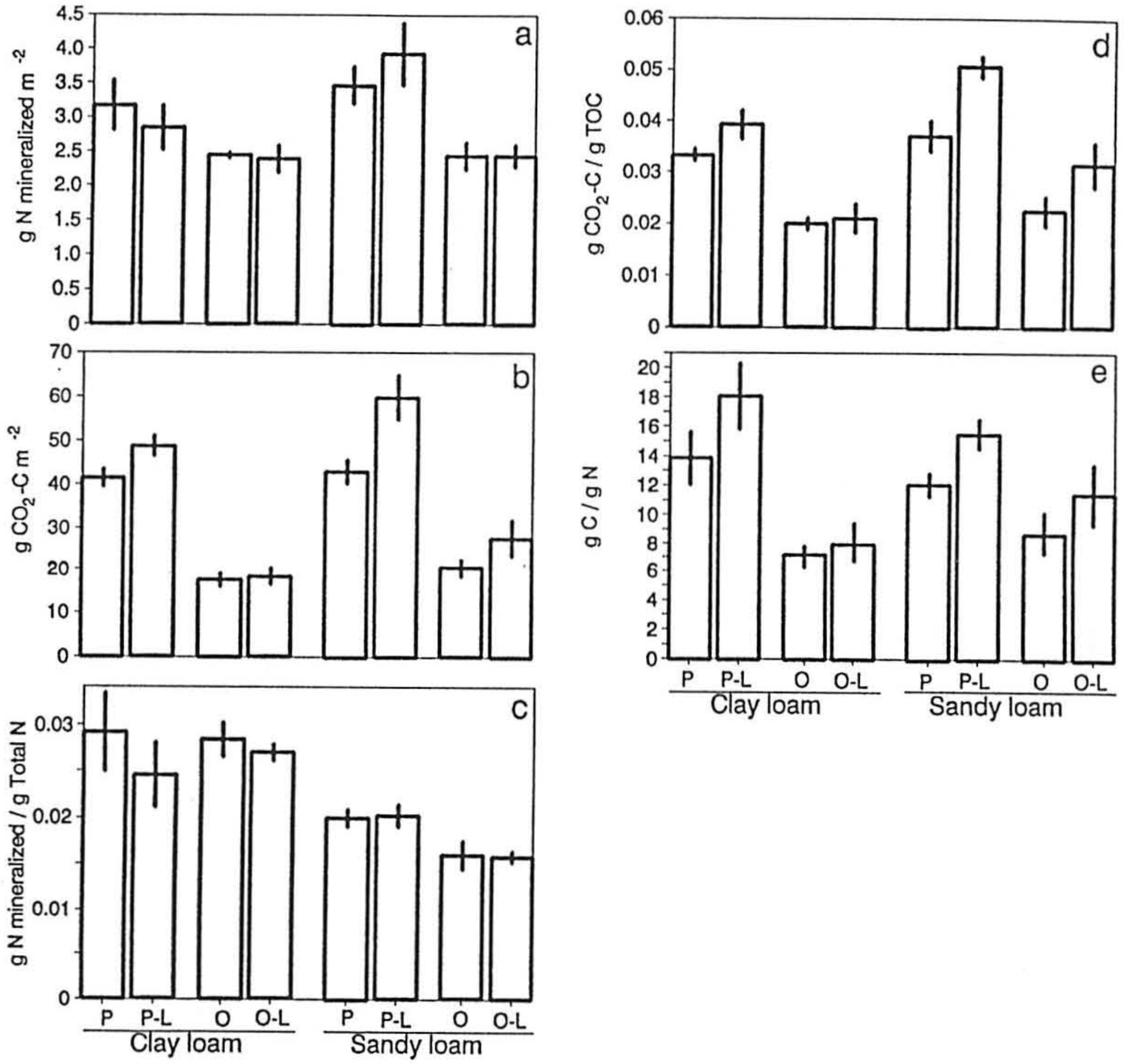

a
g N mineralized m -2
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
b
g CO2-C m -2
70
60
50
40
30
20
10
0
c
g N mineralized / g Total N
0.03
0.02
0.01
0
P
P-L
O
O-L
Clay loam
P
P-L
O
O-L
Sandy loam
d
g CO2-C / g TOC
0.06
0.05
0.04
0.03
0.02
0.01
0
e
g C / g N
20
18
16
14
12
10
8
6
4
2
0
P
P-L
O
O-L
Clay loam
P
P-L
O
O-L
Sandy loam

Figure 14.

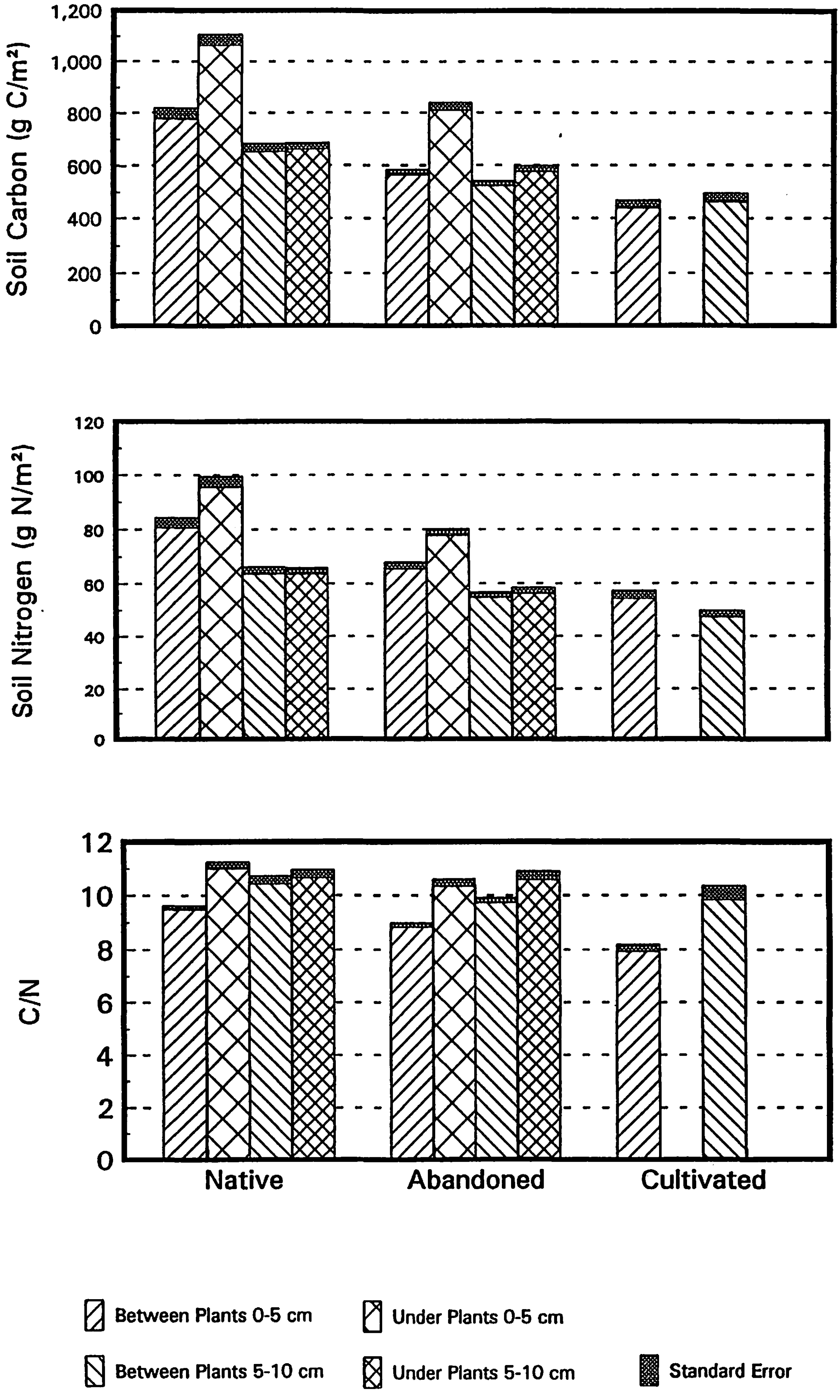

Soil Carbon (g C/m²)
1,200
1,000
800
600
400
200
0
Soil Nitrogen (g N/m²)
120
100
80
60
40
20
0
C/N
12
10
8
6
4
2
0
Native
Abandoned
Cultivated
Between Plants 0-5 cm
Under Plants 0-5 cm
Between Plants 5-10 cm
Under Plants 5-10 cm
Standard Error

Figure 15.

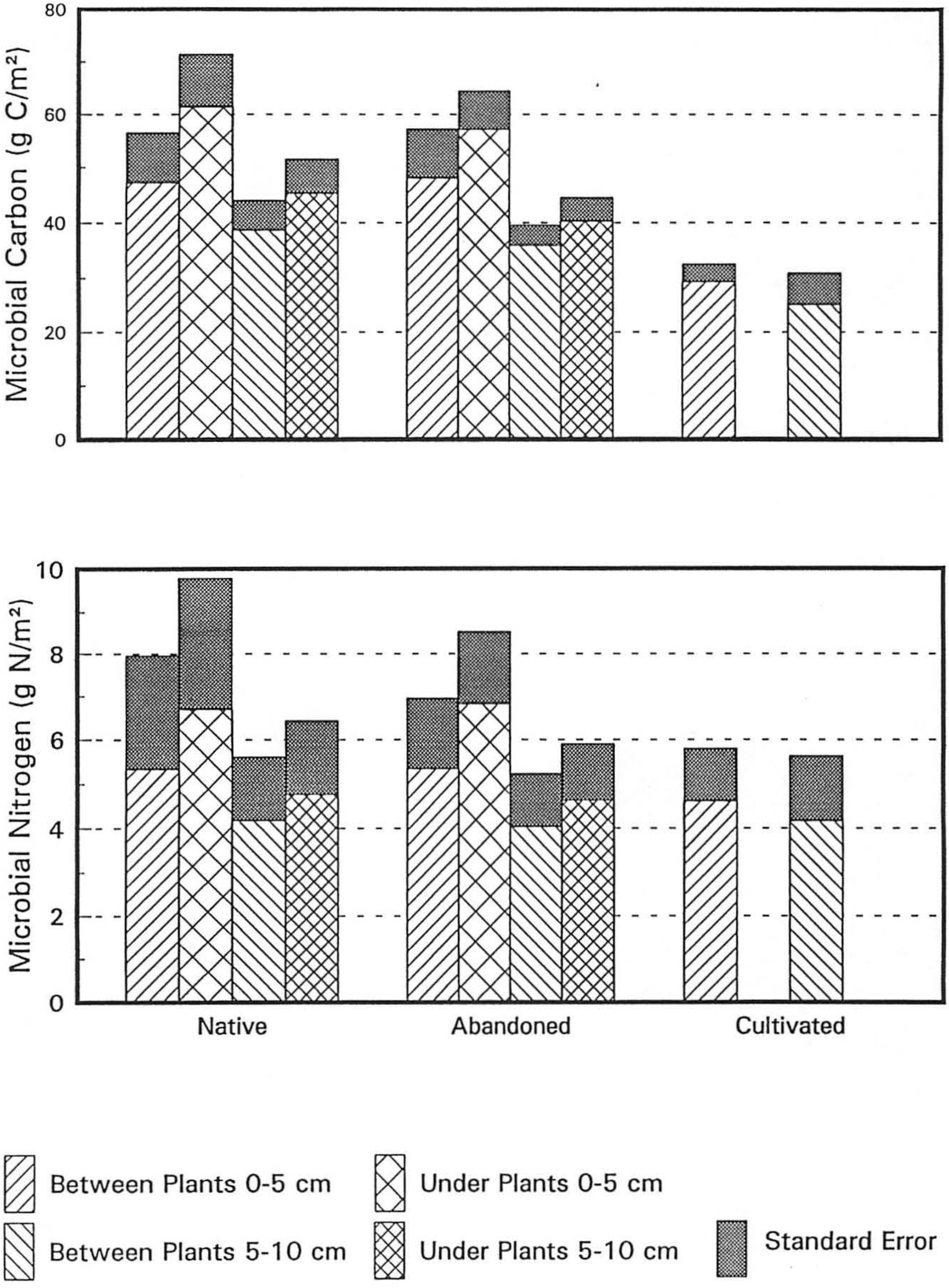

Microbial Carbon (g C/m²)
80
60
40
20
0
Microbial Nitrogen (g N/m²)
10
8
6
4
2
0
Native
Abandoned
Cultivated
Between Plants 0-5 cm
Under Plants 0-5 cm
Between Plants 5-10 cm
Under Plants 5-10 cm
Standard Error

Figure 16.

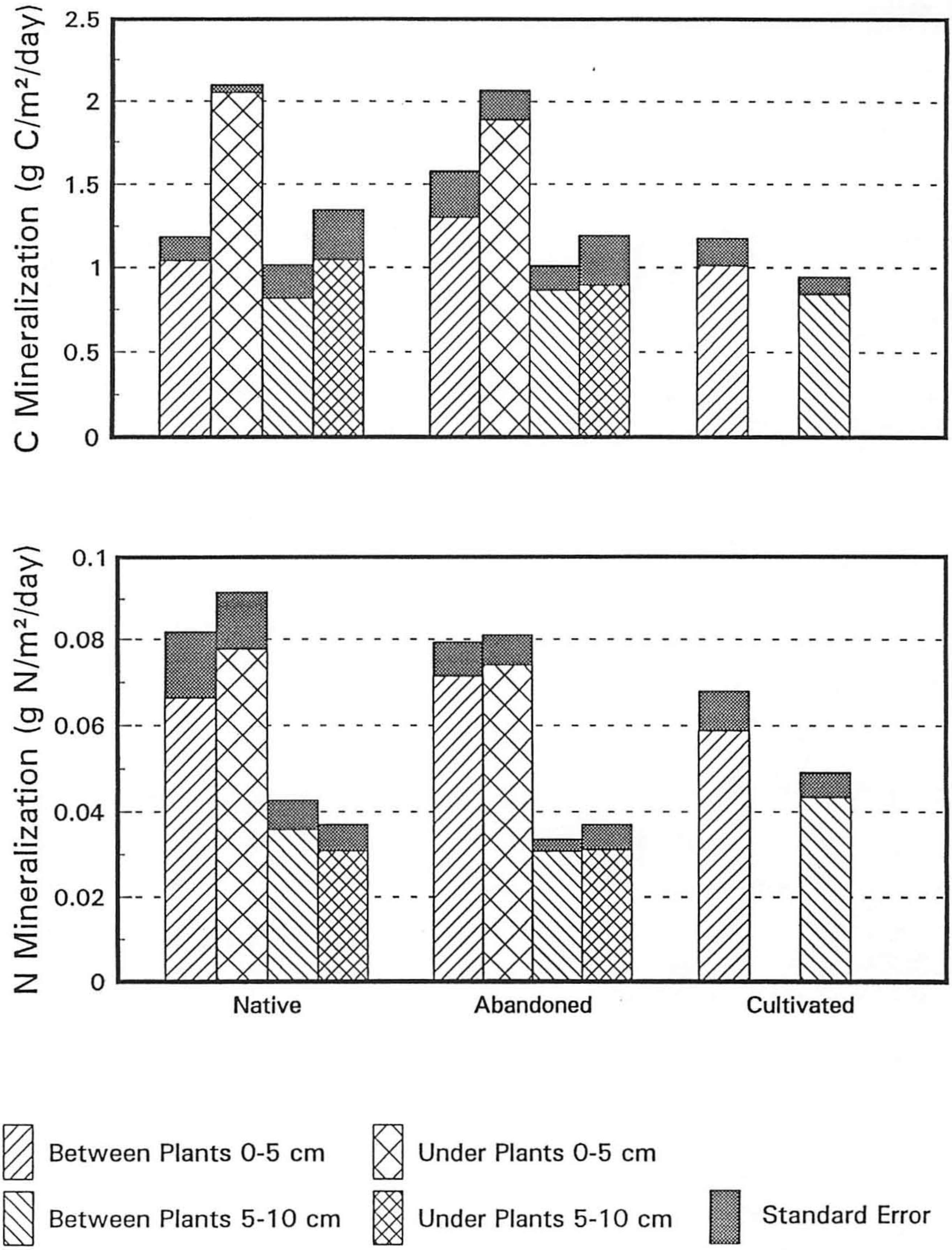
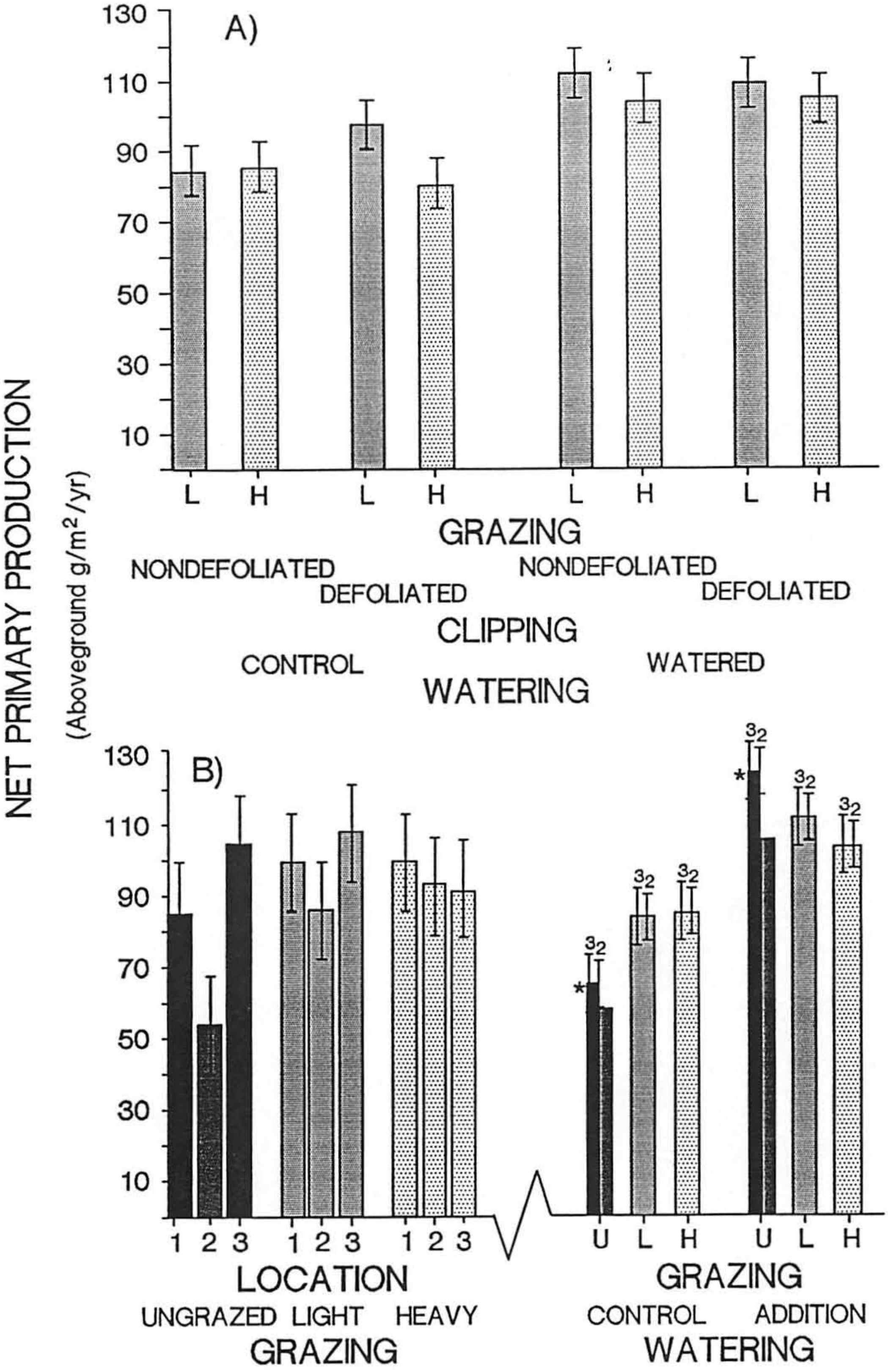

C Mineralization (g C/m²/day)
2.5
2
1.5
1
0.5
0
N Mineralization (g N/m²/day)
0.1
0.08
0.06
0.04
0.02
0
Native
Abandoned
Cultivated
Between Plants 0-5 cm
Under Plants 0-5 cm
Between Plants 5-10 cm
Under Plants 5-10 cm
Standard Error

Figure 17.



NET PRIMARY PRODUCTION
(Aboveground g/m2/yr)
A)
130
110
90
70
50
30
10
L
H
L
H
L
H
L
H
GRAZING
NONDEFOLIATED
DEFOLIATED
NONDEFOLIATED
DEFOLIATED
CLIPPING
CONTROL
WATERED
WATERING
B)
130
110
90
70
50
30
10
1 2 3
1 2 3
1 2 3
LOCATION
UNGRAZED
LIGHT
HEAVY
GRAZING
*
*
3 2
U
L
H
U
L
H
GRAZING
CONTROL
ADDITION
WATERING

Figure 18.

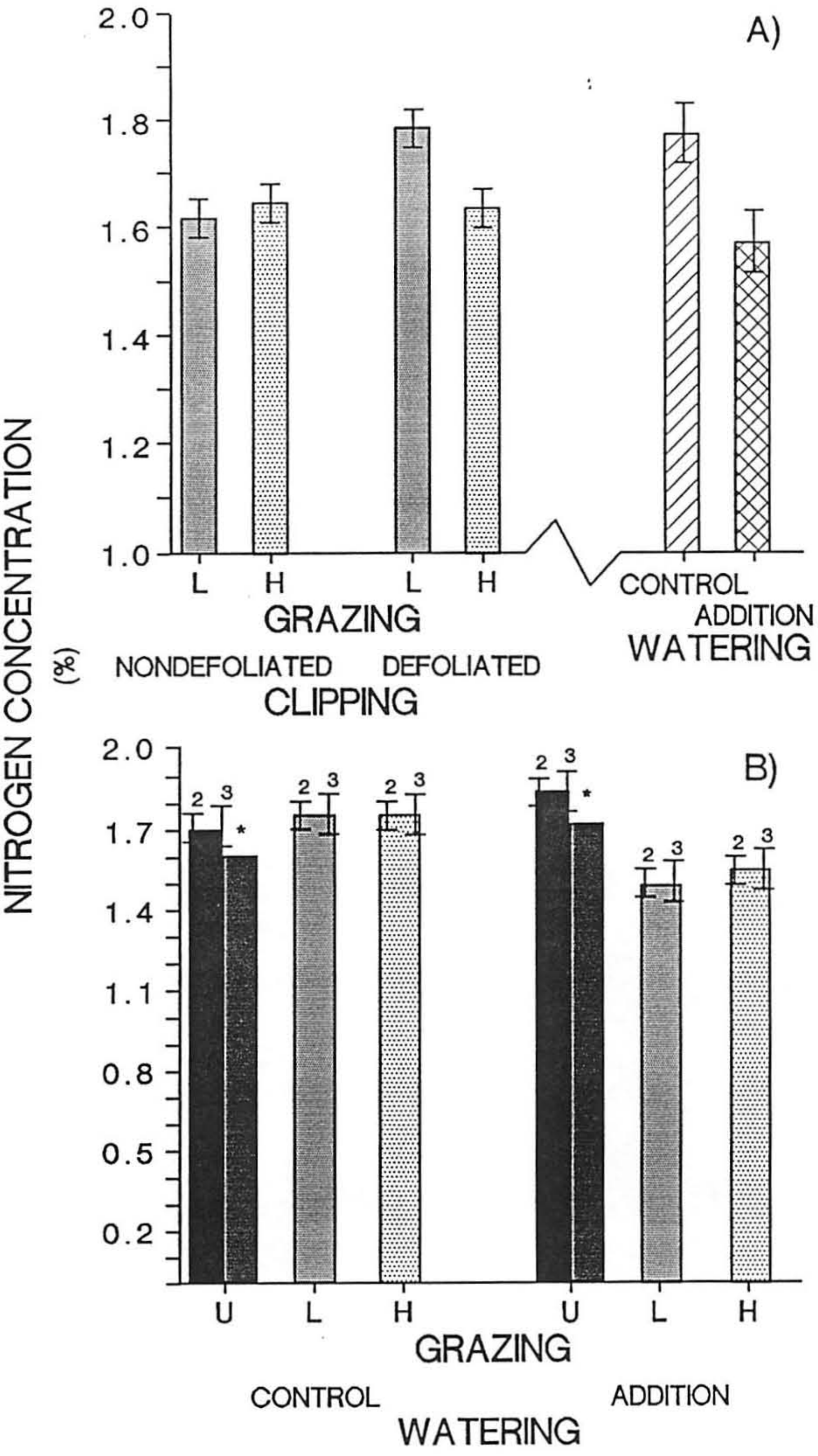

NITROGEN CONCENTRATION (%)
A)
2.0
1.8
1.6
1.4
1.2
1.0
L
H
L
H
GRAZING
NONDEFOLIATED
DEFOLIATED
CLIPPING
CONTROL
ADDITION
WATERING
B)
2.0
1.7
1.4
1.1
0.8
0.5
0.2
2
3
*
U
L
H
U
L
H
GRAZING
CONTROL
ADDITION
WATERING

Figure 19.

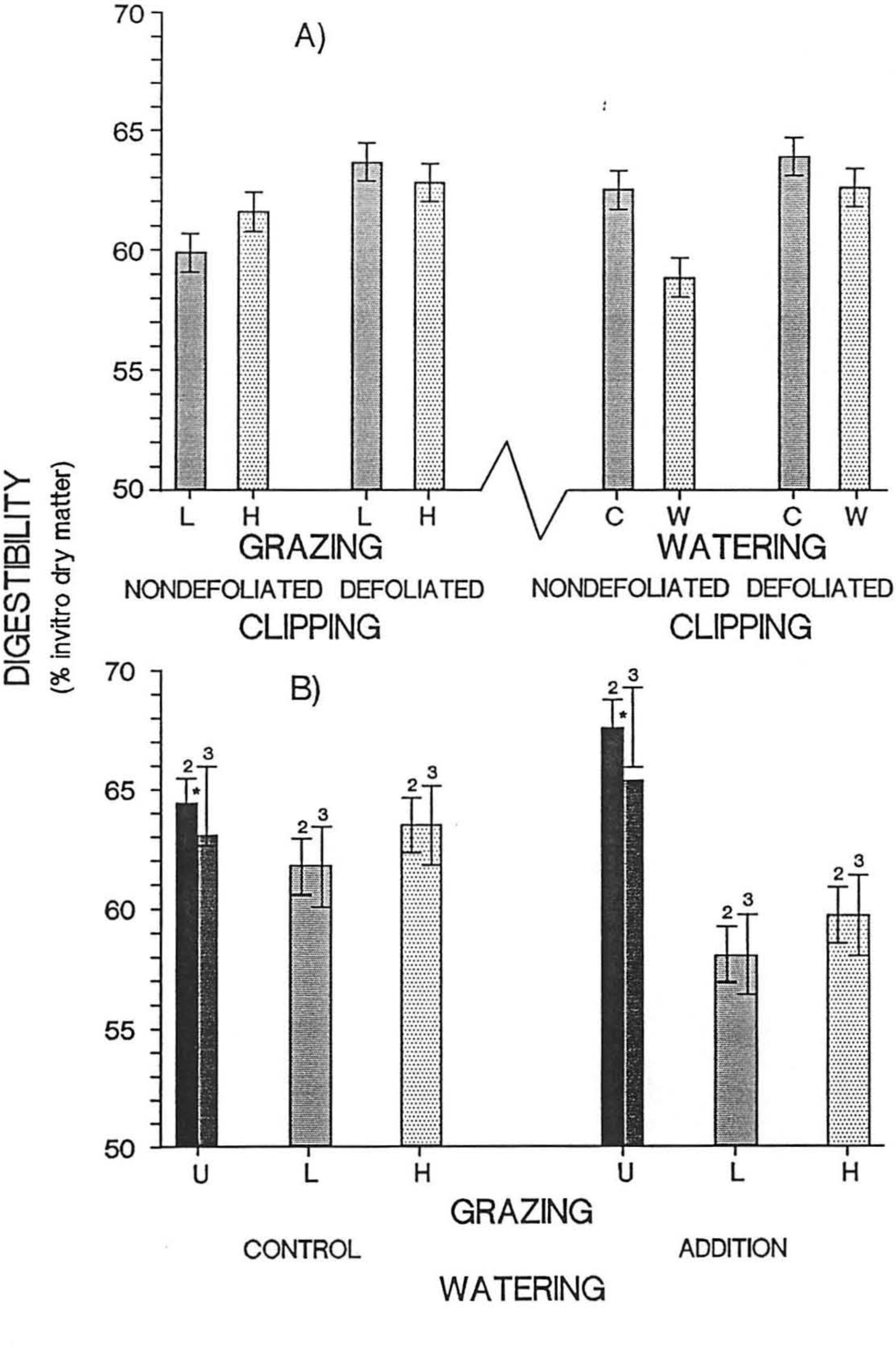

A)
B)
DIGESTIBILITY
(% invitro dry matter)
70
65
60
55
50
L
H
L
H
C
W
C
W
GRAZING
NONDEFOLIATED DEFOLIATED
CLIPPING
WATERING
NONDEFOLIATED DEFOLIATED
CLIPPING
2
3
*
U
L
H
U
L
H
GRAZING
CONTROL
ADDITION
WATERING

Figure 20.

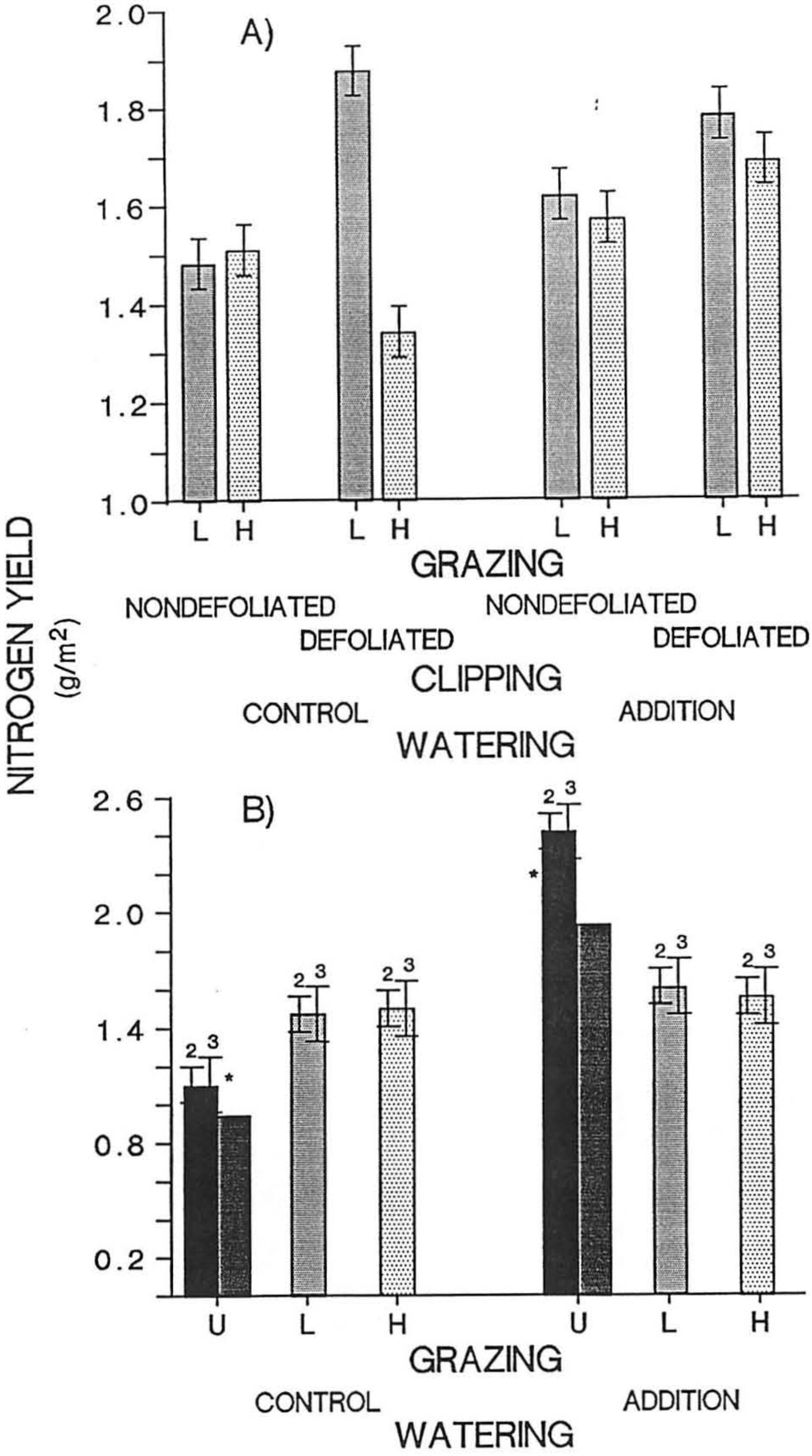

NITROGEN YIELD
(g/m²)
A)
2.0
1.8
1.6
1.4
1.2
1.0
L
H
L
H
L
H
L
H
GRAZING
NONDEFOLIATED
DEFOLIATED
NONDEFOLIATED
DEFOLIATED
CLIPPING
CONTROL
ADDITION
WATERING
B)
2.6
2.0
1.4
0.8
0.2
2
3
*
U
L
H
U
L
H
GRAZING
CONTROL
ADDITION
WATERING

Figure 21.

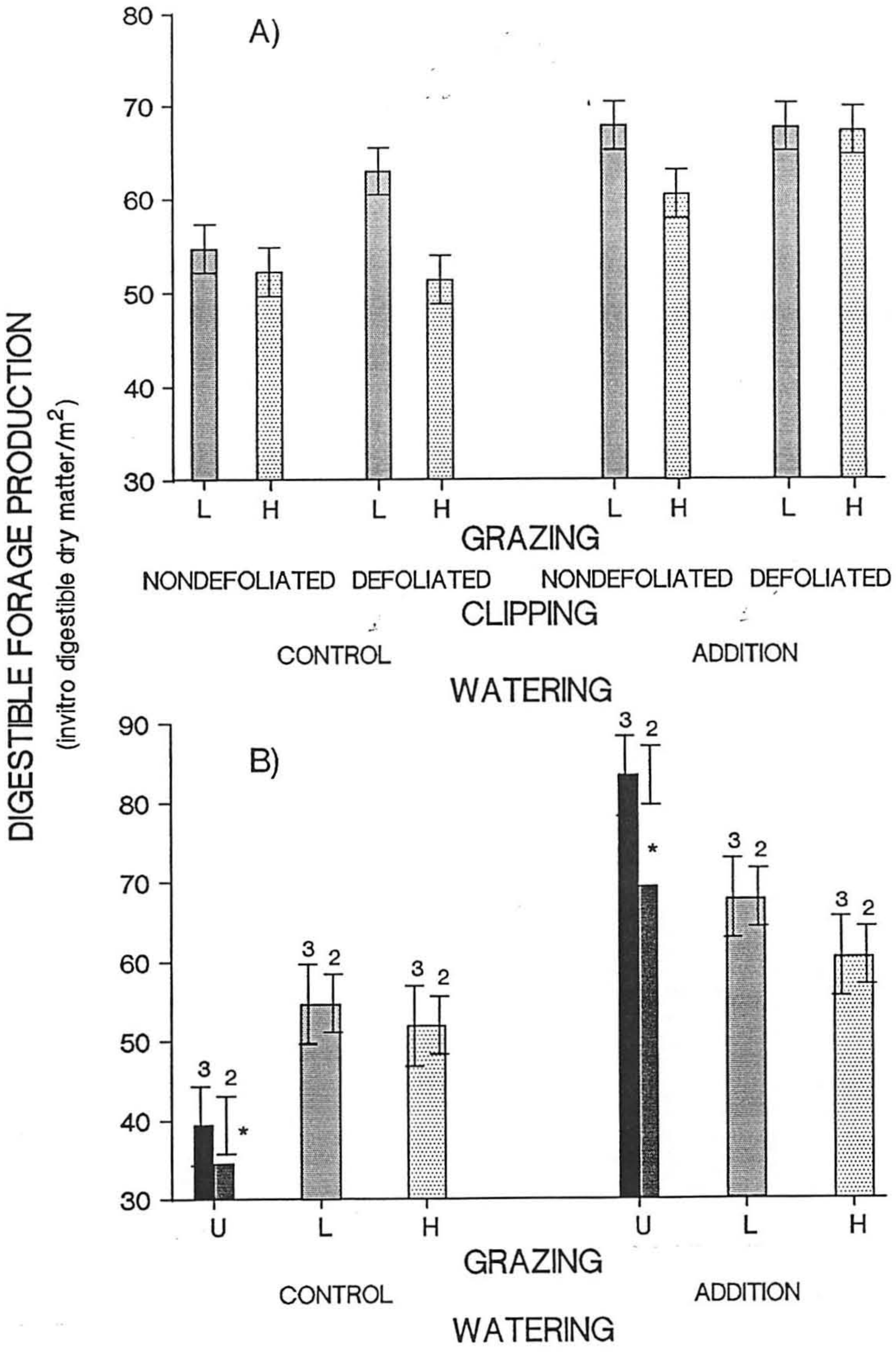
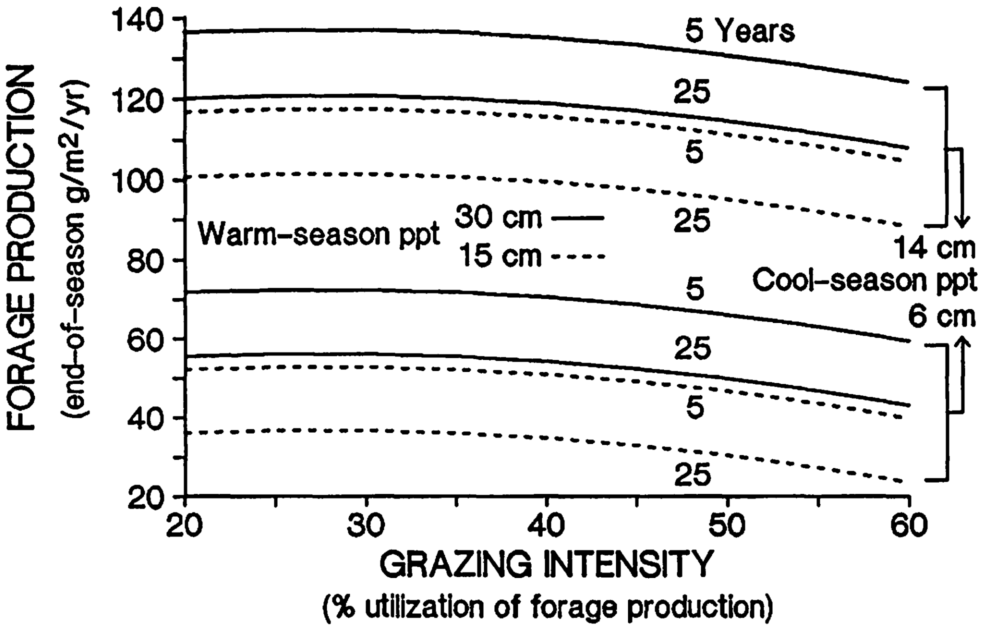

DIGESTIBLE FORAGE PRODUCTION
(invitro digestible dry matter/m²)
A)
80
70
60
50
40
30
L
H
L
H
L
H
L
H
GRAZING
NONDEFOLIATED
DEFOLIATED
NONDEFOLIATED
DEFOLIATED
CLIPPING
CONTROL
ADDITION
WATERING
B)
90
80
70
60
50
40
30
3
2
*
U
L
H
U
L
H
GRAZING
CONTROL
ADDITION
WATERING

Figure 22.



FORAGE PRODUCTION
(end-of-season g/m2/yr)
140
120
100
80
60
40
20
20
30
40
50
60
GRAZING INTENSITY
(% utilization of forage production)
5 Years
25
5
25
5
25
5
25
Warm-season ppt
30 cm
15 cm
14 cm
Cool-season ppt
6 cm

Figure 23.

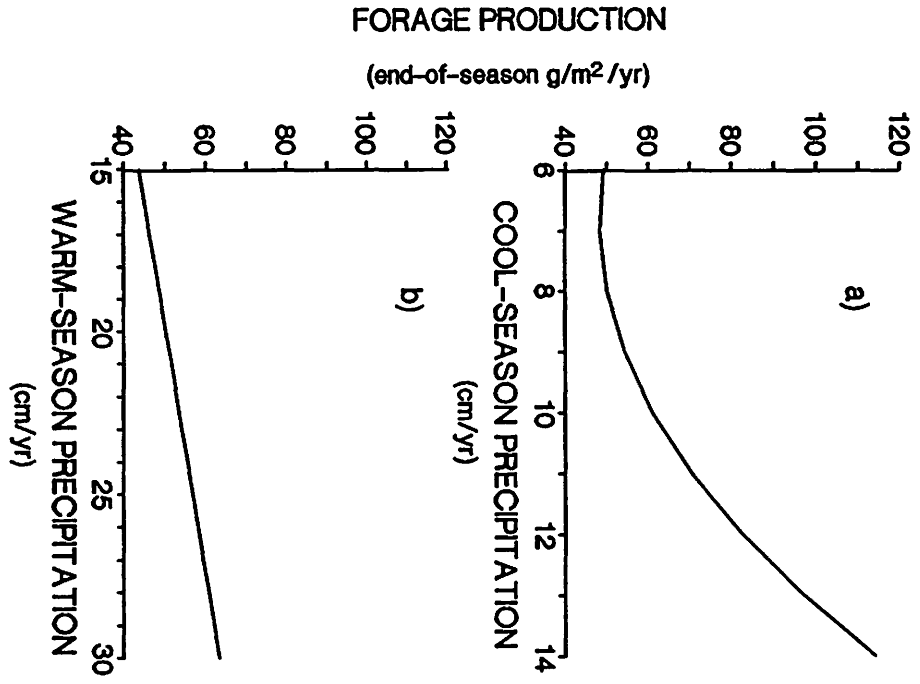

FORAGE PRODUCTION
(end-of-season g/m2 /yr)
a)
40
60
80
100
120
6
8
10
12
14
COOL-SEASON PRECIPITATION
(cm/yr)
b)
40
60
80
100
120
15
20
25
30
WARM-SEASON PRECIPITATION
(cm/yr)

Figure 24.

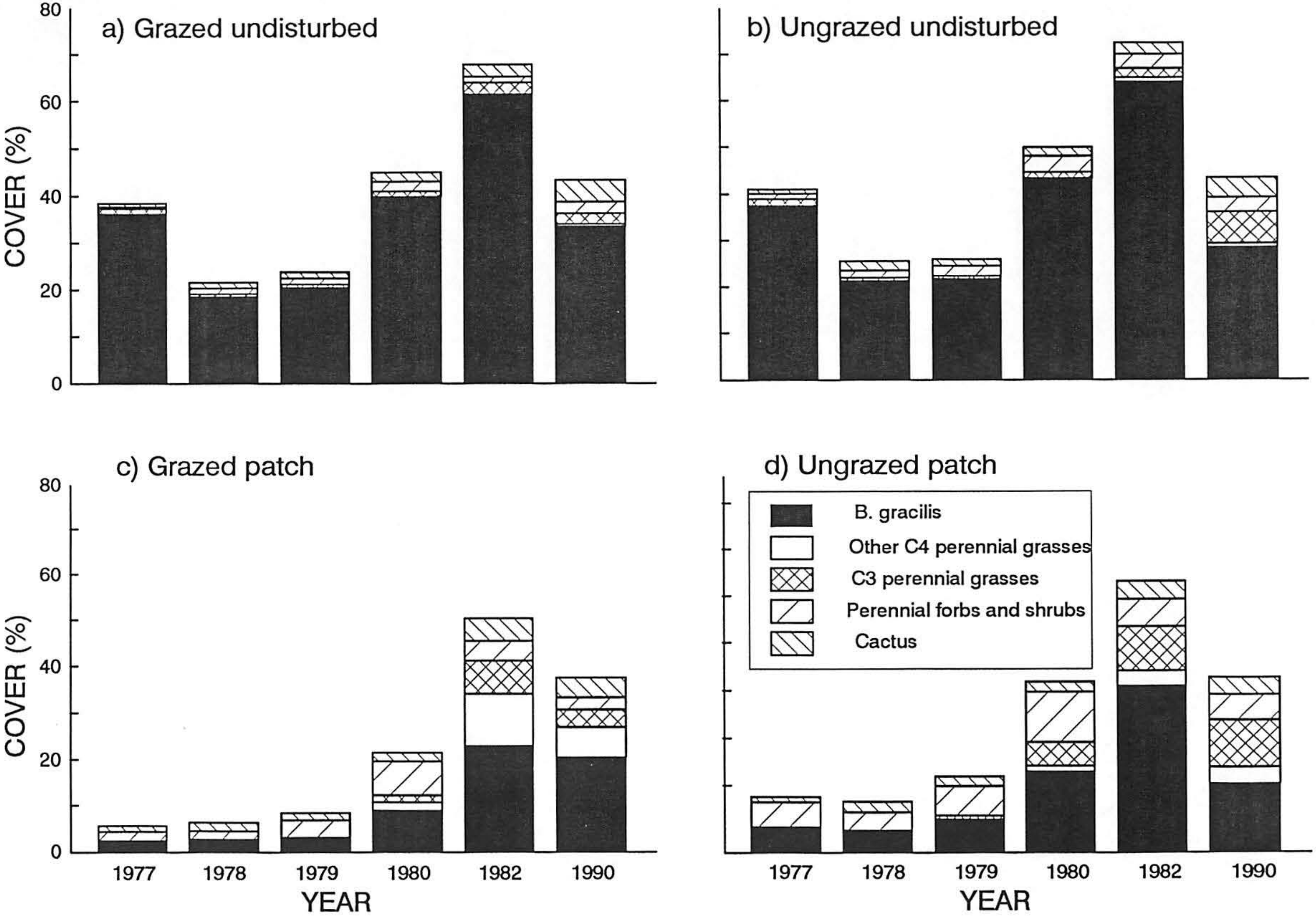

a) Grazed undisturbed
b) Ungrazed undisturbed
c) Grazed patch
d) Ungrazed patch
COVER (%)
0
20
40
60
80
1977
1978
1979
1980
1982
1990
YEAR
B. gracilis
Other C4 perennial grasses
C3 perennial grasses
Perennial forbs and shrubs
Cactus

Figure 25.

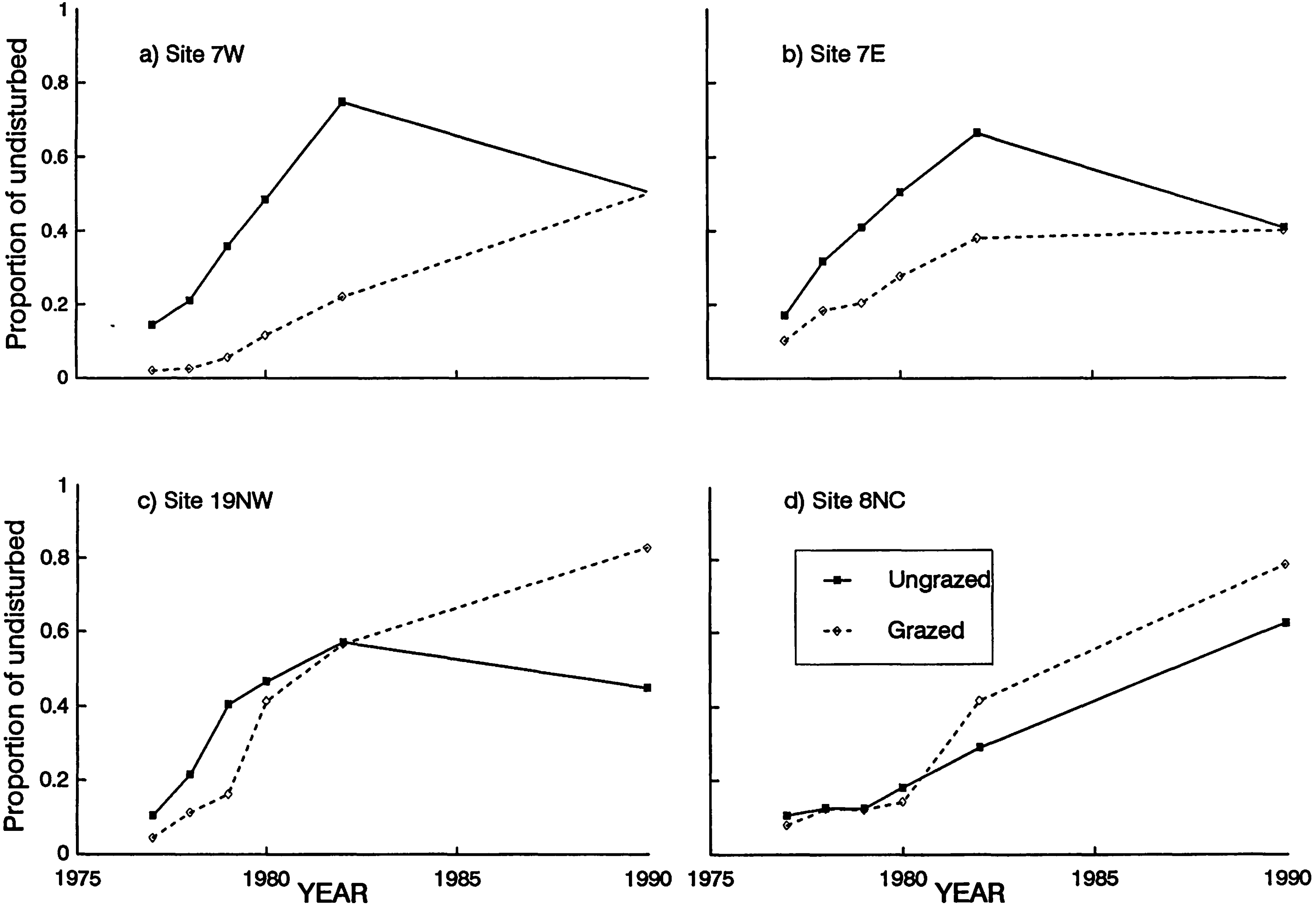

a) Site 7W
b) Site 7E
c) Site 19NW
d) Site 8NC
Proportion of undisturbed
Proportion of undisturbed
1
0.8
0.6
0.4
0.2
0
1975
1980
1985
1990
YEAR
Ungrazed
Grazed

Figure 26.

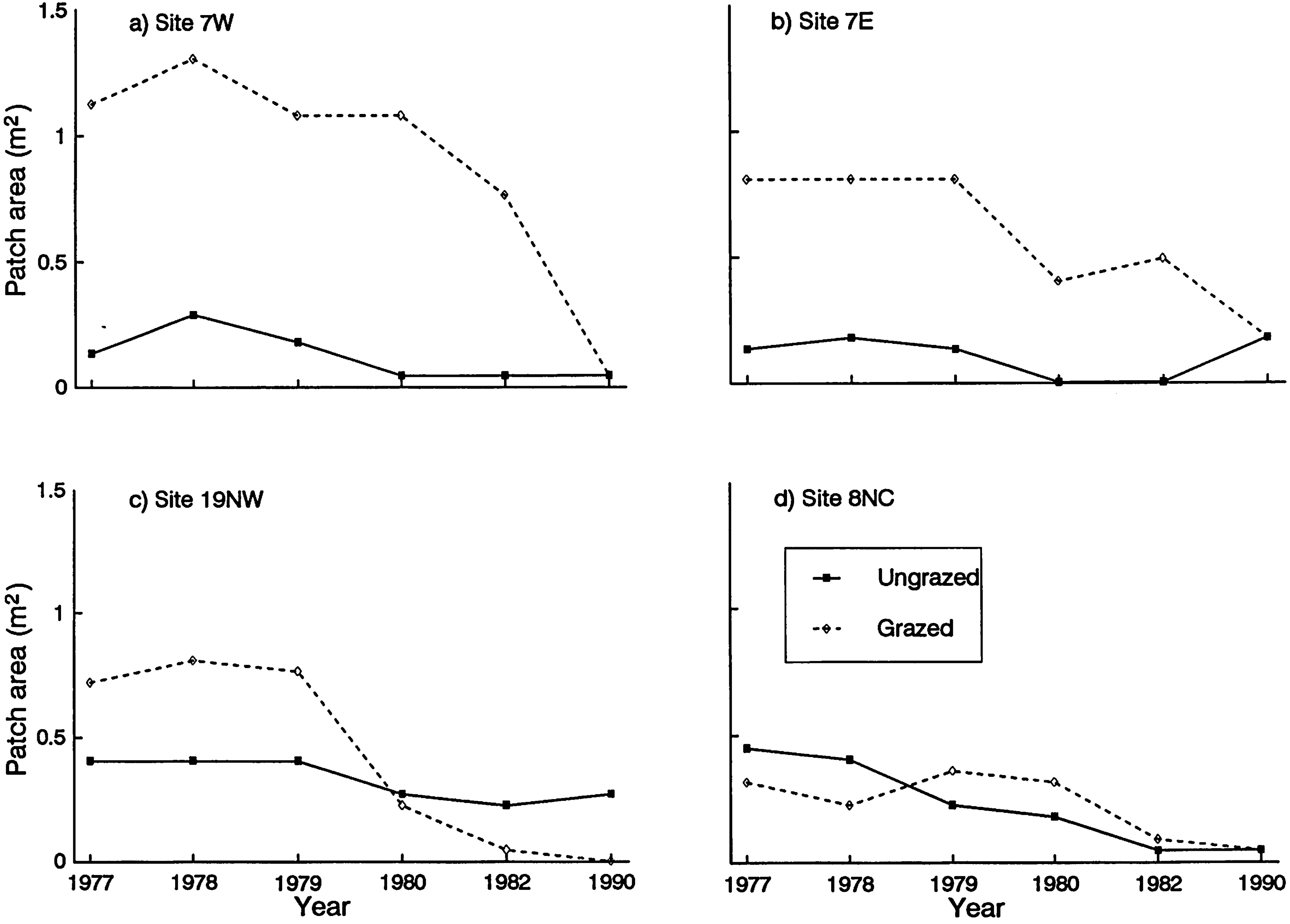

a) Site 7W
b) Site 7E
c) Site 19NW
d) Site 8NC
Patch area (m²)
Patch area (m²)
1.5
1
0.5
0
1977
1978
1979
1980
1982
1990
Year
Year
Ungrazed
Grazed

Figure 27.

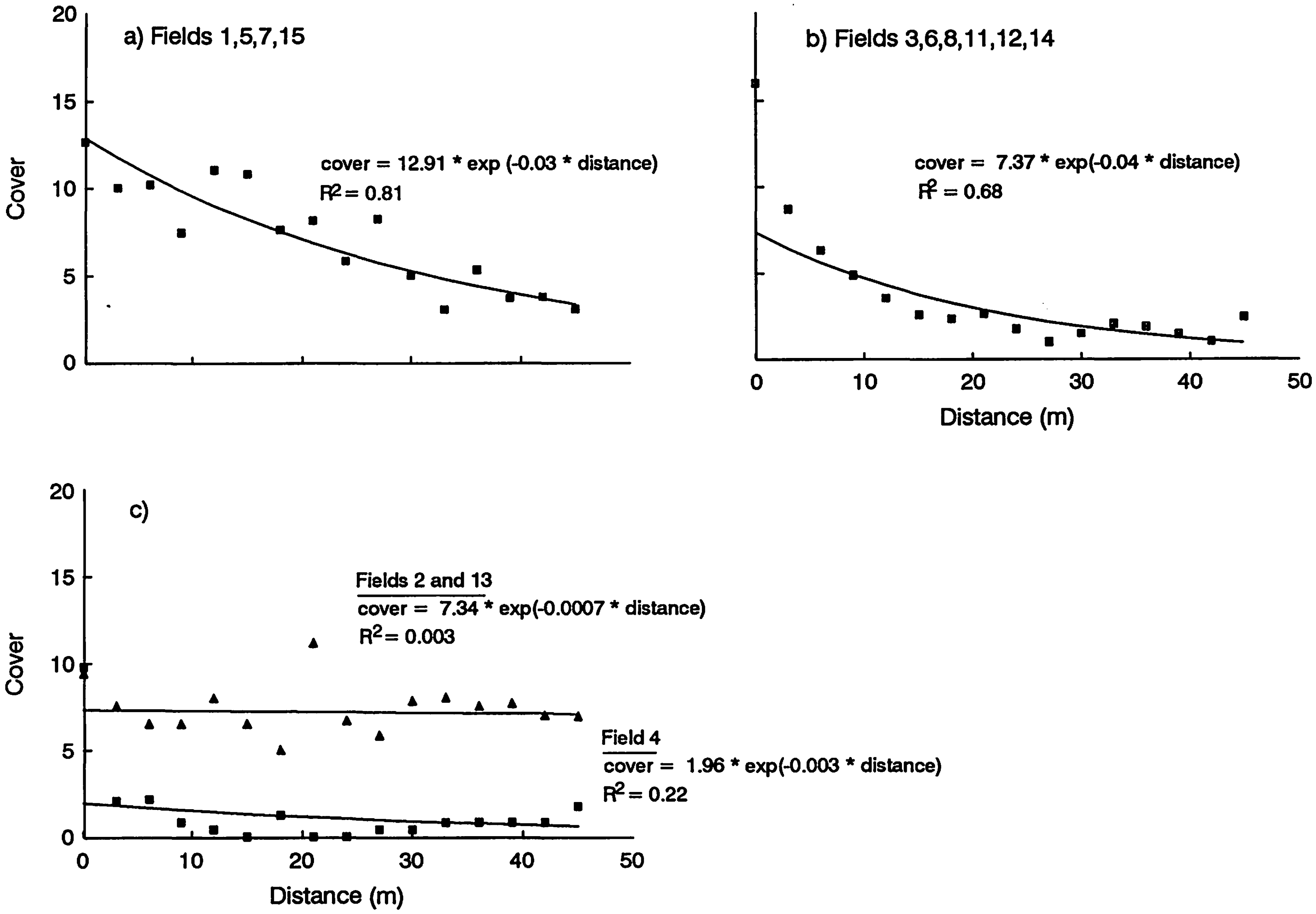

a) Fields 1,5,7,15
Cover
20
15
10
5
0
cover = 12.91 * exp (-0.03 * distance)
R2 = 0.81
b) Fields 3,6,8,11,12,14
cover = 7.37 * exp(-0.04 * distance)
R2 = 0.68
0
10
20
30
40
50
Distance (m)
c)
Fields 2 and 13
cover = 7.34 * exp(-0.0007 * distance)
R2 = 0.003
Field 4
cover = 1.96 * exp(-0.003 * distance)
R2 = 0.22

Figure 28.

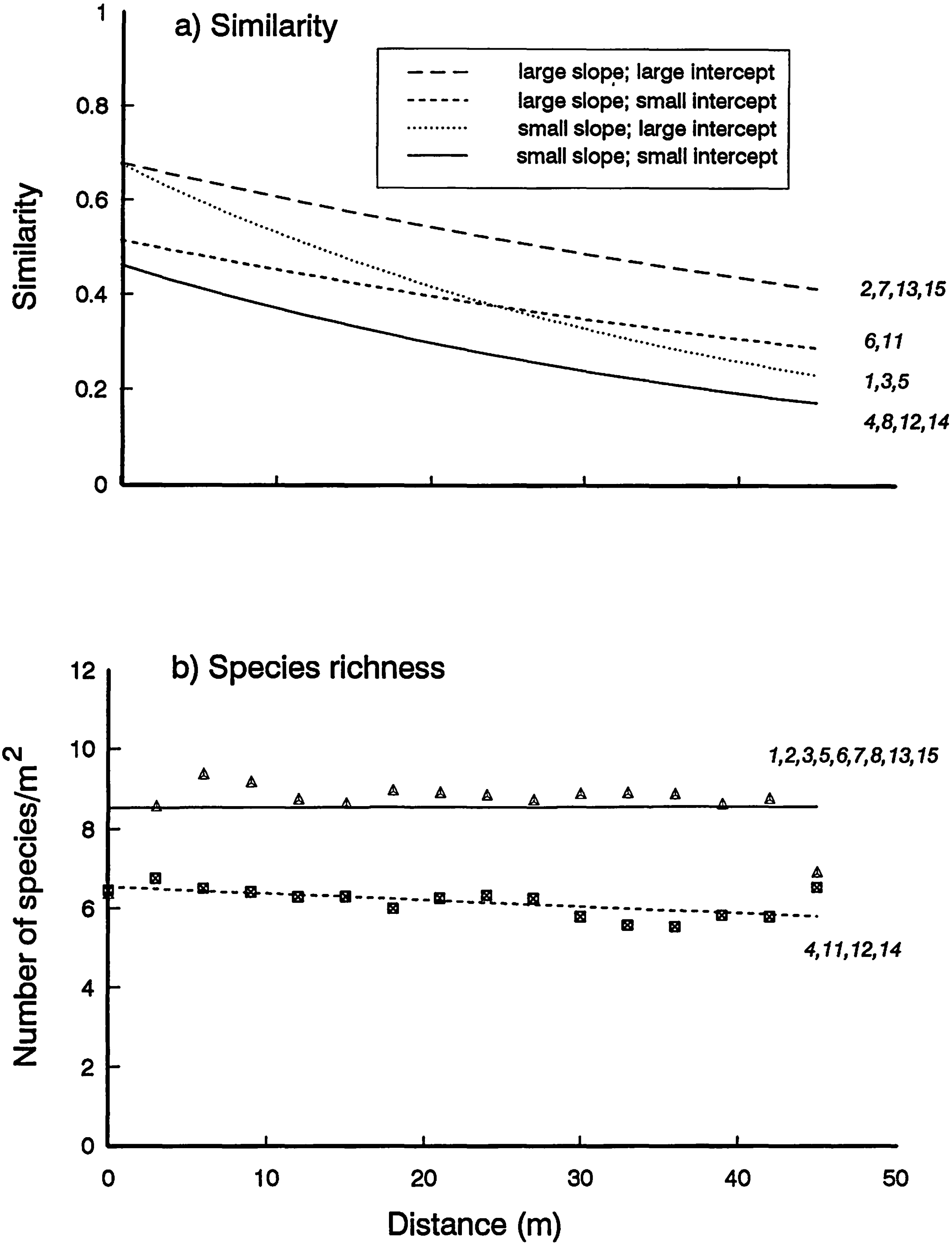

a) Similarity
Similarity
1
0.8
0.6
0.4
0.2
0
large slope; large intercept
large slope; small intercept
small slope; large intercept
small slope; small intercept
2,7,13,15
6,11
1,3,5
4,8,12,14
b) Species richness
Number of species/m^2
12
10
8
6
4
2
0
1,2,3,5,6,7,8,13,15
4,11,12,14
0
10
20
30
40
50
Distance (m)

Figure 29.

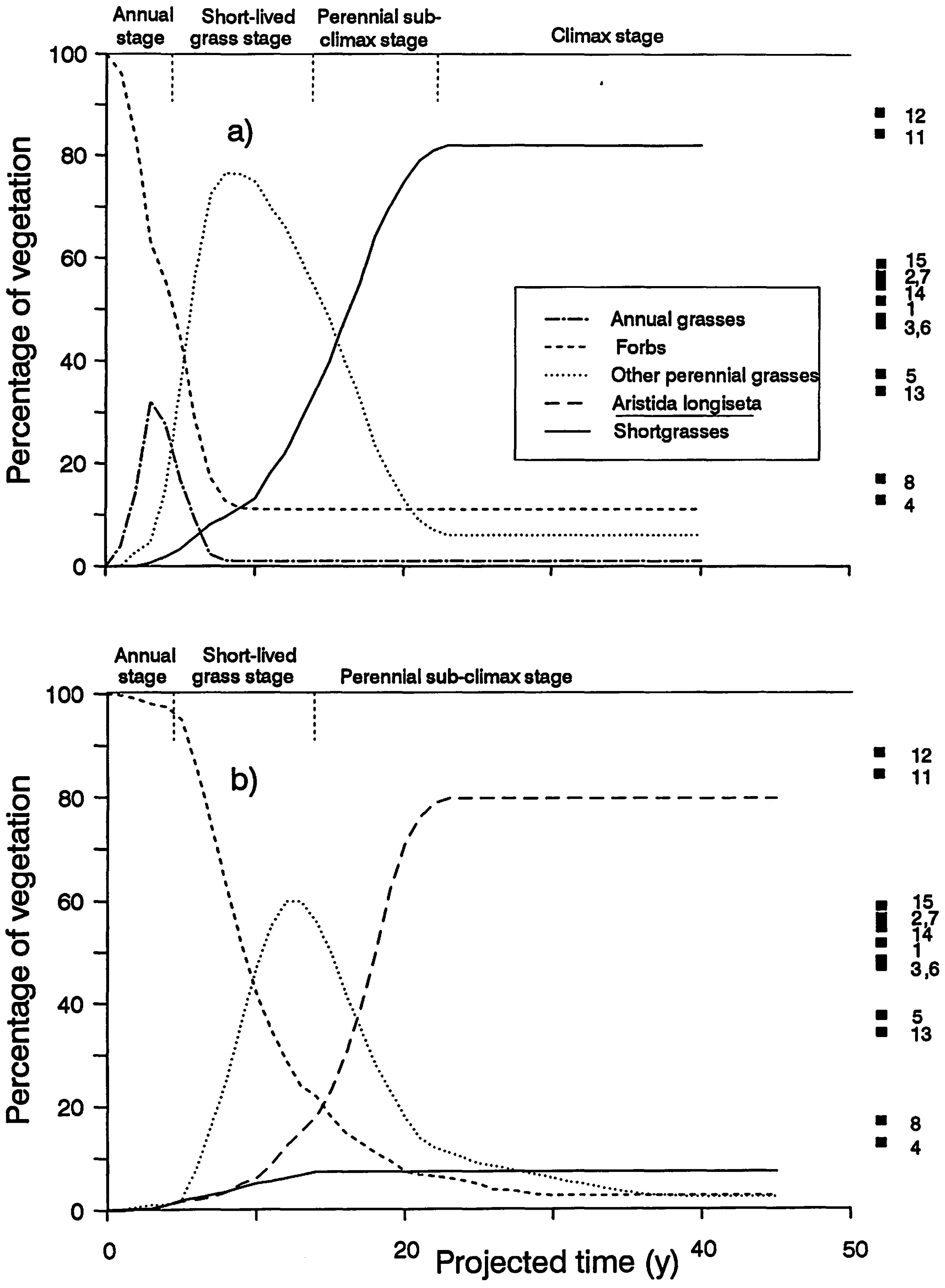

Annual stage
Short-lived grass stage
Perennial sub-climax stage
Climax stage
a)
Percentage of vegetation
100
80
60
40
20
0
Annual grasses
Forbs
Other perennial grasses
Aristida longiseta
Shortgrasses
12
11
15
2,7
14
1
3,6
5
13
8
4
Annual stage
Short-lived grass stage
Perennial sub-climax stage
b)
Percentage of vegetation
100
80
60
40
20
0
12
11
15
2,7
14
1
3,6
5
13
8
4
0
20
Projected time (y)
40
50

Figure 30.

```
--------------------------------------------------------------------------------------------------------
FileName            btpw71f
Data_set_id         btemp71
Data_set_type       ASCII
Title               1971 belowground temperature (pawnee) summary data file
Fortran_format      (a2,i2,a3,3i2,i3,i4,21f5.1)
INTEGER              Number_data_items       3
Column_format {
        Item datype {
                Variable datype
                Type    a
                Definition data type ('59')
                Units   <something ... here if not currently an n/a>
                INTEGER Start 1
                INTEGER End 2
        }
        Item date {
                Variable date
                Type    i
                Definition date of sampling
                INTEGER Start 3
                INTEGER End 8
         }
         Item rain {
                Variable rain
                Type    f
                Definition Amount of rainfall
                 INTEGER Start 9
                INTEGER End 12
        }
}
Missing_value_code          M
Description {
        Principal_investigator {
                Name George Van Dyne
                TEXT Address {
                        some department
                        CSU ... etc
                }
                Phone  491-0000
        }
        Technician Ray Souther
         Date_of_beginning_study 71/01/01
         Date_of_ending_study 71/12/31
        Sampling_frequency daily after 26/4/71
        TEXT General_purpose {
```

Figure 31.

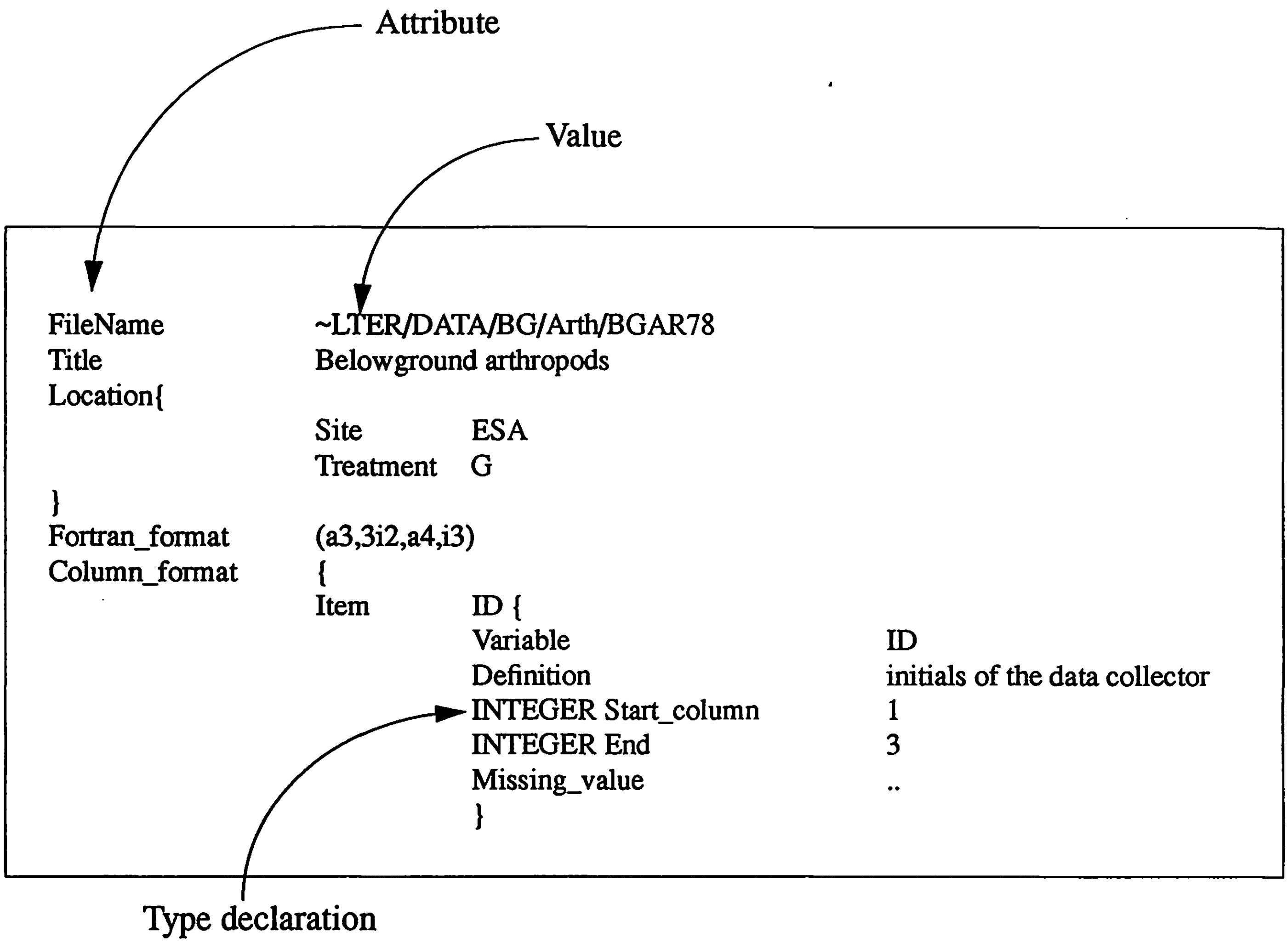
```
        Minimum, maximum and average soil temperatures in
        degrees Centigrade are recorded daily for belowground
        depths of 1, 2.25, 4, 8, 20, 40, and 72 inches.
}
LIST Keywords {
        temperature
        soil
}
Data_form     nrel-59
Location_of_data_forms      microfilm
TEXT Data_entry_instruction {
        A record will appear for each day of the year. Missing
        code is '-99.9' for temperatures and '-99' for time.
        This data is created by program 'bgtemp'.
}
TEXT Permanent_locations {
        Central Plains Experimental Range Station,
        Nunn, CO Elevation 1652m Exclosure E1/2 Section 23 T10N R66W 6th P.M.
}
TEXT Related_data_sets {
        Pawnee Standard Weather measurements are recorded
        at same time and location as the belowground temperature measurements
 }
TEXT Restrictions_on_use {
        See Bill Lauenroth
}
Programs {
        Program deptmps {
                Name deptmps
                TEXT Description {
                        This program, written in fortran 66 for use on the CYBER, is
                        not presently used. It is stored on magnetic tape n0001 at
                        NREL. It was replaced by program 'bgtemp' in 1986.
                }
        }
        Program bgtemp {
                Name bgtemp
                TEXT Description {
                        This program, written in fortran 77 for use on the VAX, uses
                        field data as input. It produces a summary data file
                        consisting of maximum, minimum, and average temperatures in
                        degrees Centigrade. A julian date is added to each record.
                        A record exists for each day of the year.
                        The missing code is '-99.9' for temperatures and '-99' for
                        time. In addition, a human readable file is created that
                        includes daily records with temperatures in degrees Centigrade
```

Figure 31 (Continued)

```
                                        and monthly averages. Summaries of monthly averages are given
                                        at the end of each year and the end of the entire data set.
                                        Missing code for this file is 'M'. This program is located on
                                        the VAX and on magnetic tape n0001.
                              }
                    }
          }
          Programmer    jerry d. peltz (program deptmps); cinda a. liggon
}

EXTERNAL_FUNCTION    DisplayData/bin/cat $FileName
EXTERNAL_FUNCTION    SelectData~LTER/bin/Extract $THIS_FILE
-----------------------------------------------------------------------------------------------------------------
```

Figure 31 (Continued)



```
FileName          ~LTER/DATA/BG/Arth/BGAR78
Title             Belowground arthropods
Location{
                  Site        ESA
                  Treatment   G
}
Fortran_format    (a3,3i2,a4,i3)
Column_format     {
                  Item        ID {
                              Variable                  ID
                              Definition                initials of the data collector
                              INTEGER Start_column      1
                              INTEGER End               3
                              Missing_value             ..
                              }
```

Figure 32.