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Herbage dynamics on 2 Northern Great Plains range sites

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Abstract

Quantity and quality of forage produced are primary determinants of level of livestock production derived from grazing lands. Moreover, species composition of herbage is often considered a primary determinant of the ecological condition of rangelands. The broad objective of this study was to quantify the productivity, growth dynamics, and quality of herbage growing on 2 Northern Great Plains range sites and to concurrently relate magnitude and composition of production to the ecological condition of the sites. Using frequent harvest techniques, the 2-year study showed herbage production on the highly productive silty range site averaged 219 g m^{-2} as compared to 218 g m^{-2} on the supposedly less productive clay pan range site. The primary reason the clay pan site proved to be as productive as the silty site was attributed to the greater amounts of introduced annual grasses on the clay pan (148 g m^{-2}) than the silty site (104 g m^{-2}). The annual grass component on the clay pan was a near equal mix (71 vs 51 g m^{-2}) of Japanese brome (*Bromus japonicus* Thunb.) and cheatgrass (*B. tectorum* L.) whereas the overwhelming dominant on the silty site was cheatgrass (73 g m^{-2}). Western wheatgrass [*Pascopyrum smithii* Rydb. (Love)] was the dominant perennial grass on both sites averaging 49 g m^{-2} on the clay pan site and 57 g m^{-2} on the silty site. There were minimal differences between sites in terms of nutrient quality values (i.e., crude protein, acid detergent fiber, neutral detergent fiber) with results showing clearly that age of tissue was the major factor altering seasonal forage quality values. Range condition analyses revealed the clay pan site was in fair ecological condition and the silty site was in good condition. Study results demonstrate the need for land management agencies to continue to refine productivity estimates as well as adopt new techniques for assessing the ecological condition of rangelands.

Key Words: aboveground net primary production, acid detergent fiber, crude protein, ecological condition, forage quality, neutral detergent fiber, species composition

Quantity and quality of forage produced are the principal factors affecting livestock production from grazing lands. The 3 major factors affecting quantity and quality of herbage produced on rangelands are: 1) the inherent characteristics of a site as it relates to slope, aspect, and soil fertility; 2) climatic conditions; and 3) the kinds, size, and density of plants present. Although extensive rangeland management tactics tend not to impact inherent site characteristics and climatic conditions greatly, they can alter the kinds, size, and density of plants present (e.g., see Tueller 1988, Holechek et al. 1989, Valentine 1990, Heitschmidt and Stuth 1991).

The primary objective of this study was to quantify the productivity, growth dynamics, and quality of herbage growing on 2 Northern Great Plains range sites. Our goals were to: 1) develop baseline data for long-term monitoring of these rangelands; and 2) refine current productivity estimates. In addition, we were interested in examining the fundamental problems associated with the quantitative assessment of ecological condition when the functional role of introduced species, in this instance annual bromes (*Bromus* spp.), is disregarded. Historically, plant species composition has been used by land management agencies as the principal parameter for assessing the ecological condition of a site and its primary and secondary productivity potential (West et al. 1994). Although a number of practical and theoretical problems are associated with this technology (e.g., see Westoby 1989, Lauenroth and Laycock 1989, Joyce 1993), certainly one of the largest concerns centers on the basic role that introduced plant species play in assessing the ecological condition of a site and its productivity potential.

Materials and Methods

Study Site

Research was conducted from June 1991 to April 1993 at the Fort Keogh Livestock and Range Research Laboratory located near Miles City, Mont. (46°22'N 105°5'W). Regional topography ranges from rolling hills to broken badlands with small intersecting streams that flow intermittently into large permanent rivers

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meandering through broad nearly level valleys. The potential natural vegetation on the 22,500-ha station is a grama-needlegrass-wheatgrass (*Bouteloua-Stipa-Agropyron*) mixed dominant (Kuchler 1964). Longterm annual precipitation averages 338 mm with about 60% received during the 150 day, mid-April to mid-September, growing season (Fig. 1). Average daily temperatures range from a low of –10°C in January to a high of 24°C in July with daily maximum temperatures occasionally exceeding 37°C during summer and daily minimums occasionally dipping below –40°C during winter.

Study Areas and Experimental Design

The eight 30 × 30-m study areas (2 range sites, 4 replicates) were located in a 6-pasture, fall-winter grazing area. The 6 pastures varied in size from 38 to 80 ha, and all were grazed with mature cows at a moderate rate during fall and winter.

Soils of the 8 areas were either Eapa loam (i.e., silty range site) or Sonnet silty clay (i.e., clay pan range site). The Eapa series (Aridic Argiborolls, fine-loamy, mixed) is a deep, well drained, silty loam soil of moderate permeability. Vegetation was a midgrass dominant of western wheatgrass [*Pascopyrum smithii* Rydb. (Love)], a cool-season perennial, and 2 exotic annual grasses; Japanese brome (*Bromus japonicus* Thunb.) and cheatgrass (*Bromus tectorum* L.). Other important perennial grasses were needle-and-thread (*Stipa comata* Trin. and Rupr.), a cool-season species, and blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths], a warm-season species. Threadleaf sedge (*Carex filifolia* Nutt.) was also common. Dominant forbs were western salsify (*Tragopogon dubius* Scop.), fringed sagewort (*Artemisia frigida* Willd.), and common dandelion (*Taraxacum officinale* Weber). Plains prickly pear (*Opuntia polycantha* Haw.) was the dominant succulent and Wyoming big sagebrush (*Artemisia tridentata* Pursh. subsp. wyomingensis Beatle and Young) was the dominant shrub. All 4 silty study sites were located on moderate upland slopes (<5%). Estimated range condition was good (SCS 1983).

The 4 clay pan study sites were located on nearly level lowland benches. The Sonnet soil series (Typic Eutroborolls, fine, montmorillonitic) is a rather impermeable clay loam soil that has an impervious B horizon claypan 5 to 20 cm below the soil surface. Plant species composition on these soils was similar to that of the Eapa soil with the dominant grasses being western wheatgrass, Japanese brome, and cheatgrass. However, Sandberg's bluegrass (*Poa sandbergii* Vasey), a cool-season perennial, was the principal subdominant graminoid as opposed to blue grama and needle-and-thread on the Eapa soil. The dominant forbs, succulents, and shrubs were the same as on the Eapa soil. Estimated range condition was fair (SCS 1983).

Field Sampling and Laboratory Procedures

Standing crop inside 10 randomly located 0.25-m^2 quadrats per replication per sample date was harvested by species at ground level on 10 dates over a 2-year period beginning in June 1991. Minor species (<1 g m^{-2}) were composited in the field by functional group (e.g., warm-season perennial grasses). Before weighing, samples were oven dried at 60°C to a constant weight. After weighing, live-dead ratios were estimated by hand separation of tissue. Samples were then ground for crude protein, acid detergent, and neutral detergent fiber determinations. Crude protein and acid detergent fiber concentrations were estimated following AOAC (1989) procedures and neutral detergent fiber concentrations were estimated following Goering and VanSoest (1970).

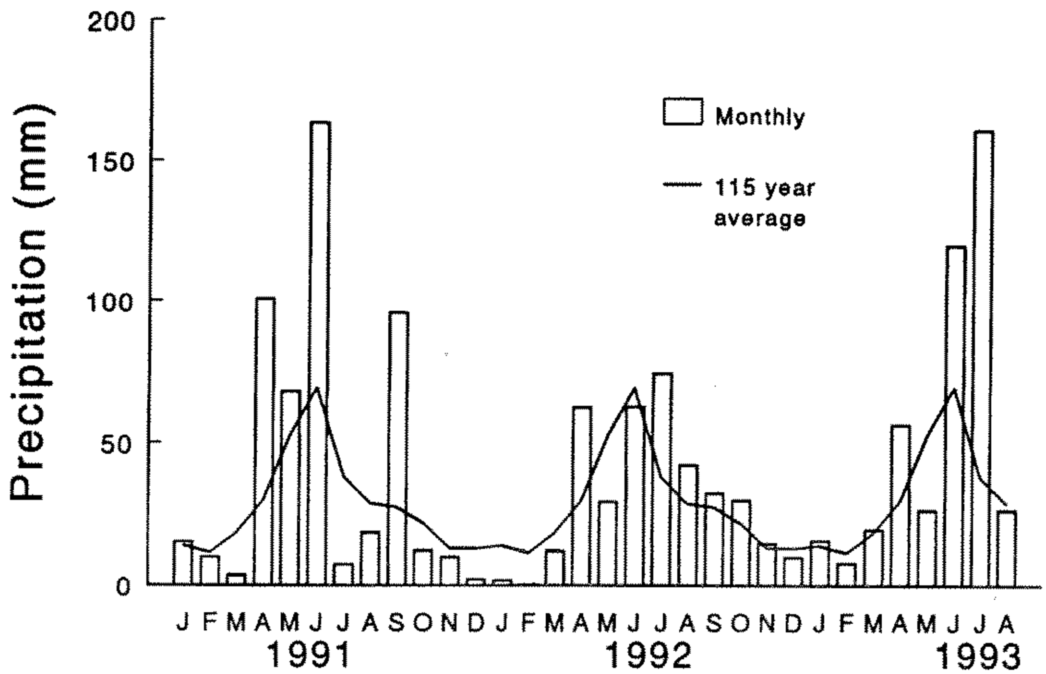

Fig. 1. Monthly precipitation from January 1991 through April 1993 and long-term monthly averages at the Miles City, Mont. weather station (NOAA 1991-1993) located about 8 km north of study areas.

Data Analyses

Aboveground net primary production was estimated by functional group using peak standing crop values. Data were statistically analyzed using a split-split plot analysis of variance model. Main effects in the full model were range site (silty and clay pan), plant species group (cool-season perennial grasses, warm-season perennial grasses, cool-season annual grasses, sedges, and forbs), and year (1991 and 1992). The error term for testing differences between sites was site by replication. The error term for testing differences among species groups and the 2-way interaction effects of site and species groups was the species group by replication mean square plus the sites by species group by replication mean square. The remaining residual mean square was used to test for year and associated 2- and 3-way interaction effects. When necessary, significantly ($P<0.05$) different means were identified using Tukey-Q procedures.

The forage quality data were statistically analyzed using analysis of various models similar to those used in the primary productivity analyses. Estimates for whole plant qualitative values were obtained mathematically using live-dead ratios in combination with live and dead tissue qualitative data. For example, if estimated crude protein contents of live and dead tissue were 10 and 5%, respectively, and percentage live was 30%, then estimated whole plant crude protein concentration would be 5.5%. Because western wheatgrass was the only species which occurred on both sites and for which live and dead tissue was harvested on every sample date, it was the only species wherein range site × tissue class interaction effects could be examined. This model included the main effects of range site, date, and tissue class and all associated 2- and 3-way interactions. Effects of range sites were tested using the replicate within range site mean square as the error term. Tissue class and tissue class × range site effects were tested using the replicate within range site × tissue class mean square as the error term. Data for all other species groups were analyzed with a model that included tissue class, date and their interaction. Tukey-Q procedures were used to separate significantly ($P<0.05$) different means.

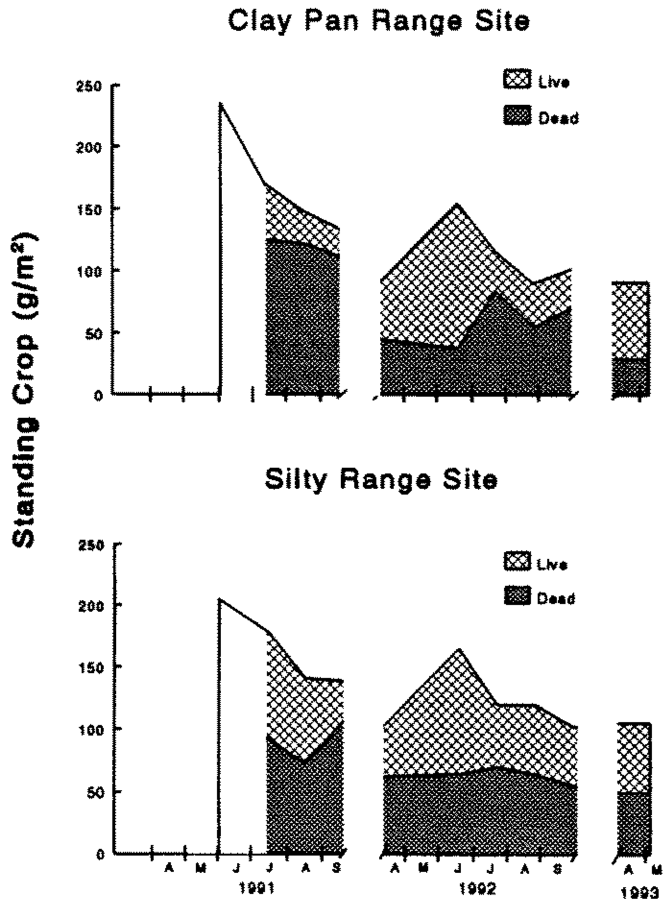

Fig. 2. Live, dead and total herbage standing crops on clay pan and silty range sites. Amounts of live and dead biomass were not estimated separately on the 8 June 1991 sample date.

Results

Growing Conditions

Spring time precipitation was well above normal in 1991 and near normal in 1992 (Fig. 1). Temperatures during late winter and early spring of 1991 were well above normal (≈4°C) whereas temperatures during late spring, summer, and fall were near normal (NOAA 1991-1993). Temperatures during the winter of 1991-92 were again well above normal (≈6°C) with temperatures thereafter near to slightly below normal. As a result of these climatic conditions, 1991 was an exceptional growing year with 1992 considered an average to slightly above average year.

Growth Dynamics

Detailed analyses of seasonal growth dynamics were limited to the 1992 data because the initial sample date of 8 June 1991 was well after the beginning of the 1991 growing season. Moreover, because of a post-harvest technical error, live-dead estimates were not attained on this sample date thereby further limiting definitive conclusions about growth dynamics during 1991. We assume, however, that peak standing crop in 1991 occurred near the 8 June sample date. Support for this assumption is rendered by the 1992 data (Fig. 2) and data from Lauenroth et al. (1975), Dodd et al. (1982), and Singh et al. (1983).

Relative to the 1992 data, substantial growth occurred before the first sample date in late April (Fig. 2) with the average amount of live tissue on the clay pan site being 47 ± 9 g m^{-2} ($\bar{x}$ ± SE) as compared to 41 ± 3 g m^{-2} on the silty site. The major contributing species on the clay pan site were western wheatgrass (19%), Sandberg's bluegrass (13%), and annual grass seedlings (64%). On the silty site, the major contributors were western wheatgrass (29%), needle-and-thread (10%), and the annual grass seedlings (41%). Western wheatgrass (12%) and Japanese brome (28%) were the major contributors to the 92 ± 20 g m^{-2} of winter carryover of dead tissue on the clay pan site. The major contributors to this component (102 ± 9 g m^{-2}) on the silty site were western wheatgrass (37%) and cheatgrass (11%).

Peak standing crops in 1992 were achieved on both sites in early June. Major contributors to the clay pan site total of 155 ± 25 g m^{-2} were western wheatgrass (29%), Japanese brome (36%), and cheatgrass (25%). Major contributors to the silty site total of 165 ± 7 g m^{-2} were western wheatgrass (32%), needle-and-thread (10%), cheatgrass (44%), blue grama (4%), and threadleaf sedge (4%).

Amount of live material declined sharply on both sites after early June. The decline was greatest on the clay pan site in that by mid-July only 32 ± 6 g m^{-2} of live material remained as compared to 71 ± 4 g m^{-2} on the silty site. This decline in live material accompanied a rather dramatic increase in amount of dead material on the clay pan but not the silty site. We attribute these differences primarily to differences in the dynamics of the annual grass component in that the amount of live annual grasses present on the clay pan site declined 74 g m^{-2} from June to July but only 44 g m^{-2} on the silty site. Conversely, the amount of dead annual grasses increased on the clay pan site from 21 to 62 g m^{-2} whereas on the silty site the increase in dead tissue was only 4 g m^{-2} from 29 to 33 g. Following the sharp early summer decline in live material, amounts of live and dead material remained relatively constant thereafter. There was generally, however, a greater amount of live plant material on the silty than clay pan site. We attribute this difference primarily to the more xeric conditions of the clay pan site resulting from the Sonnet soil's greater clay content coupled with the presence of the shallow clay hardpan.

In general, growth dynamics during the summer and fall of 1991 appeared to be similar to 1992 although total standing crop was greater. Relative proportions of live and dead tissue were similar in 1991 to 1992 levels although greater proportions of dead occurred on the clay pan than silty site. Similarly, the single clipping in April 1993 showed early season standing crops similar to those found in April 1992. These general observations seem reasonable in light of the differences between years in amount and temporal distribution of precipitation (Fig. 1).

Aboveground Net Primary Production (ANPP)

Statistical analyses of estimated herbage produced (Fig. 3) revealed no differences between range sites. Estimated production on the clay pan site averaged 218 g m^{-2} as compared to 219 g m^{-2} on the silty site. However, because growing conditions during 1991 were more favorable than 1992, estimated production was significantly greater in 1991 than 1992 averaging 259 g m^{-2} as compared to 178 g m^{-2}. The year by range site interaction effect was not significant.

The full analysis of variance model used to test for species effects revealed a number of statistically significant effects with the overwhelming effect being that of species which explained 73% of the total variation. Of the remaining variables, only 2 explained greater than 2% of the variation. The species by range site interaction, which was primarily the result of greater amounts of cool-season perennials and sedges on the silty than clay pan site and lesser amounts of annual grasses, explained 5% of the variation. The species by year interaction effect accounted for 9% of the variation and resulted primarily from differences between 1991 and 1992 in the absolute amounts of annual grass biomass.

Forage Quality

Age of tissue was the principal factor affecting forage quality values. This was evidenced in that crude protein concentrations were greater and acid and neutral detergent fiber concentrations were less in live (i.e., younger) than in dead (i.e., older) tissue (Table 1). Moreover, analyses of live tissue showed crude protein concentrations declined and fiber concentrations increased within a tissue class as age increased (data not shown). For example, crude protein content of live western wheatgrass tissue declined from 17.9 to 9.5% from April to July 1992 largely because most of the live tissue was 4 months older in July than April.

There were some differences between soils in whole plant forage quality values largely because of differences in live-dead

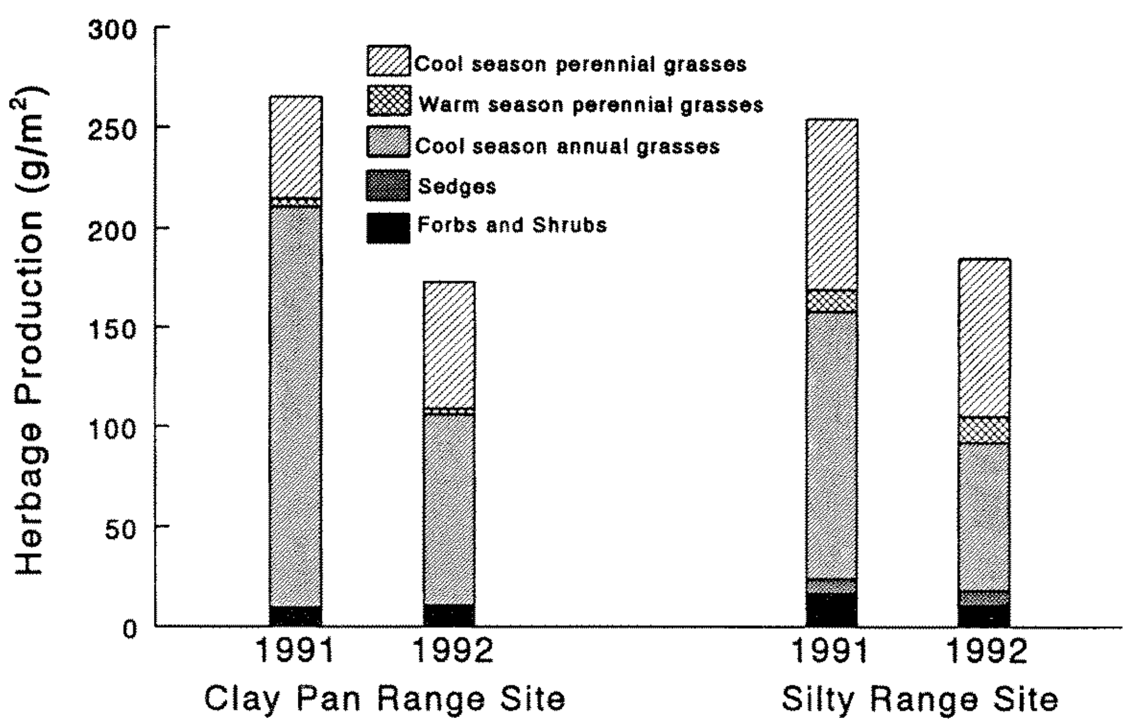

Fig. 3. Estimated herbage production for 1991 and 1992 for clay pan and silty range sites.

Table 1. Average percentage crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) for live (i.e., green) and dead (i.e., senesced) tissue for western wheatgrass and 5 species groups. Averages include only those dates on which both live and dead tissue were present.

Species	Tissue class	No. of Dates	CP	ADF	NDF
			Variable		
			% of DM (± S.E.)		
Western wheatgrass	Live	9	10.3±0.1**	36.3±0.3**	63.2±0.3**
	Dead		4.5±0.1	48.9±0.3	74.4±0.3
Other cool-season grasses	Live	6	9.6±0.6**	39.2±1.2**	69.0±2.0**
	Dead		4.5±0.3	49.8±0.6	78.2±1.0
Warm-season grasses	Live	6	8.7±0.3**	38.5±0.8**	76.5±1.3
	Dead		5.7±0.5	47.9±1.4	74.9±2.3
Annual Bromes	Live	4	15.6±0.2**	27.7±0.8**	53.0±1.0**
	Dead		4.8±0.2	53.7±0.7**	75.2±0.8
Sedges	Live	5	11.9±0.3**	32.6±1.6*	63.9±3.0
	Dead		6.7±0.4	47.2±1.9	75.1±3.7
Forbs	Live	5	15.3±0.7**	26.2±2.1**	33.9±2.3**
	Dead		5.5±1.0	50.4±3.2	66.2±3.6

**,* Tissue class varied within a species at $P<0.01$ and $P<0.05$, respectively.

mix. For example, in September 1992 annual grass crude protein concentrations averaged 5.1 and 9.4% on the clay pan and silty sites, respectively. This difference was primarily because 6% of the biomass on the clay pan site was live whereas 14% of the biomass on the silty site was live.

Community level analyses of forage quality values revealed significant date effects for all variables, no significant range site effects, and significant date by range site interaction effects for fiber concentrations (Fig. 4). Differences between range sites occurred in July 1991, August 1991, and April 1993. The reasons for these differences were unknown.

Discussion and Conclusions

The quantitative results of this study agree in large part with the findings from similar native grassland studies conducted in the Northern Great Plains (Lewis et al. 1971, Coupland 1974, Laurenroth et al. 1975, Lauenroth and Whitman 1977, Sims and Singh 1978a and 1978b, Dodd et. al. 1982), of which the multi-facet results from these and other studies have been succinctly summarized by Singh et. al. (1983). Specifically, the results of these studies agree broadly with our seasonal growth dynamics (Fig. 2), although time of peak total standing crop was slightly earlier in our study than previous Northern Great Plains studies (mid-June vs. mid-July). We assume the reason for this was related largely to differences among study sites in plant species composition. The 2 annual grasses, Japanese brome and cheatgrass, were co-dominants at our study sites but only minor or sub-dominant species at the other regional sites including the 6 southeastern Montana study sites (Lauenroth et al. 1975), and the single western North Dakota (Lauenroth and Whitman 1977), western South Dakota (Lewis et al. 1971), and southern Saskatchewan (Coupland 1974) sites. Because these annual grasses complete most of their growth by early June, they tend to begin to senesce and transfer into the ground litter component by early July. This in turn shifted time of our peak live and total standing crops from mid-July to mid-June which was 15 to 30 days earlier than reported in the other studies.

Estimated herbage productions in this study were considerably greater than for the 6 southeastern Montana sites included in the Singh et al. (1983) summaries (218 vs. 163 g m^{-2}). Although the exact reasons for this are unclear, there are 3 plausible explanations. Firstly, annual growing conditions during the 2 years of our study (Fig. 1) certainly favored above average production more so than conditions during the 3 years (1974-76) of the earlier study (Lauenroth et al. 1975, Heitschmidt 1977, Dodd et al. 1982). Secondly, it may be reasoned that our failure to separate current year's dead from previous year's dead tissue resulted in an over-estimation of amount of herbage produced. Singh et al. (1983) showed that in the Northern Great Plains the percentage of the standing crop comprised of previous year's dead material declines from about 25% in mid-June to about 10% in mid-August. Because of the preponderance of annual grasses on our study areas, it seems likely that amount of carryover of previous year's standing crop to time of peak would be less in our study than in those studies reported by Singh et al. (1983). Still, it seems reasonable to assume some carryover did occur on our study areas which would lead us to conclude that our greater estimates may be partially the result of our failure to separate previous year's dead tissue from current year's dead. Thirdly, differences in plant species composition may have also played a role particularly with the considerable production derived from the annual grasses (Fig. 3). On our study areas, the dominant functional group was the annual grasses whereas in the other studies the dominant functional group was the cool-season perennial grasses. An interesting side light to this observation is whether this difference in composition is related to inherent site differences or whether it is related to temporal changes (mid 1970's vs early 1990's) associated with the ingress of these annual grasses into the Northern Great Plains. Although definitive data are not presently available to address this phenomenon, we do know that annual grasses were not a major component of these communities during the late 1950's (Houston and Woodward 1966). We also know that climatic conditions affect abundance of annual grasses on an annual basis. For example, Haferkamp et al. (1993) showed from a study at Fort Keogh spanning an 8-year period, that average standing crop of annual grasses during late spring varied

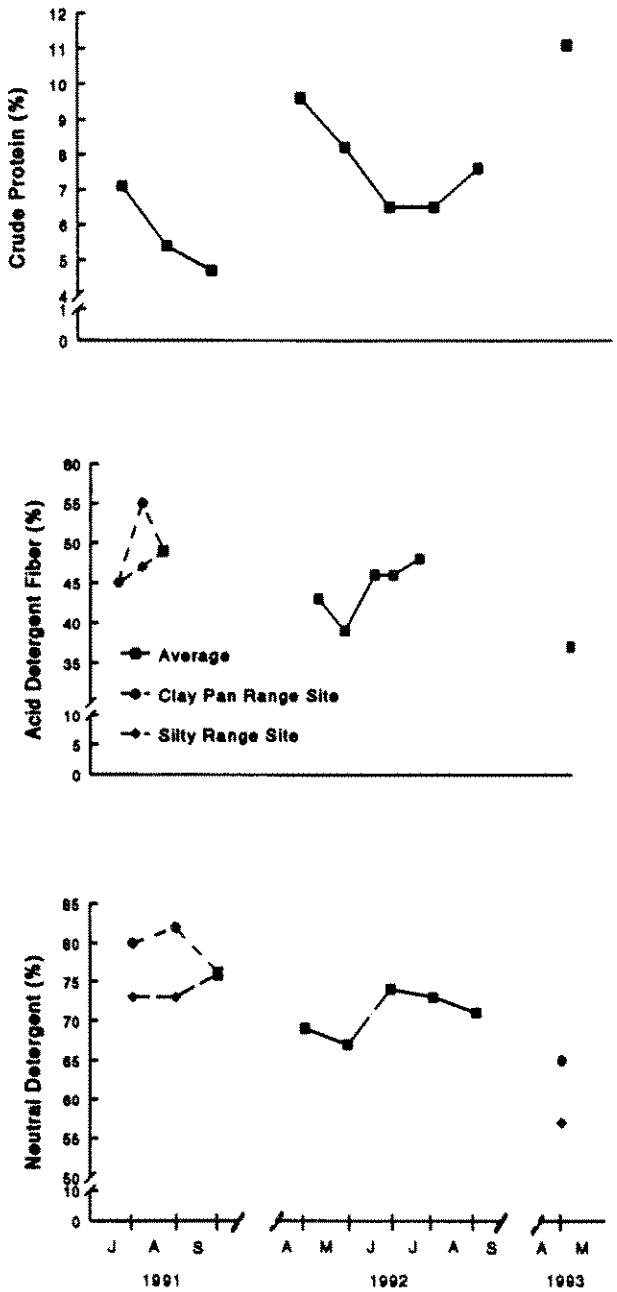

Fig. 4. Herbage standing crop nutrient values for clay pan and silty range sites. Average values were used on all dates when differences between sites were not significant at $P = 0.05$.

from 3 to 51 g m^{-2} when averaged across 7 range improvement treatments installed on 2 study sites. Thus, the dominance of annual grasses during this 2-year study must also be viewed in part as a function of the specific and favorable climatic conditions of 1991 and 1992.

The results of this study also demonstrate the need for land management agencies to recognize that some introduced species, in this instance the annual bromes, play a significant role in regulating seasonal growth patterns and productivity of "indigenous" plant communities. For example, estimated (SCS 1983) herbage production for silty range sites located in this region ranges from 246 g m^{-2} during favorable years to 118 g m^{-2} during unfavorable years which is double the 123 and 56 g m^{-2} estimates for clay pan range sites. These estimates compare to our favorable year (i.e., 1991) estimates of 254 and 264 g m^{-2} for the silty and clay pan sites, respectively, and our average to above average year (i.e., 1992) estimates of 184 and 173 g m^{-2}, respectively. From these comparisons, we conclude that current SCS herbage production estimates for silty range sites are appropriate and those for clay pan range sites are inappropriate at least during those years when annual grasses are abundant.

When the species composition data from our production estimates were used to estimate the ecological condition of our study sites in accordance with SCS (1983) guidelines, we found the silty site was in good ecological condition whereas the clay pan site was only in fair ecological condition. The primary reason the clay pan site's ecological condition was determined to only be fair was because the classification guidelines do not acknowledge the fundamental role that the 2 dominant plant species (i.e., Japanese brome and cheatgrass, Fig. 3) play in regulating the overall productivity and temporal growth dynamics of the resident plant community. We believe the results from this study provide additional evidence in support of the position (e.g., see Lauenroth and Laycock 1989, West et al. 1994) that land management agencies need to explore and eventually adopt new methodology for assessing and monitoring the ecological condition of U.S. rangelands.

The forage quality data from this study clearly show that age of plant tissue was the overwhelming factor affecting herbage crude protein and fiber concentrations. This is in close agreement with findings from other studies (e.g., see Huston and Pinchak 1991) and serves to emphasize that "greenness" is often a more appropriate indicator of herbage quality than is plant species composition.

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