Technical Report No. 72

# SOME MEASUREMENTS OF VEGETATION STRUCTURE ON THE PAWNEE GRASSLAND, 1970

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## ABSTRACT

This report contains the results of measurements on the vegetation structure of the Pawnee Grassland in 1970. The measurements were made primarily at microwatersheds 2, 3, 5, and 7--one each in management units subject to heavy, moderate, light, and zero grazing pressure by cattle. Estimates are presented for total green leaf area index (LAI), total green and brown LAI, *Bouteloua gracilis* green LAI, and *Bouteloua* brown LAI. Also summarized in this report are data on percent cover by the succulent, bunch grass, and shrub growth forms; percent bare ground; percent vegetation cover from various solar angles; percent mulch cover; and average vegetation height. These measurements will be used for ecosystem simulation, for intra- and interbiome comparisons, and for evaluating the magnitude of energy and water flux modification by vegetation structure.

# INTRODUCTION

The functioning of an ecosystem can be expressed in terms of productivity and biogeochemical cycling, or more specifically, in terms of energy flux, water flux, and nutrient flux. To understand the functioning of an ecosystem, it is necessary to determine what aspects of ecosystem structure are modifiers of flux rate and flux direction. Vegetation structure is clearly a flux modifier, and my objective during 1970 has been to measure those aspects of vegetation structure on the Pawnee Grassland that might prove useful for a better understanding of the Pawnee ecosystem. Measurements were taken for vegetation cover (by growth form), mulch cover, vegetation height, and leaf area index (LAI). LAI was measured periodically during the growing season.

# LOCATION OF STUDY AREAS

The measurements on vegetation structure were taken in or adjacent to the microwatersheds on the Pawnee Grassland, especially numbers 2, 3, 5, and 7. Fig. 1 shows the location of the half-hectare microwatersheds and Fig. 2 shows the specific area around the microwatersheds from which most of the data were gathered. Microwatershed 2 is located in a 30 year exclosure adjacent to watershed 3 which has been heavily grazed for 30 years. Microwatershed 5 is nearby in a lightly grazed unit and watershed 7 is in a moderately grazed unit. All of the grazing on these management units has been in the summer for the last 30 years, and all of the microwatersheds are on the Ascalon soil series (see IBP Grassland Biome Technical Report No. 5 for further information on the microwatersheds).

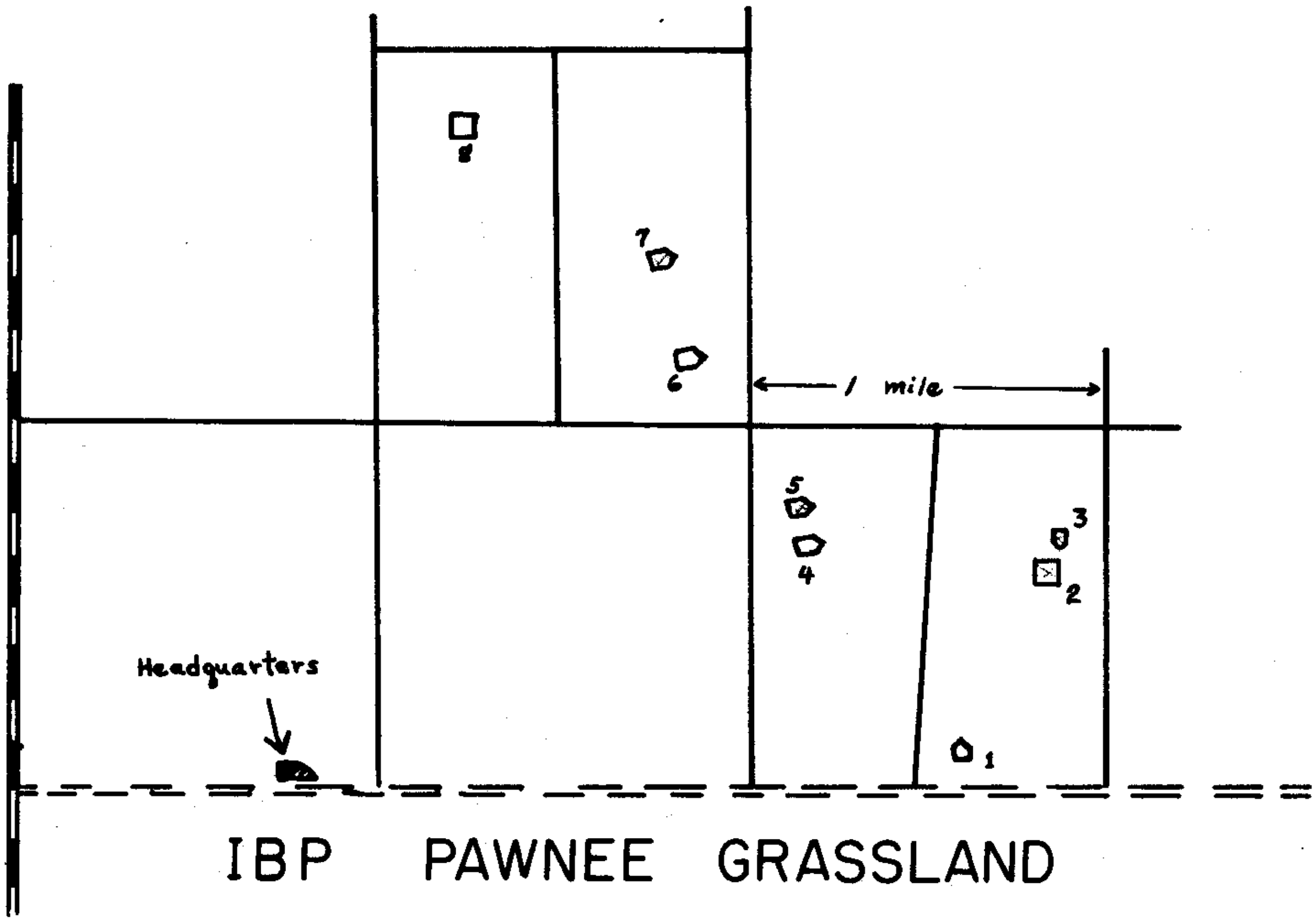


Fig. 1. The location of the microwatersheds on the Pawnee Grassland. Most of the data were gathered from microwatershed no. 2, 3, 5, and 7. The squares are microwatersheds located in exclosures.

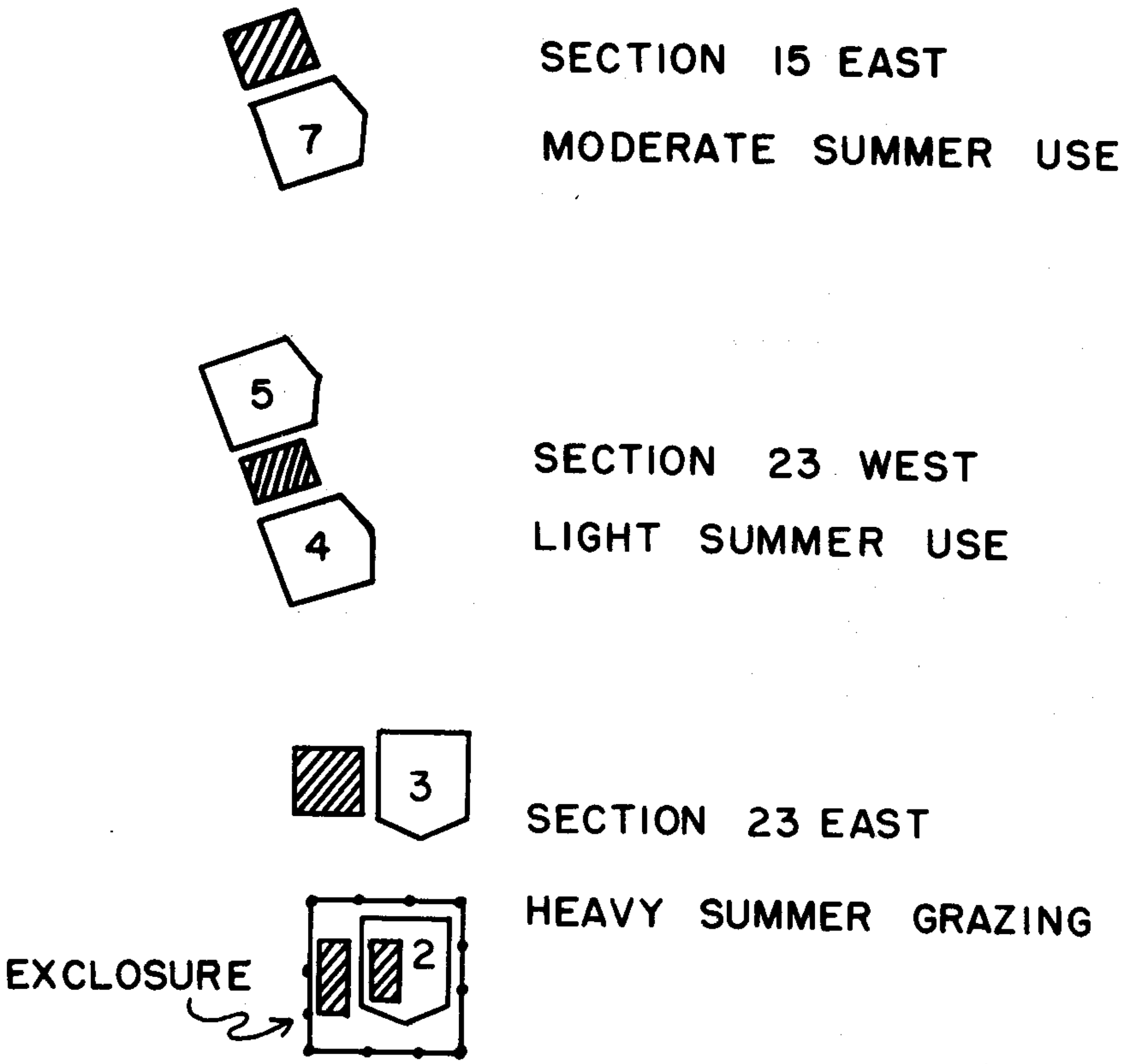


Fig. 2. The hatched areas are the principal locations from which data were gathered for vegetation structure.

The microwatersheds were selected for study areas because they are being studied for runoff, evapotranspiration, soil moisture, and insect populations, as well as herbage dynamics, and because they provided an opportunity to compare vegetation structure under zero, light, moderate, and heavy grazing pressure by cattle. This study is not, however, an evaluation of grazing pressure on grasslands, since only one study area per treatment was used.

## METHODS

### Leaf Area Index

Leaf area index (LAI) is defined as the amount of leaf area per unit ground area and can be measured in several ways depending on the nature of the vegetation and whether or not a non-destructive technique is desired (Knight 1969). Three techniques were used on the Pawnee Grassland: the Warren Wilson point quadrat technique for the general grass and forb ground cover; a plant weight/leaf area ratio for the bunch grass *Aristida longiseta* Steud., the dwarf shrub *Artemisia frigida* Willd., and the cactus *Opuntia polyacantha* Haw.; and the average plant technique for the shrubs *Chrysothamnus nauseosus* (Pall.) Britt. and *Gutierrezia sarothrae* (Pursh) Britt. & Rusby.

*The general grass and forb ground cover.* Over 95% of the LAI on the Pawnee Grassland is in the general grass and forb ground cover; bunch grasses, shrubs, and cactus contribute very little to the total LAI. It was necessary then to select a method well adapted to scattered forbs and matts of *Bouteloua gracilis* (H.B.K.) Laq. and *Buchlöe dactyloides* (Nutt.) Engelm.

sample was adequate for *Bouteloua*, then it was adequate for total green contacts of all species combined.

After determining sample adequacy, the LAI was calculated by the equation suggested by Warren Wilson (1963).

$$LAI = .089f_{8°} + .462f_{32.5°} + .453f_{65°} \qquad (1)$$

where $f_n$ is the average number of contacts *per pin* for each of the three angles. Separate calculations were made for total green LAI, total brown and green LAI, *Bouteloua* green LAI, and *Bouteloua* brown LAI. Species other than *Bouteloua gracilis* were not contacted frequently enough for an accurate LAI determination. LAI was measured at least three times during the summer, at about 30 day intervals, on each of microwatersheds 2, 3, 5, and 7.

In the field, the procedure was first to locate a 2.5-m by .5-m platform in a systematic random manner. Three platforms were used, one for each of three men using one of the point frames. The platform provided protection for the investigator from the cacti and prevented trampling of the vegetation. About five frame settings were made around each platform setting.

Pin contact data were recorded into a small portable tape recorder by species, as well as whether the material contacted was green or brown (living or dead). If a leaf was mostly green, but the portion contacted was in fact brown, a brown contact was recorded. All material recorded for the LAI calculations had to be self-supporting, i.e., standing live or standing dead, and the data were not separated by height strata.

The pins were kept very sharp, so that they literally pricked the leaves when touched, and the points tapered sufficiently so that rarely did

The point quadrat technique of Warren Wilson (1963) was selected as the most feasible method. It offered the further advantage of being non-destructive.

The point quadrat method for LAI has been described in detail by Warren Wilson (1963) and applied more recently for leaf angle measurements as well as LAI by Philip (1965) and Miller (1967). Essentially, the method requires the determination of the average number of contacts per pin at various angles from the horizontal. The averages are then multiplied by theoretically obtained coefficients to obtain LAI. The more pin angles used, the more accurate the estimate, but Warren Wilson suggests that three should be very adequate if LAI is the main objective.

Three pin angles were used to measure LAI on the Pawnee Grassland: 8°, 32.5°, and 65°. A motorized point frame was constructed for each of the three angles. Having the pins motorized speeded the field work considerably.[1/] The frames were constructed so that the pins were 2.5 cm apart; five pins per frame were observed for the 8° angle, and 10 pins per frame for the other two angles. Usually, a total of 350 pins were observed at the 8° angle, about 750 pins at the 32.5° angle, and 750 pins at the 65° angle.

Sample adequacy was evaluated by determining the mean number of contacts per frame for living *Bouteloua gracilis*, then calculating the standard error of that mean, N being equal to the number of frames. A sample was considered adequate when the standard error of the mean for each angle was less than 10% of the mean for that respective angle. I assumed that if the

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1/ The details of the motorized point frame will be published at a later time.

the shank interfere. Wind shields were used on windy days, though wind was rarely a problem in the low vegetation.

It is tempting to doubt whether or not the point quadrat method and equation (1) do, in fact, produce the ratio between leaf area and ground area on the Pawnee Grassland. The method has not yet been compared with a direct LAI measurement technique at Pawnee, though I plan to do so. Other observations that I have made suggest that LAI actually is obtained, but if it is not, at least the data represent relative foliage density and are still useful.

*LAI determination for bunch grasses, fringed sage, and cactus.* The point quadrat technique was not utilized for bunch grasses and fringed sage because of the difficulty of observing the point as it moved through these more densely foliated plants. The method used instead was to carefully measure the leaf area on different sized plants, then to develop a regression line of plant leaf area to plant dry weight. The regression lines for *Aristida longiseta* and *Artemisia frigida* are presented in Fig. 3 and 4. About the same technique was used for *Opuntia polyacantha*, but the data are too meager at this time to present here.

Biomass data on a per unit area basis (kg/ha) were available from the IBP data bank for each of the three species. With this information, average dry plant weight per square meter could be determined, and this could be readily converted to leaf area per square meter (LAI) using the regression lines. These estimates are crude, but since the three species contribute less than 5% to the total LAI, a more careful measurement did not seem necessary.

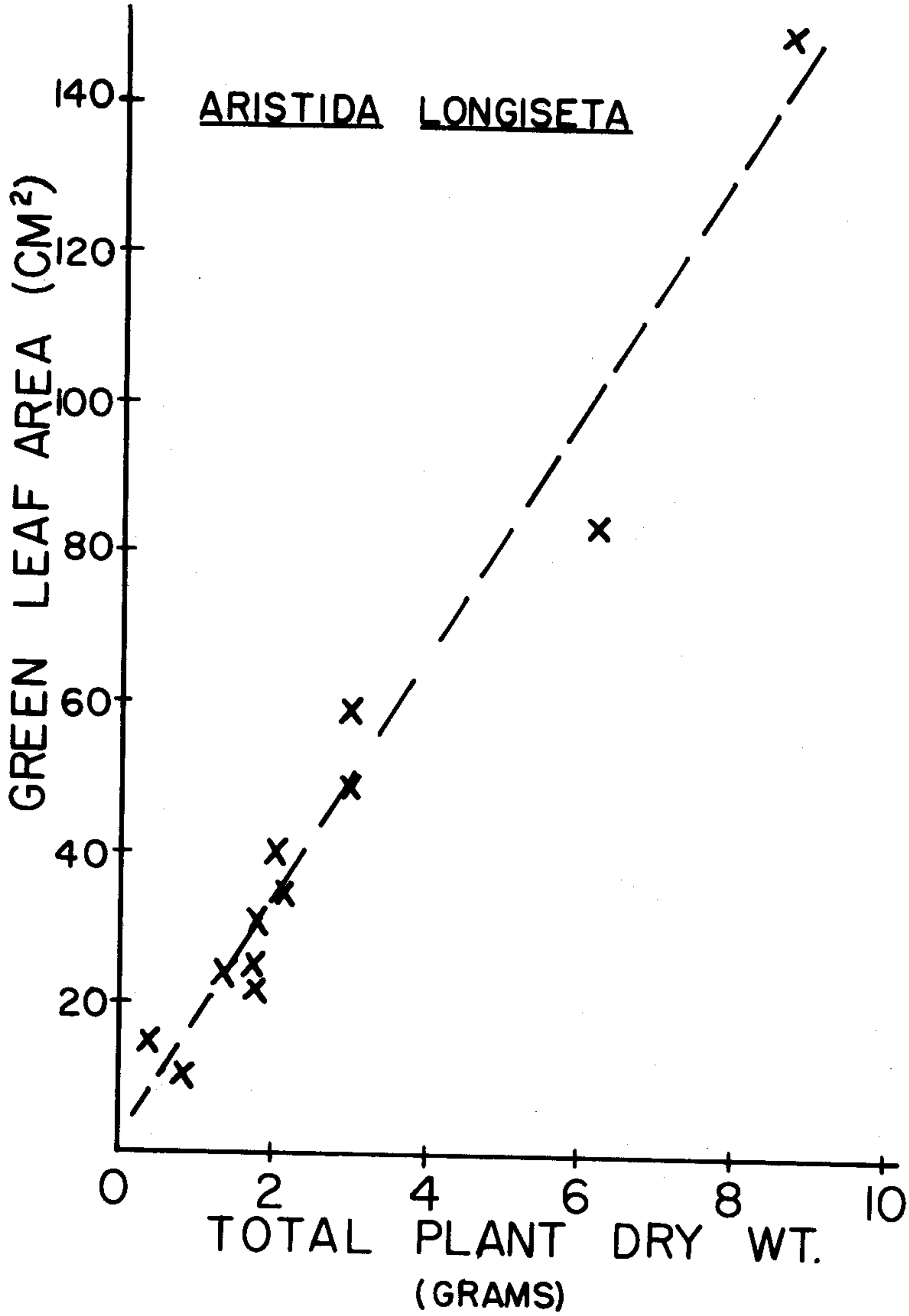


Fig. 3. An estimated regression line of green leaf area on plant dry weight for the bunch grass, *Aristida longiseta*.

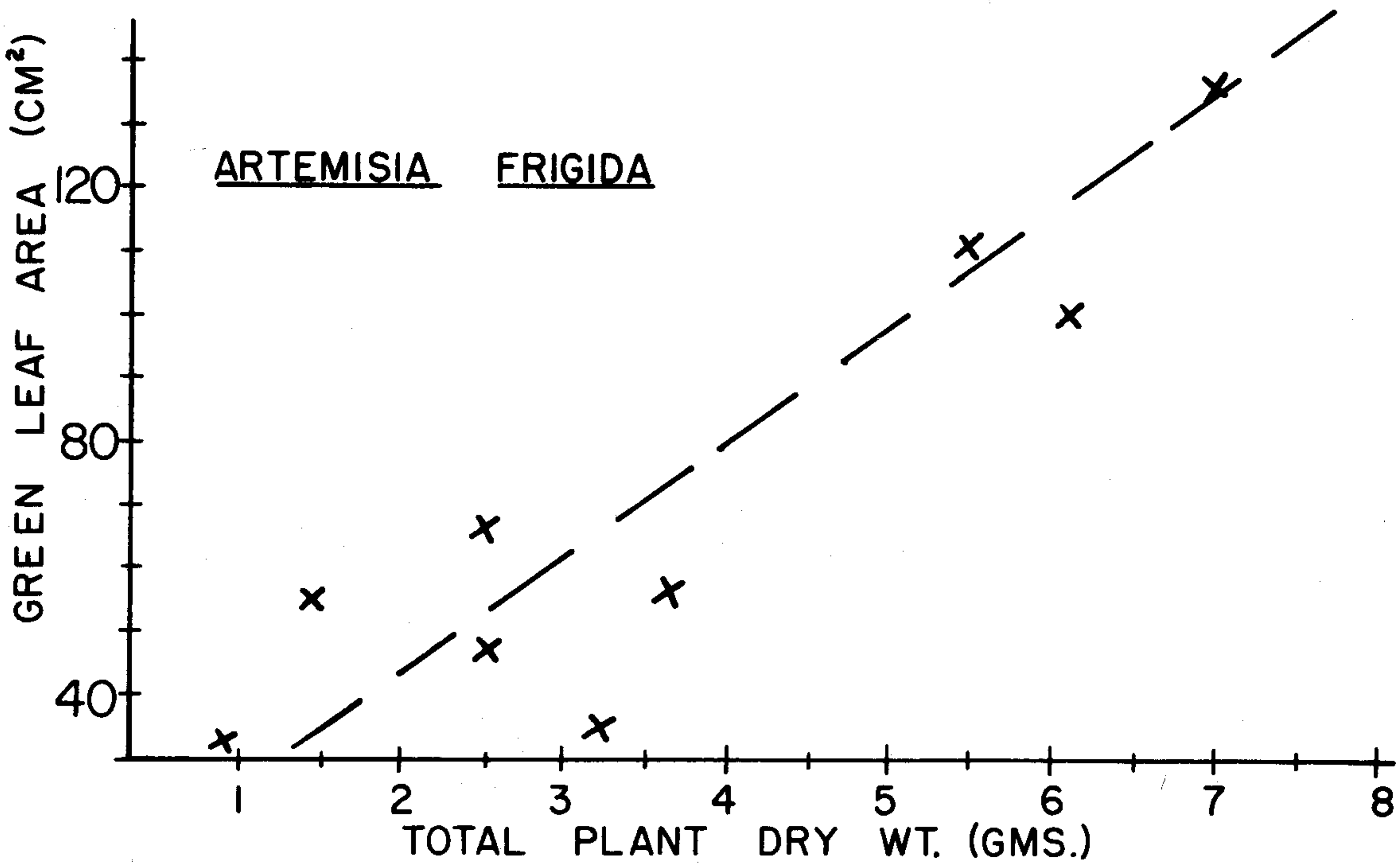


Fig. 4. An estimated regression line of green leaf area on plant dry weight for the dwarf shrub, *Artemisia frigida*.

*The larger shrubs.* Shrubs were not common in the study areas, but an LAI estimate for this growth form did seem desirable. Again, the point quadrat method was not appropriate, primarily due to the low number of contacts.

Two shrub species were most common, *Chrysothamnus nauseosus* and *Gutierrezia sarothrae*. From other data, it was possible to determine the average size of each species, in terms of average height and diameter. Two average sized plants were found for both species and the amount of leaf area measured. It was then possible to estimate LAI by multiplying the average area per plant by the plant density. The LAI estimates are crude, but the shrubs contributed no more than 2% to the total LAI.

*Total LAI.* When considering grassland productivity, a useful parameter could be total green LAI, rather than LAI by species or growth form. Total green LAI was estimated with the equation;

Total Green LAI = General Ground Cover LAI + Shrub LAI + Bunch-grass LAI + Cactus LAI

LAI for the bunch grasses, shrubs, and succulents was estimated only once during the growing season, in July after the peak biomass had been reached by most species. Probably the best total LAI estimate then is for this month. The total LAI in June and August was estimated by using the July succulent and shrub measurements, and a subjectively corrected July bunch grass estimate. A more precise estimate of these categories in June and August can be obtained next summer if this seems desirable. Since over 95% of the total LAI is in the general ground cover, the majority of our effort in 1970 was devoted to this category.

Percent Cover

Another parameter of vegetation structure is cover, conceived as the vertical projection of the plant canopy onto the ground surface and expressed as a percentage of the study area. Percent cover was determined for shrubs, succulents, bunch grasses, and bare ground using the line intercept method. Mulch cover was measured with the point quadrat technique. Cover estimates were made only once during the growing season, in July.

*The line intercept method.* This method was applied in the usual manner, using at least 8 lines (usually 10 - 20), each 30 m long. Intercept readings were made to the nearest cm. The total intercept for shrubs, including *Artemisia frigida* and *Eriogonum effusum* Nutt., was divided by the total length of all the lines to give percent shrub cover. The other cover percentages were calculated similarily, but it should be noted that only the intercept of cactus joints (pads) was recorded for succulents, not the clump diameter; and the canopy intercept of the bunch grasses was recorded, not basal area. Any patch of loose soil larger than 2 cm, without mulch or root crown, was recorded as bare soil.

Sample adequacy for the cover estimates was checked by calculating the standard error of the mean intercept per line. In most cases the standard error of the mean was less than 15% of the mean for bare ground and the more common growth form. If this was not the case, additional lines were measured.

*The point quadrat method for mulch cover.* Mulch cover was determined with the same 65° pin used for LAI measurement. Any pin that touched dead plant or animal material was recorded as one mulch contact. Mulch cover was then calculated by dividing the total pins that touched mulch by the total pins observed. No statistical test was applied to evaluate the adequacy of these data, but repeated sampling in the same study area gave about the same result. It would have been better to use a 90° pin for the mulch cover estimate, but the error is probably negligible since the litter is usually very thin and sparse on the Pawnee Grassland.

### Vegetation Height

Average vegetation height was measured by simply holding a ruler vertically on the ground at 100 objectively selected locations in the study area and reading the height of the leaf canopy at each location. The 100 readings were then averaged. Patches of bare ground, shrubs, and bunch grasses were avoided. Essentially, the height estimate is for the general ground cover on August 20, 1970.

### Vegetation Cover by Solar Angle

The traditional cover estimate is based on the vertical projection of the plant canopy. Although a useful measurement, this parameter is probably relevant to certain aspects of ecosystem function only when the sun is directly overhead during mid-day. At other times, a more appropriate cover estimate might be measured by projecting the plant canopy parallel to the sun's rays, rather than vertically.

Vegetation cover from various solar angles was readily measured with the point quadrat method. After the frame was located, the pin angle was adjusted so that it was approximately equal to the solar angle. This was easily done by adjusting the pin until it cast no shadow. The pins were then lowered through the vegetation until a contact with a green plant was made; this was recorded as a hit, and only the first hit was counted. Pins were read as rapidly as possible for one hour at intervals during the day.

Two frames were used, one man per frame. Cover for each solar angle was calculated by dividing the total number of pins with a hit at that angle by the total number of pins observed during the hour.

These cover measurements are preliminary and were made only in one location, in a control plot of the experimental area located just west of the headquarters on the Pawnee Grassland. The data were gathered only for the general ground cover; shrubs, cacti, and bunch grasses were avoided.

## RESULTS

The data gathered during 1970 are summarized in this section; graphs or charts are presented and in some cases additional information is included in the appendices. A duplicate set of the field data will be sent soon to the Grassland Ecology Research Laboratory at Colorado State University.

### Leaf Area Index

The data for LAI have been summarized into four categories: total green LAI, total green and brown LAI, *Bouteloua gracilis* green LAI, and *Bouteloua* brown LAI. Graphs are presented here that summarize the values included in Appendix I.

*Total green LAI*. Fig. 5 shows the phenology of total green LAI during 1970 in microwatershed 2, an exclosure. The peak LAI was about 0.5 in this exclosure and was reached about the middle of June. A day or so after the June 13 measurement, the area received a heavy rainfall. Nine days later the LAI was measured again; no increase in LAI occurred--a contradiction it would seem to the idea that the dominant grasses, namely *Bouteloua gracilis*, respond to precipitation by a spurt of growth.

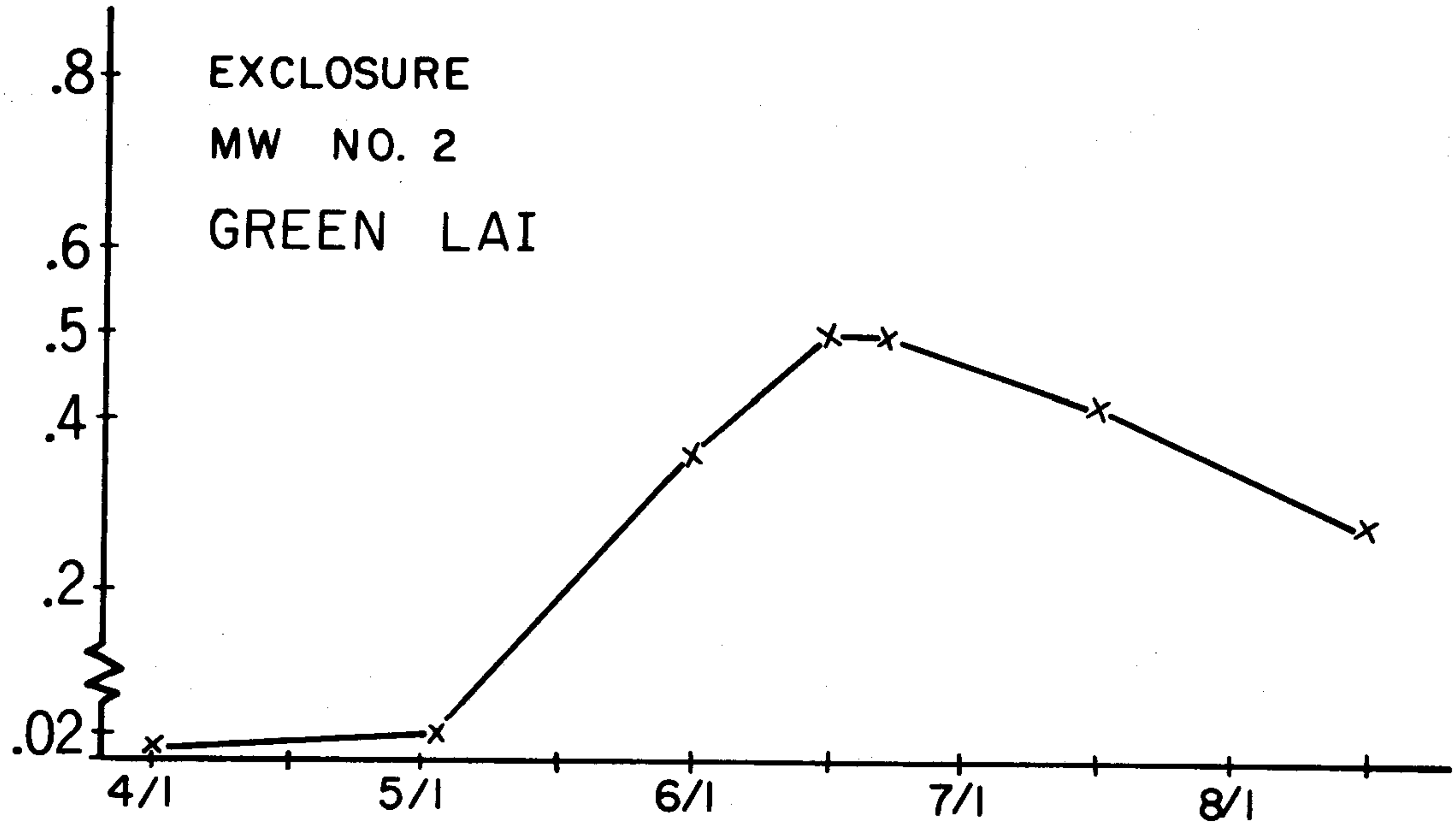


Fig. 5. The phenology of total green LAI in microwatershed 2, an exclosure.

Fig. 6 summarizes the total green LAI phenology for study areas 2 (exclosure), 3 (heavy use), 7 (moderate use), and 5 (light use). The most striking feature about this graph is the similarity of the management units. Also, it is interesting to note that the highest LAI was reached in the heavily grazed unit, even though the exclosure had the highest LAI on August 15.

The steady decline of total green LAI after June 15 is mirrored by a similar decline of chlorophyll content found by Rauzi and Dobrenz (1970). They studied *Agropyron smithii* Rydb. and *Bouteloua gracilis* at the Archer Experiment Station, 25 miles north of the Pawnee Grassland, just east of Cheyenne, Wyoming.

*Total green and brown LAI.* Some aspects of energy and water flux are probably influenced not just by green leaf area but by dead leaf area as well. Fig. 7 shows the phenology of total green and brown LAI in the four principal study areas. The maximum total LAI during 1970 was about 0.8 and occurred in mid-June. The end of season LAI under the three grazing treatments is not what might be expected initially, but the differences are not great, and other factors besides grazing pressure are probably operative.

*Bouteloua green LAI.* Blue grama is by far the most common species on the Pawnee Grassland. In fact, at least 60% of the total green LAI is actually *Bouteloua gracilis*. It is interesting to note that the proportion of blue grama LAI in June is 60% in the exclosure, 77% in the lightly and moderately grazed units, and 86% in the heavily grazed unit. This trend supports the idea that blue grama is an increaser with some grazing pressure.

The phenology of *Bouteloua* green LAI is shown in Fig. 8 for each of the four principal study areas. The lowest maximum LAI is 0.3 in the exclosure, and the highest is 0.48 in the heavily grazed unit. Note that the LAI in

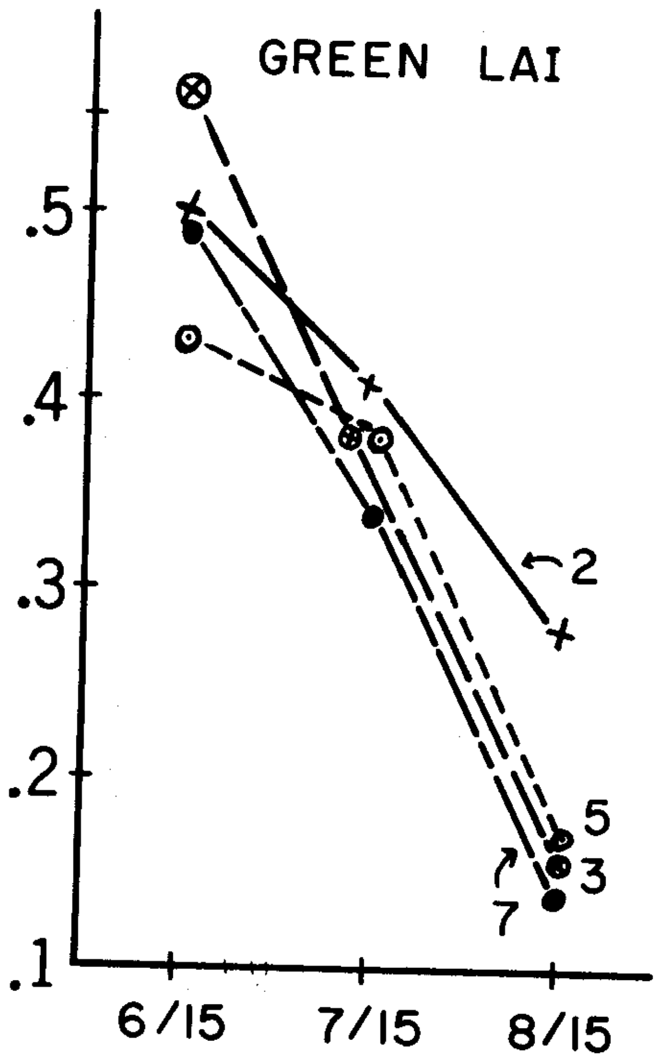


Fig. 6. The phenology of total green LAI in the four principal study areas, each subjected to different grazing intensities--heavy (3), moderate (7), light (5), and the exclosure (2).

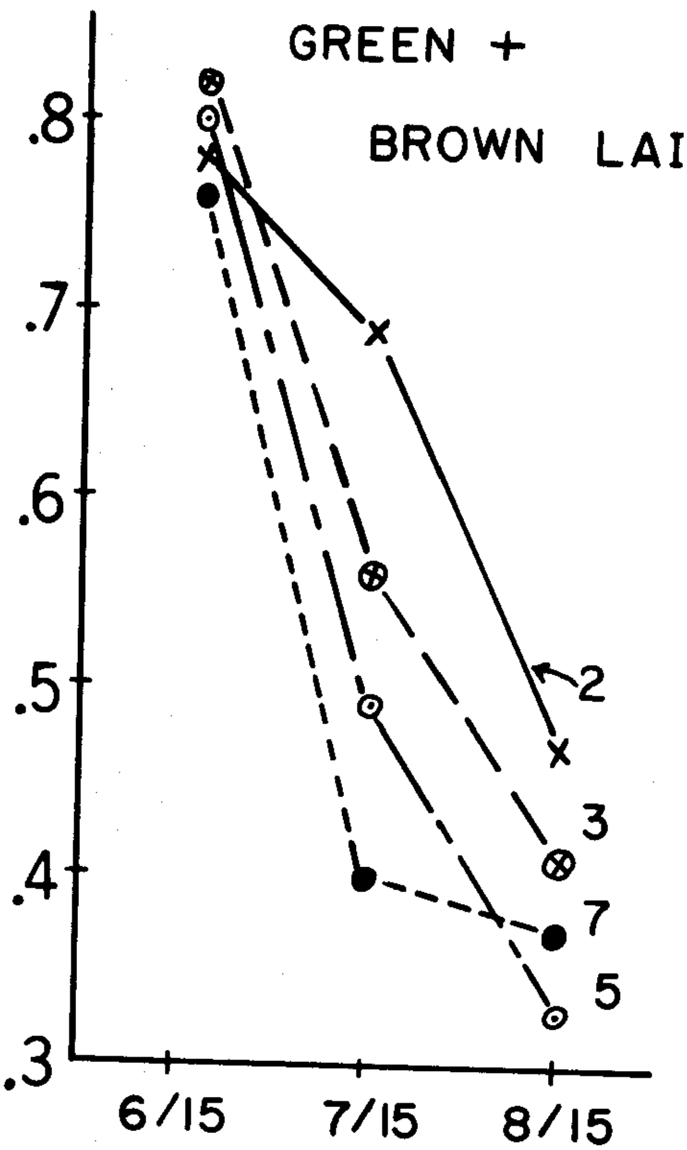


Fig. 7. The phenology of total green and brown LAI in the four principal study areas, each subjected to different grazing intensities--heavy (3), moderate (7), light (5), and the exclosure (2).

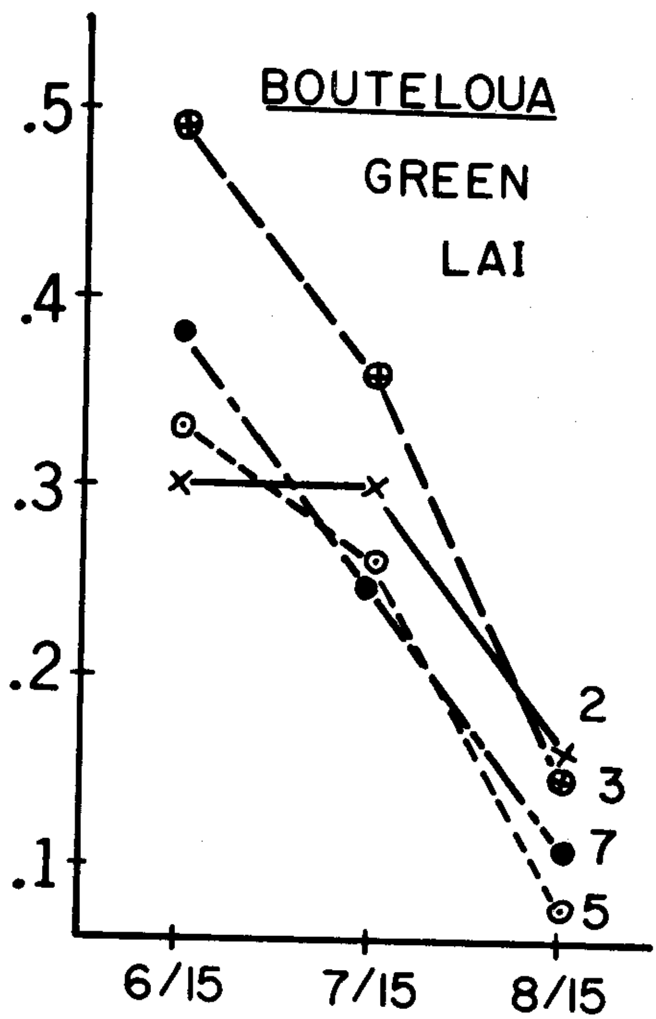


Fig. 8. The phenology of *Bouteloua gracilis* green LAI in the four principal study areas, each subjected to different grazing intensities--heavy (3), moderate (7), light (5), and the exclosure (2).

the exclosure did not decrease from June 15 to July 15, presumably due to the lack of grazing by cattle. The highest values for *Bouteloua* green LAI in each management unit were in mid-June.

*Bouteloua brown LAI*. Grasslands are characterized by standing dead vegetation, but the dynamics of this compartment have not been well studied. Fig. 9 and 10 depict some interesting patterns for dead blue grama and suggest that the LAI approach, or the point quadrat method, may be useful for studying the standing dead compartment of short grass prairie.

In Fig. 9 it is apparent that *Bouteloua* brown LAI decreases until about the middle of July in the grazed study areas, but after that time the LAI increases. Apparently, in August the rate of browning was greater than either the grazing rate or the rate at which the standing dead material was transferred to the mulch compartment. Unfortunately, since the rate of cattle grazing on blue grama is not now available, the other rates cannot be estimated. Even in the exclosure, only approximate estimates could be made since the rate of grazing by rabbits and insects must be considered, and this information is also unavailable.

Fig. 10 summarizes both *Bouteloua* green and brown LAI in microwatershed 2, the exclosure. Three interesting problems are apparent. First, note the sharp dip in the brown LAI just after the June 13 sampling date. This dip is most likely a result of the heavy rain that occurred, causing a large portion of the standing dead to be transferred to the mulch compartment. Mulch cover did in fact increase between the June 13 and June 22 sampling dates (Fig. 17).

But the subsequent rapid increase of brown LAI before July 15, with no corresponding decrease in green LAI, is another problem that remains unsolved.

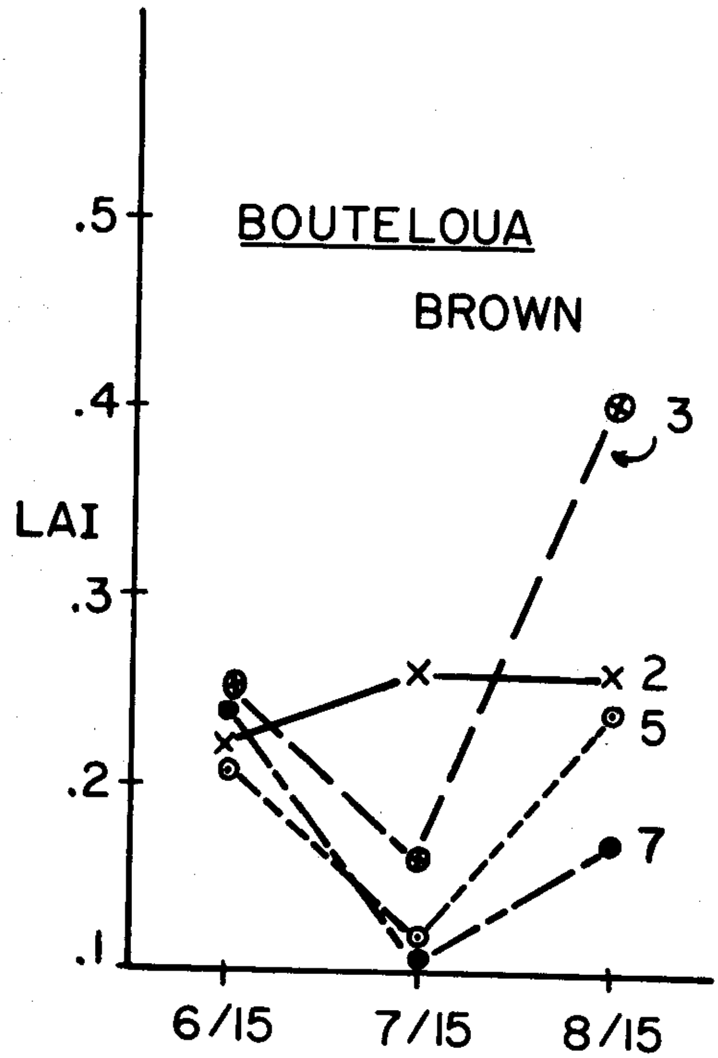


Fig. 9. The phenology of *Bouteloua gracilis* brown LAI in the four principal study areas, each subjected to different grazing intensities--heavy (3), moderate (7), light (5), and the exclosure (2).

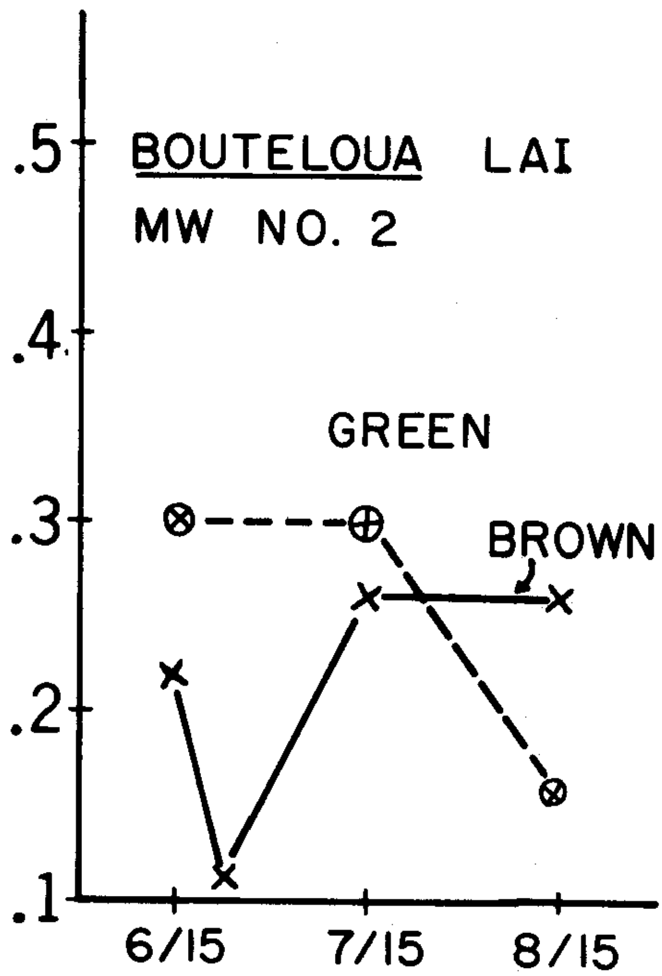


Fig. 10. The phenology of *Bouteloua gracilis* green LAI and brown LAI in the exclosure, microwatershed 2. See the text for a discussion of this graph.

There are two possible explanations, neither of which is very satisfactory. One, perhaps *Bouteloua* leaves were browning between the June 13 and July 15 sampling periods, but at the same time new growth was occurring so that the green LAI remained the same. Or, a slightly different area in the exclosure was sampled on July 15 to avoid excess trampling of the area sampled on June 13 and June 22, and there may have been a difference in the vegetation.

The last problem in Fig. 10 is not really solved either. Note the decline of *Bouteloua* green with no corresponding increase in *Bouteloua* brown. I suspect that the cause of this anomaly is the trampling pressure of the scientists in this exclosure, causing an increase in the transfer rate of standing dead to mulch.

Percent Cover by Growth Form

Another parameter useful for describing vegetation structure is cover by growth form. The cover of three growth forms was measured in 1970 on the Pawnee Grassland: succulents, bunch grasses, and shrubs. I assumed that cover fluctuations for these growth forms would be very slight during a single growing season, and therefore, measurements were made only once. The graphs in this section summarize the data in Appendix II.

*Succulent cover.* The highest succulent cover was found in the heavily grazed microwatershed 3, which had a value over 100% higher than the other microwatersheds. As can be seen in Fig. 11, there is hardly any difference between microwatershed 2, 5, and 7; the lowest succulent cover was found in microwatershed 8, another exclosure. Nearly all of the succulent cover is *Opuntia polyacantha* Haw.

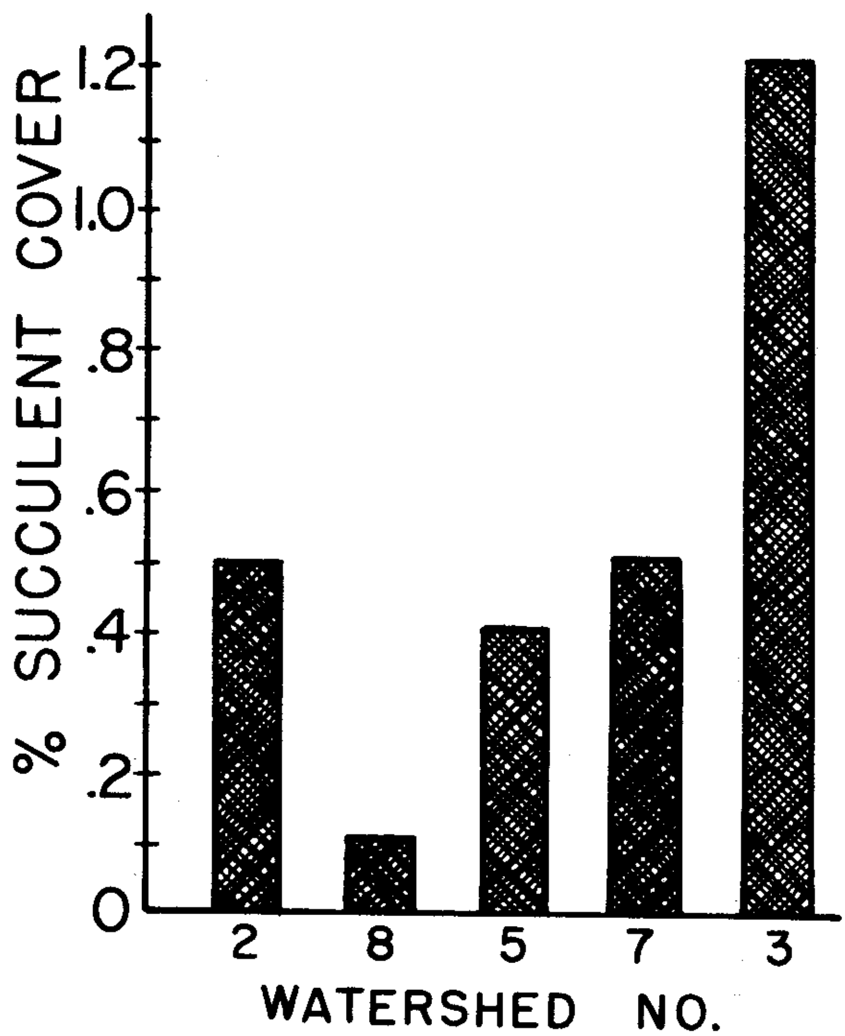


Fig. 11. Percent succulent cover on the four principal study areas. Grazing intensity increases from left to right (microwatershed no. 2 and 8 are exclosures, 5 is lightly grazed, 7 is moderately grazed, and 3 is heavily grazed).

The succulent cover values range from 0.1 to 1.2% and may seem low. It should be remembered, however, that the intercept measurements were taken for the individual cactus joints, not the total clump.

*Bunch grass cover.* This category is comprised primarily of *Aristida longiseta*, with just a slight amount of *Stipa comata* Trin. & Rupr. The cover values range from 4.5% in the lightly grazed study area to 0.2% in the heavily grazed unit 3 and exclosure 2. The moderately grazed microwatershed 7 has a bunch grass cover intermediate between the heavily grazed unit 3 and the lightly grazed unit 5, Fig. 12 and Appendix II.

Although Fig. 12 shows exclosure 8 to have a much higher bunch grass cover than exclosure 2, this may be misleading. Exclosure 2 actually has a considerable amount of *Stipa comata*, but most is clustered in the north-east corner, outside the sampling area (see Fig. 2). This heterogeneity in exclosure 2 is unfortunate, but cannot be ignored. Some separate measurements for *Stipa comata* were made in the north-east portion of the exclosure, and the bunch grass cover was recalculated; the result is 5 to 6%. This calculation is based on the fact that the *Stipa* is found in an area of about 965 sq miles, and assuming that about 30% of this area is actually covered by the bunch grass ($965\ m^2 \times .30 = 289\ m^2$, and $289\ m^2 \div 5{,}000\ m^2 = 5.8\%$).

*Shrub cover.* The shrub cover measurements included the very small shrubs, e.g., *Artemisia frigida*, as well as the larger *Chrysothamnus*, *Gutierrezia*, and *Atriplex*. The values ranged from a high of about 5% in the lightly grazed unit 5, to a low of 0.01% in the heavily grazed unit 3. The moderately grazed unit 7 and the exclosures 2 and 8 were intermediate (Fig. 13).

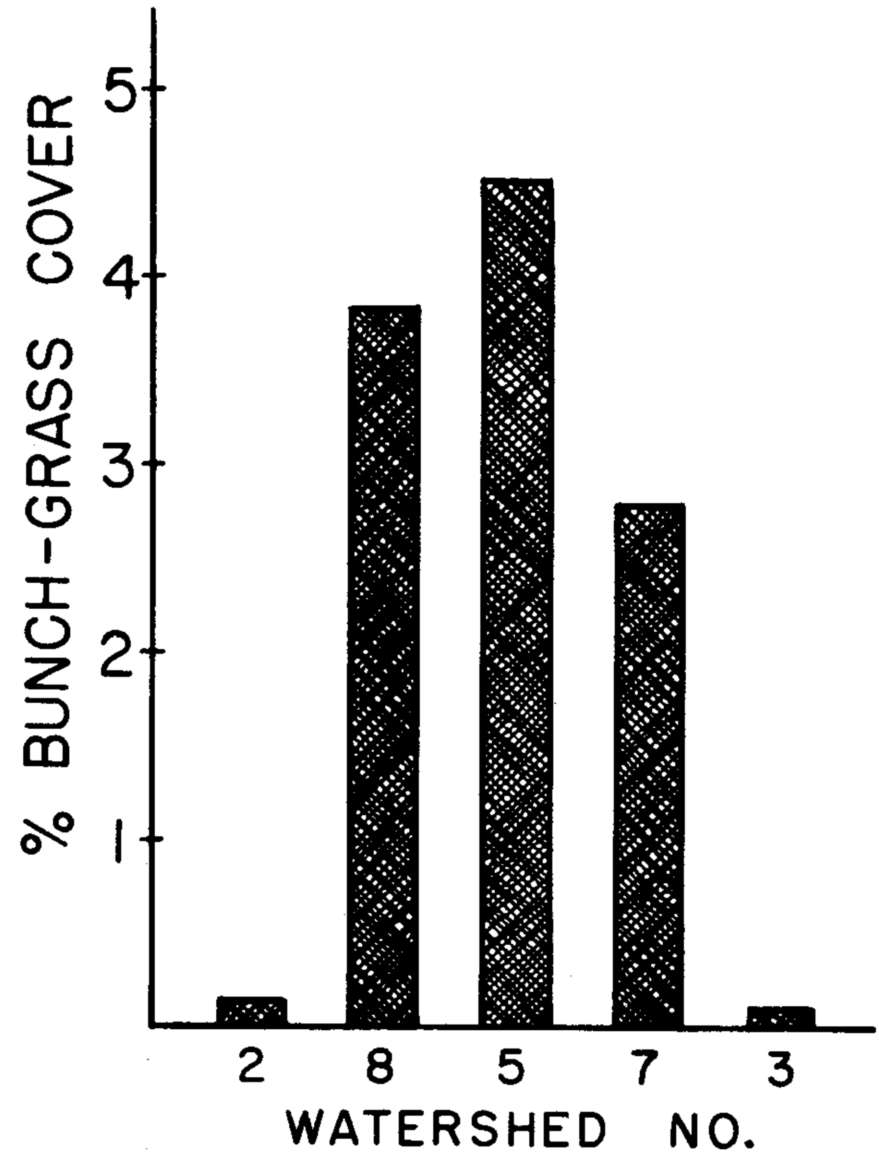


Fig. 12. Bunch grass cover in five study areas. Microwatersheds 2 and 8 are in exclosures, 5 is lightly grazed, 7 is moderately grazed, and 3 is heavily grazed. See the text for further information on exclosure 2.

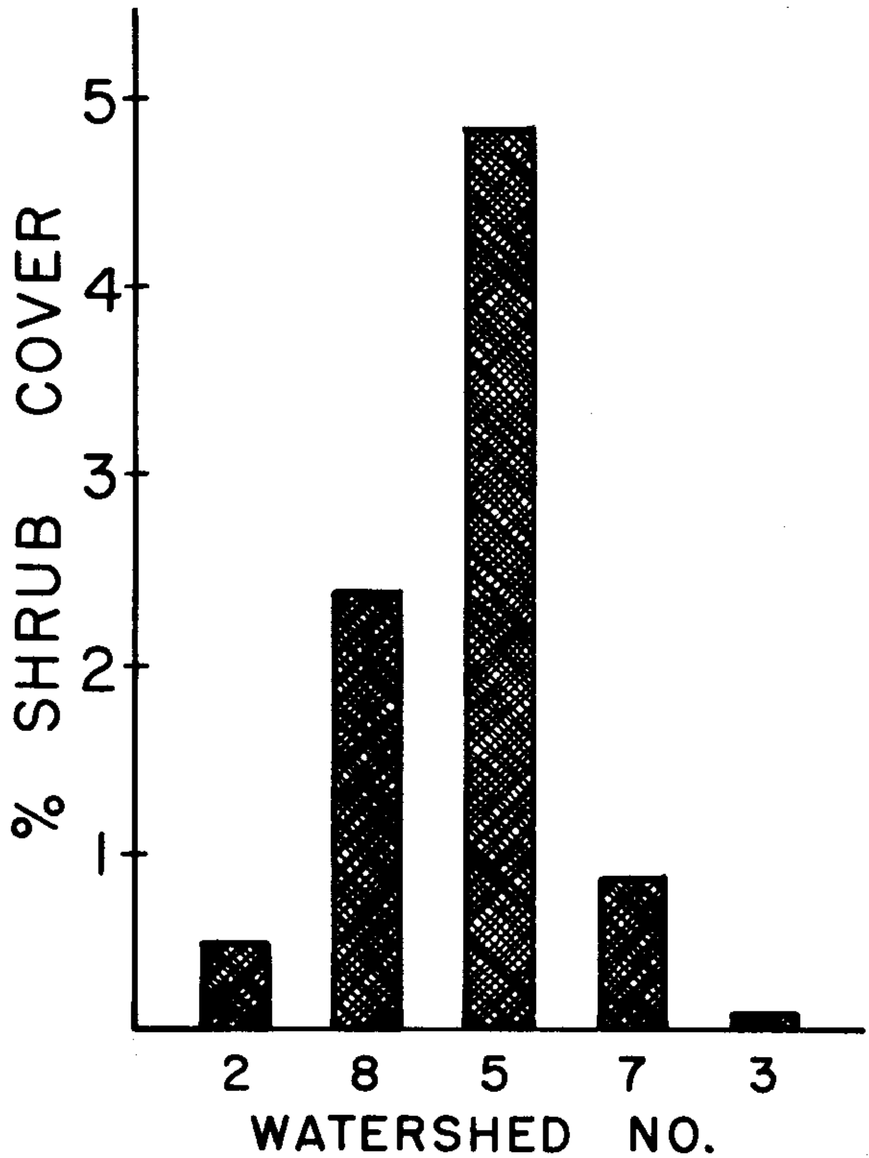


Fig. 13. Shrub cover on five study areas. Microwatersheds 2 and 8 are in exclosures, 5 is lightly grazed, 7 is moderately grazed, and 3 is heavily grazed.

## Percent Bare Ground

Fig. 14 shows the percentage of each study area without vegetation cover, root crown cover, or mulch cover. Note that the amount of bare ground is not very different in the three grazed study areas, but that these grazed areas have over 150% more bare ground than the exclosures. The question to be answered is whether this difference is of much significance to runoff, infiltration, evapotranspiration, or other aspects of ecosystem function.

## Percent Vegetation Cover From Various Solar Angles

Using the point quadrat method, it was possible to calculate the percent cover from various solar angles. This seemed to be a parameter worth measuring, since estimates could then be made of the amount of direct light intercepted by the vegetation at different times during the day, potentially useful information for predicting rates of photosynthesis.

The data gathered on two different days are summarized in Fig. 15. It is apparent that the least amount of direct light interception would be during mid-day when the sun is overhead. Early or later in the day, a larger amount of light would be intercepted. This could have been predicted, since most of the leaves are angled or vertical, but the magnitude of the differences was unknown. Whether this information is really relevant or not to ecosystem function depends on the effectiveness of diffuse light as a driving force on a cloudless day, a question still unanswered for the Pawnee Grassland. It is interesting, however, that on several days during the summer, photosynthesis had stopped by 11:00 A.M., presumably due to stomatal closure (A. J. Dye, personal communication). A cover measurement made with vertical pins could, therefore, be less relevant to photosynthetic rate than a

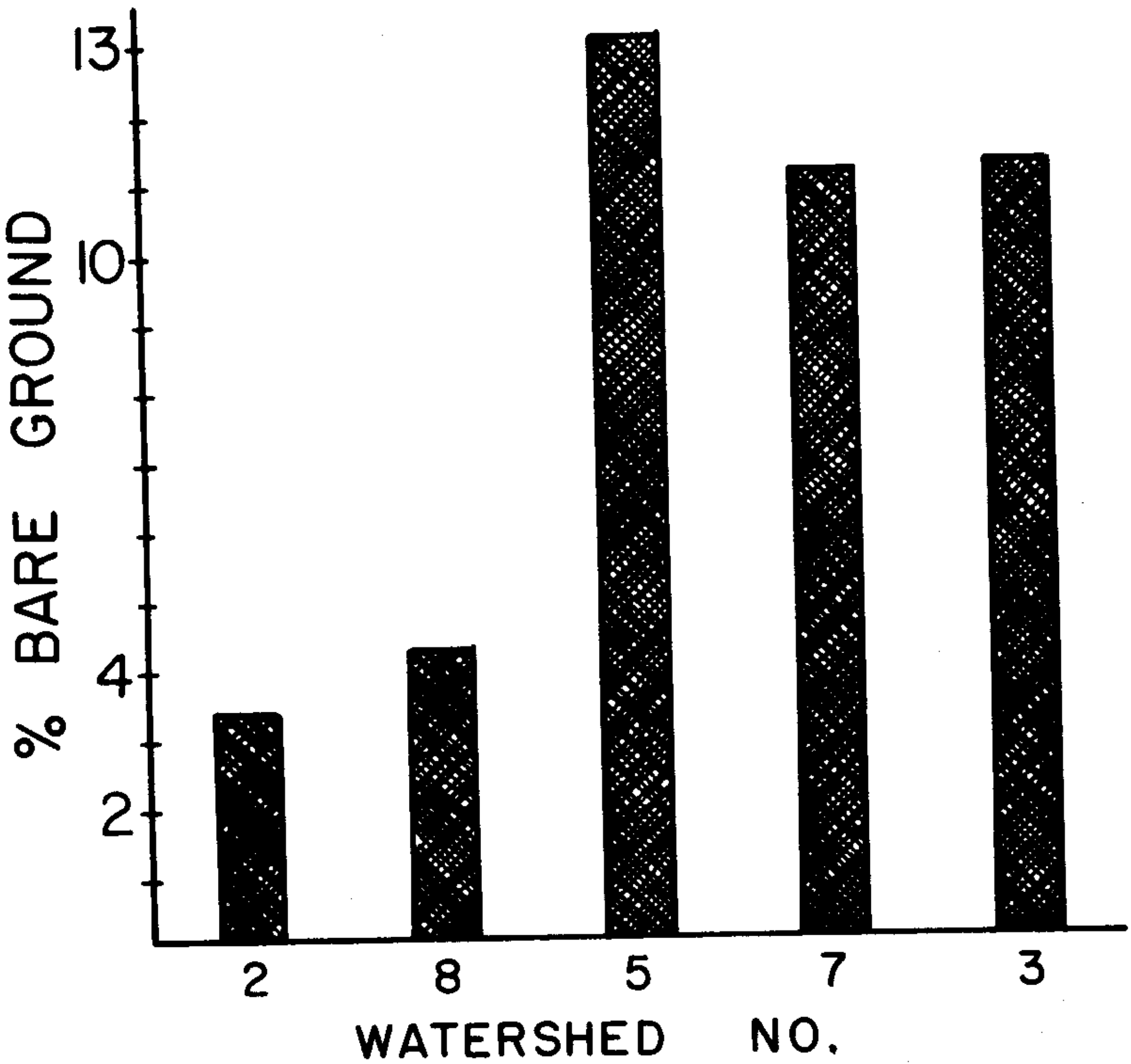


Fig. 14. Percent bare ground in five study areas. Grazing intensity increases from left to right; microwatersheds 2 and 8 are in exclosures, 5 is lightly grazed, 7 is moderately grazed, and 3 is heavily grazed.

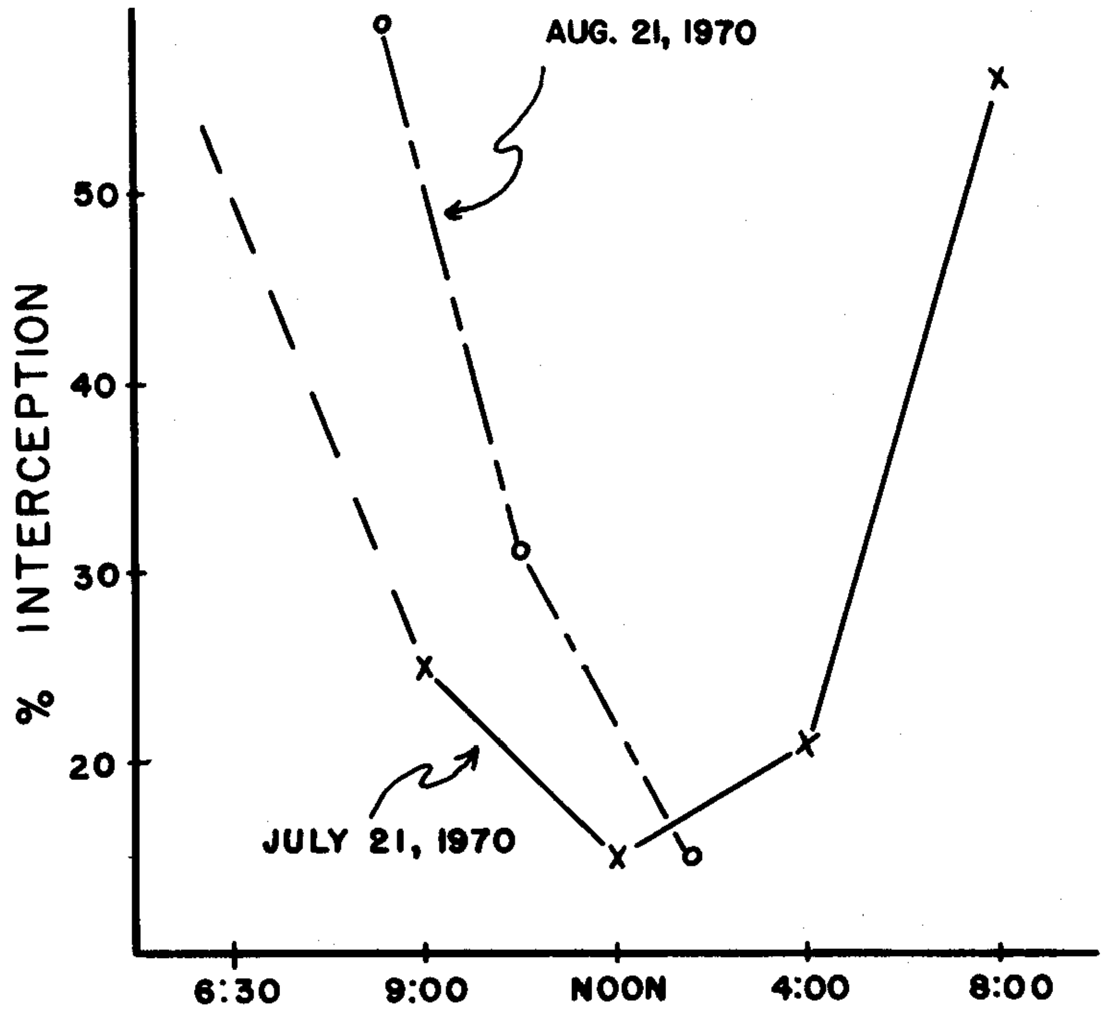


Fig. 15. Percent interception (or cover) at various times on two separate days. See the text for methods.

measurement made with pins parallel to the sun's rays previous to the time of stomatal closure.

The differences in Fig. 15 that emerge for the two sampling dates are probably explained in terms of photoperiod change; additional measurements will be made in 1971 to clarify the interaction between day length and growth stage.

Mulch Cover

Mulch cover was measured using the point quadrat method; the results are presented in Fig. 16. The lowest mulch cover (42%) was in the heavily grazed unit 3, and the next lowest in the adjacent exclosure 2. The lightly and moderately grazed microwatersheds were higher and not particulary different, both about 49%.

The mulch cover on exclosure 2 was observed to increase from 43% to 51% following a heavy rainstorm (Fig. 17), suggesting that the transfer of standing dead to the mulch compartment may be hastened by the impact of rainfall.

Vegetation Height

Fig. 18 summarized the data on vegetation height, a feature that was measured only once during the growing season, on August 20, after the peak biomass had been reached. Vegetation height was greatest in exclosure 2, least in heavily grazed unit 3, and intermediate in the lightly and moderately grazed units (5 and 7).

The clumps of *Opuntia polyacantha* in the heavily grazed study area 3 had a noticeable influence on vegetation height (Fig. 18). The spines apparently discouraged grazing in the cactus clumps, and consequently, the vegetation there was about 5.7 cm tall instead of the average 2.7 cm for the vegetation outside the cactus clumps. It is interesting, however, that the

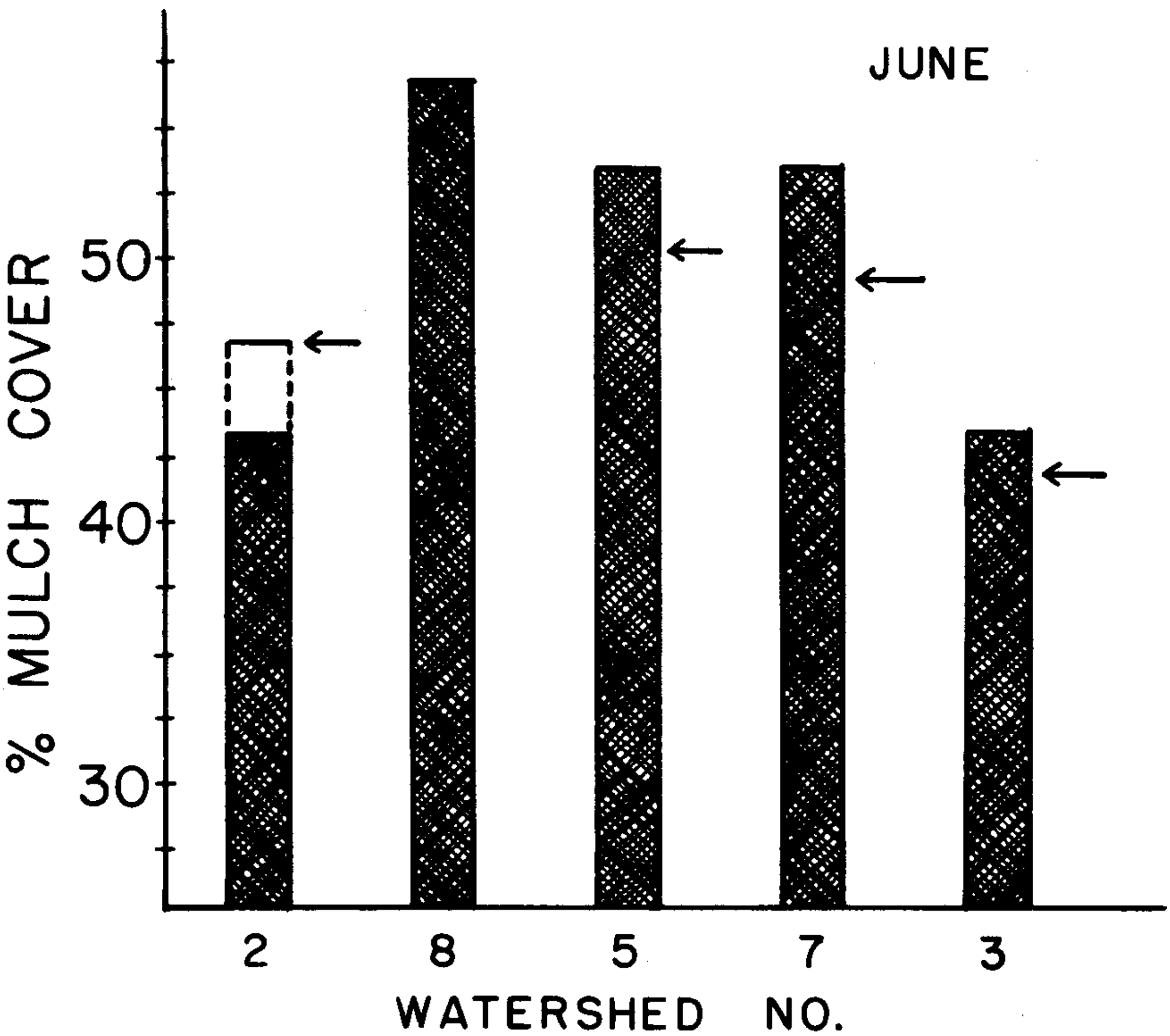


Fig. 16. Percent mulch cover in five study areas arranged in order of increasing grazing intensity from left to right. Microwatersheds 2 and 8 are exclosures, 5 is lightly grazed, 7 is moderately grazed, and 3 is heavily grazed. All values are for June, except no. 8 which was measured only in August; the arrows indicate the average of the June, July, and August cover estimates.

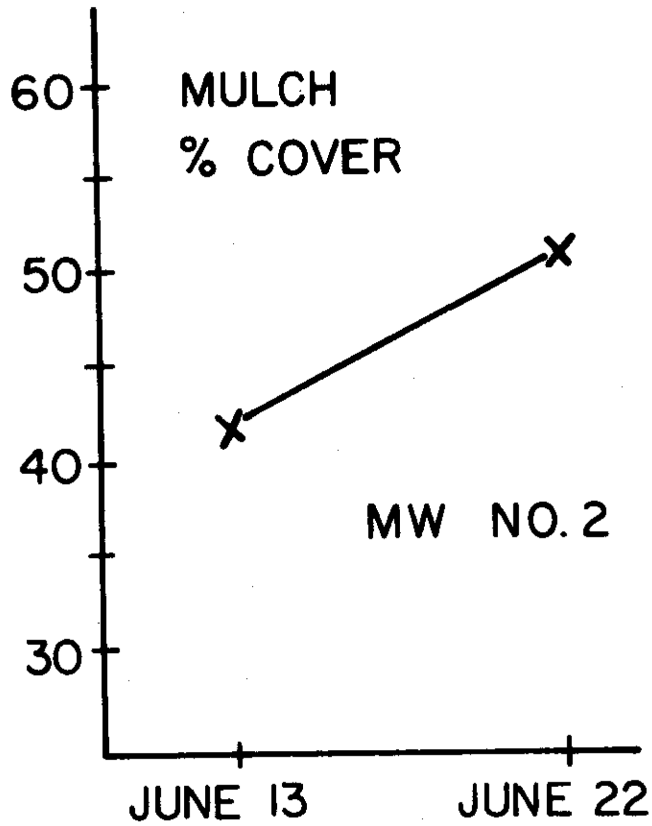


Fig. 17. Percent mulch cover on June 13 and June 22 in microwatershed 2, an exclosure. A heavy rain occurred shortly after the first date.

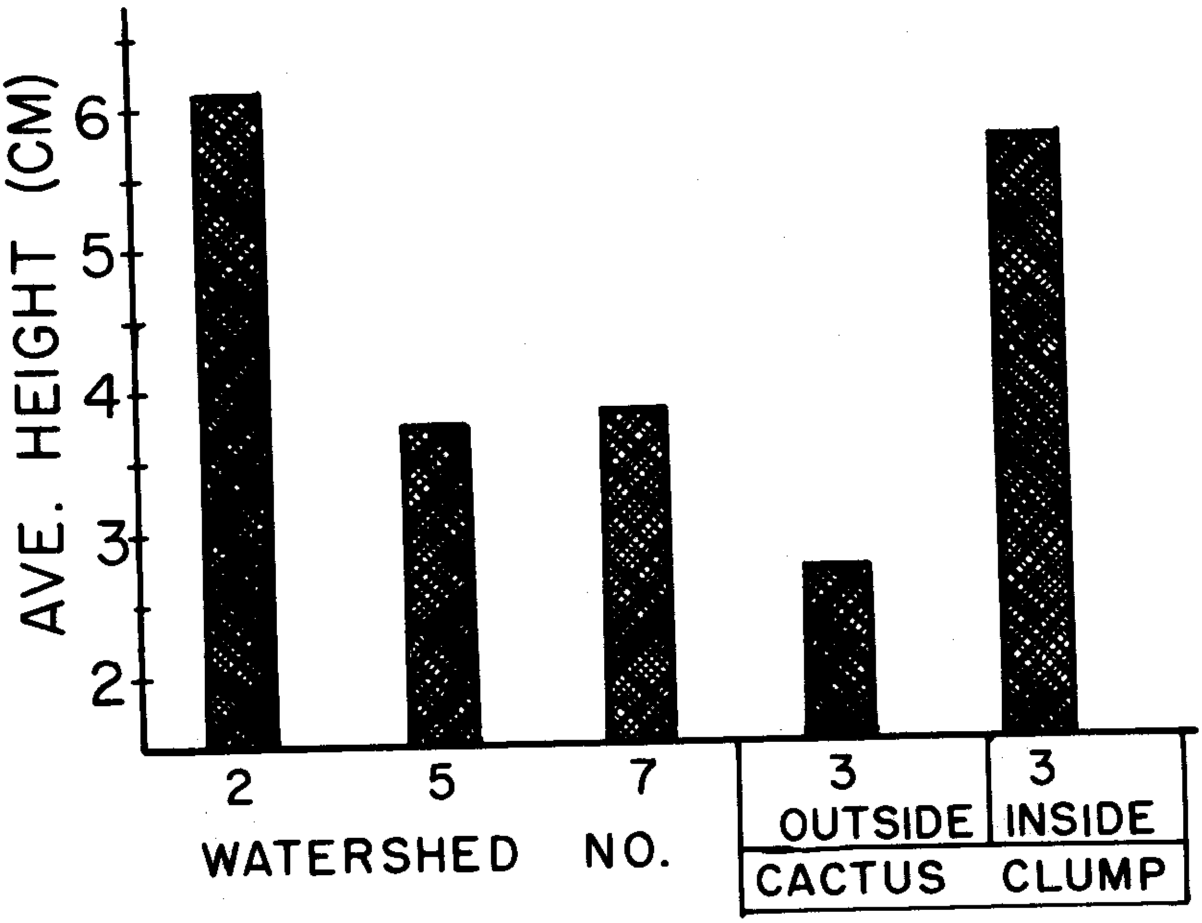


Fig. 18. Average vegetation height in the four principal study areas, each subject to a different grazing intensity. Microwatershed 2 is an exclosure, 5 is lightly grazed, 7 is moderately grazed, and 3 is heavily grazed. Measurements were made only to the top leaves.

foliage density of *Bouteloua gracilis* green was only slightly higher in the cactus clumps, Fig. 19.

## DISCUSSION

There is little need for further discussion of the results presented in this report. The data on vegetation structure can now be used for ecosystem simulation and, hopefully, for evaluating the magnitude of the vegetative influence on various aspects of ecosystem function. This work remains to be done.

Of the measurements on vegetation structure, the most useful will probably be leaf area index, percent cover by solar angle, and percent bare ground. Numerous papers have shown the relationship of LAI to photosynthesis, and very likely, the index is related to evapotranspiration and plant water stress as well. A usefull goal, I believe, would be to express Pawnee productivity as a function of LAI, net radiation, and leaf water stress; or to express leaf water stress as a function of soil moisture, atmospheric moisture, and LAI. Other models are possible. Percent cover by solar angle may prove more relevant than LAI, and percent bare ground is, apparently, an important parameter for evaluating runoff and infiltration.

The seasonal changes in LAI are considerable. If leaf area is found to be a significant flux modifier on the Pawnee Grassland, then the proposed dynamic models should incorporate these seasonal changes, perhaps as a rate of LAI increase or decrease. Leaf maturity and leaf hydration would also be relevant, however, in addition to just leaf area. In other words, a given amount of green leaf area in July may not be as effective for photosynthesis as the same leaf area in June. Another possibility is that the transpiration

| | INSIDE CACTUS CLUMP | OUTSIDE CACTUS CLUMP | WATER SHED NO. |
|---|---|---|---|
| BOUTELOUA GREEN (AVE. CONTACTS PER PIN) | .16 | .18 | 2 |
| | .18 | .15 | 3 |

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Fig. 19. Foliage density for *Bouteloua gracilis* green, expressed as the average number of contacts per 32.5° pin, inside and outside the cactus clumps of microwatershed 2 (exclosure) and 3 (heavily grazed).

rate is less in July than June, even though the green LAI is the same. This latter possibility might happen if the stomata are open more frequently in June. The influence of leaf area is probably non-linear; the need for more research is apparent.

Another aspect of ecosystem function is the transfer rate of plant material from one compartment to another. Measuring brown LAI and mulch cover with the point quadrat method, as well as green LAI, provides an opportunity to determine transfer rates between standing live and standing dead (leaf mortality), and between standing dead and mulch. Of course, as noted previously, herbivores tend to complicate the system.

The immediate need for information on vegetation structure is for a dynamic simulation of the Pawnee ecosystem and for evaluating vegetative influences in short grass prairie. The data presented in this report, however, should be useful also for intra- and interbiome comparisons, both nationally and internationally. It is likely that comparisons in terms of LAI and cover by growth form will be much more useful than a species by species comparison.

Other aspects of vegetation structure could have been measured, e.g., leaf angle or LAI by height strata. These were not measured in 1970, but could be in the future if the measurements of ecosystem function are sufficiently accurate to merit the extra work required. Species diversity is another structural feature of considerable interest and could be calculated for Pawnee using the available biomass data. Information on vegetation spatial patterns is also available for the Pawnee Grassland (see reports by Fisser and Lester). Of particular importance in this connection may be the spacing and density of the cactus clumps in the heavily grazed management unit; they contribute considerable heterogeneity to the vegetation.

## ACKNOWLEDGMENT

I was fortunate to have the assistance of two very capable students during the summer of 1970, Mike Evans and the late Tom Malloy. Tom was proving to be an exceptionally capable student of ecology before his untimely death.

I am also grateful to Dr. Donald Jameson for his ideas in connection with the work on vegetation cover at different solar angles, and to Mr. Dan Uresk for providing data on vegetation biomass. Mr. Howard Roberts, head of the University of Wyoming Mechanical Engineering Shop, was most helpful in the construction and maintenance of our motorized point frames.

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# APPENDIX I

## Table of Leaf Area Indices

### Total Green LAI

| Watershed No. | General Ground Cover LAI | Shrub LAI | Bunch Grass LAI | Cactus LAI | Total LAI |
|---|---|---|---|---|---|
| March 27, 1970 | | | | | |
| 2 | 0.0006 | | | | |
| 8 | 0.0009 | | | | |
| May 2, 1970 | | | | | |
| 2 | 0.02 | | | | |
| 8 | 0.02 | | | | |
| June 1, 1970 | | | | | |
| 2 | 0.34 | | | | |
| 8 | 0.42 | | | | |
| June 15, 1970 | | | | | |
| 2 | 0.49 | 0.006 | 0.001 | 0.004 | 0.50 |
| 5 | 0.40 | 0.02 | 0.002 | 0.006 | 0.43 |
| 7 | 0.48 | 0.003 | 0.001 | 0.003 | 0.49 |
| 3 | 0.55 | 0.0 | 0.001 | 0.007 | 0.56 |
| June 22, 1970 | | | | | |
| 2 | 0.49 | | | | |
| July 8, 1970 | | | | | |
| 3 | 0.31 | | | | |
| July 15, 1970 | | | | | |
| 2 | 0.39 | 0.007 | 0.008 | 0.004 | 0.41 |
| 5 | 0.33 | 0.02 | 0.02 | 0.006 | 0.38 |
| 7 | 0.33 | 0.004 | 0.007 | 0.003 | 0.34 |
| 3 | 0.37 | 0.0 | 0.001 | 0.007 | 0.38 |
| 8 | 0.31 | | | | |
| August 13, 1970 | | | | | |
| 2 | 0.26 | 0.005 | 0.008 | 0.004 | 0.28 |
| 5 | 0.12 | 0.02 | 0.02 | 0.006 | 0.17 |
| 7 | 0.13 | 0.003 | 0.008 | 0.003 | 0.14 |
| 3 | 0.15 | 0.0 | 0.0005 | 0.007 | 0.16 |

Appendix I (continued)

Total Green and Brown LAI

| Watershed No. | General Ground Cover LAI | Shrub LAI | Bunch Grass LAI | Cactus LAI | Total LAI |
|---|---|---|---|---|---|
| June 15, 1970 | | | | | |
| 2 | 0.77 | 0.006 | 0.001 | 0.005 | 0.78 |
| 5 | 0.77 | 0.02 | 0.003 | 0.007 | 0.80 |
| 7 | 0.75 | 0.003 | 0.001 | 0.004 | 0.76 |
| 3 | 0.81 | 0.0 | 0.002 | 0.008 | 0.82 |
| June 22, 1970 | | | | | |
| 2 | 0.66 | | | | |
| July 8, 1970 | | | | | |
| 3 | 0.40 | | | | |
| July 15, 1970 | | | | | |
| 2 | 0.67 | 0.008 | 0.01 | 0.005 | 0.69 |
| 5 | 0.43 | 0.022 | 0.03 | 0.007 | 0.49 |
| 7 | 0.38 | 0.004 | 0.01 | 0.004 | 0.40 |
| 3 | 0.55 | 0.0 | 0.002 | 0.008 | 0.56 |
| July 28, 1970 | | | | | |
| 8 | 0.43 | | | | |
| August 15, 1970 | | | | | |
| 2 | 0.45 | 0.006 | 0.01 | 0.005 | 0.47 |
| 5 | 0.27 | 0.02 | 0.03 | 0.007 | 0.33 |
| 7 | 0.35 | 0.003 | 0.01 | 0.004 | 0.37 |
| 3 | 0.39 | 0.0 | 0.007 | 0.008 | 0.41 |

Appendix I (continued)

*Bouteloua* Green LAI

| Watershed No. | General Ground Cover LAI | Shrub LAI | Bunch Grass LAI | Cactus LAI | Total LAI |
|---|---|---|---|---|---|
| June 15, 1970 | | | | | |
| 2 | | 0.30 | | | |
| 5 | | 0.33 | | | |
| 7 | | 0.38 | | | |
| 3 | | 0.48 | | | |
| June 22, 1970 | | | | | |
| 2 | | 0.26 | | | |
| July 8, 1970 | | | | | |
| 3 | | 0.28 | | | |
| July 15, 1970 | | | | | |
| 2 | | 0.30 | | | |
| 5 | | 0.26 | | | |
| 7 | | 0.25 | | | |
| 3 | | 0.36 | | | |
| July 28, 1970 | | | | | |
| 8 | | 0.25 | | | |
| August 15, 1970 | | | | | |
| 2 | | 0.16 | | | |
| 5 | | 0.08 | | | |
| 7 | | 0.11 | | | |
| 3 | | 0.15 | | | |

Appendix I (continued)

*Bouteloua* Brown LAI

| Watershed No. | General Ground Cover LAI | Shrub LAI | Bunch Grass LAI | Cactus LAI | Total LAI |
|---|---|---|---|---|---|
| June 15, 1970 | | | | | |
| 2 | | 0.22 | | | |
| 5 | | 0.21 | | | |
| 7 | | 0.24 | | | |
| 3 | | 0.25 | | | |
| June 22, 1970 | | | | | |
| 2 | | 0.11 | | | |
| July 8, 1970 | | | | | |
| 3 | | 0.17 | | | |
| July 15, 1970 | | | | | |
| 2 | | 0.26 | | | |
| 5 | | 0.12 | | | |
| 7 | | 0.11 | | | |
| 3 | | 0.16 | | | |
| July 28, 1970 | | | | | |
| 8 | | 0.11 | | | |
| August 15, 1970 | | | | | |
| 2 | | ≅ 0.26 | | | |
| 5 | | ≅ 0.24 | | | |
| 7 | | 0.17 | | | |
| 3 | | ≅ 0.40 | | | |

# APPENDIX II

## Table of Values for Percent Cover by Growth Form

| Watershed No. | Shrub Cover | Succulent Cover | Bunch Grass Cover |
|---|---|---|---|
| 2 | 0.5 | 0.5 | 0.2 |
| 8 | 2.4 | 0.1 | 3.8 |
| 5 | 4.8 | 0.4 | 4.5 |
| 7 | 0.8 | 0.5 | 2.7 |
| 3 | 0.01 | 1.2 | 0.2 |