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Leaf area, visual obstruction, and standing crop relationships on Sandhills rangeland

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Abstract

The objective of this study was to determine if leaf area index (LAI) or visual obstruction (VO) could be used in an efficient double-sampling format for estimating total above-ground standing crop on upland range sites in the Nebraska Sandhills. Sampling was conducted in pastures used for summer grazing research in which treatments consisting of stocking at 16, 32, or 48 animal-unit-days (AUD) ha^{-1} in June or July and an ungrazed control that were replicated 3 times. During trial 1, LAI, VO, and yield of standing crop were measured in 1995 and 1996 at 12 random sampling sites in each of twenty-one, 1.0-ha pastures. Trial 2 compared modified LAI and VO sampling procedures against those used in trial 1. Modifications included the use of a circular 0.25 m^2 sample plot area rather than a rectangular one and increasing both the number of LAI and visual obstruction readings that were used in the calculation of the mean value at each sampling site. During trial 2, data were collected from 12 sampling sites within each of 14 pastures that comprised 2 blocks of grazing treatments. There was a significant ($P<0.01$) linear relationship between LAI and yield of standing crop during trial 1, but only 33% of the variation in standing crop was attributable to LAI. The modified LAI sampling procedure increased R^2 to 0.59. Similarly, the relationship between visual obstruction and standing crop was significant ($P<0.01$), but R^2 values were only 0.31 and 0.41 during the first and second years of trial 1, respectively. The modified visual obstruction (VO) sampling procedure resulted in only minimal R^2 improvement compared to the trial 1 method. Pooling LAI or VO data for individual sample sites into stocking rate means resulted in the detection of significant ($P<0.01$) quadratic relationships between fall LAI or VO and summer stocking rate. Based on the sampling procedures used in this study, neither LAI nor VO would be useful as direct predictors of total standing crop at individual sample locations on upland range sites in the Nebraska Sandhills. However, with pastures as experimental units, these methods can detect the relative effects of stocking rate with replicated treatments.

Key Words: total above-ground biomass, double-sampling, LAI, plant canopy analysis

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Resumen

El objetivo de este estudio fue determinar si el índice de área foliar (IAF) o la obstrucción visual (OV) pudieran ser utilizados en un formato eficiente de doble-muestreo para estimar la cosecha en pie aérea total de los sitios de pastizal altos de Nebraska Sandhills. El muestreo se condujo en potreros utilizados para investigación de apacentamiento en verano, en la que los tratamientos fueron cargas animal de 16, 32 o 48 unidades-animal-día ha^{-1} en Junio o Julio y un control sin apacentamiento, los tratamientos tuvieron 3 repeticiones. Durante el ensayo 1, el IAF, la OV y el rendimiento de la cosecha en pie se midieron en 1995 y 1996 en 12 sitios de muestreo elegidos aleatoriamente en cada uno de los 21 potreros de 1 ha. En el ensayo 2 se compararon los métodos de muestreo modificados para el IAF y OV contra los utilizados en el ensayo 1. Las modificaciones incluyeron el uso de una parcela de muestro circular de 0.25 m^2 en lugar de una rectangular e incrementando el número de lecturas tanto para el IAF como para la OV y que fueron utilizadas para calcular el valor de la media de cada sitio de muestreo. En el ensayo 2, los datos se colectaron en 12 sitios de muestreo dentro de cada uno de los 14 potreros que comprendían 2 bloques de tratamientos de apacentamiento. En el ensayo 1 hubo una relación lineal significativa ($P<0.01$) entre el IAF y la cosecha en pie, pero solo el 33% de la variación de la cosecha en pie fue atribuible al IAF. El muestreo modificado de IAF incremento el R^2 a 59%. De igual manera, la relación entre la OV y cosecha en pie fue significativa ($P<0.0$ 1), pero los valores de R^2 fueron solo del 0.31 y 0.41 durante el primer y segundo años del ensayo 1 respectivamente. El procedimiento modificado de muestreo de OV resulto en un mejoramiento mínimo de los valores de R^2 comparado con el método del ensayo 1. La combinación de los datos de IAF y OV para cada sitio individual de muestreo con las medias de carga animal resulto en la detección de una relación cuadrática significativa ($P<0.01$) entre el IAF y la OV de otoño y la carga animal de verano. Basado en los procedimientos de muestreo utilizados en este estudio, ni el IAF ni la OV son útiles para predecir directamente la cosecha en pie total a nivel de localidad individual de muestreo de los sitios de pastizal elevados de Nebraska Sandhills. Sin embargo, con los potreros como unidades experimentales y con tratamientos repetidos, estos métodos pueden detectar los efectos relativos de la carga animal.

Standing crop or above-ground herbage biomass is an important quantitative variable needed in grazing studies and in the characterization of plant communities. Estimation of standing crop has traditionally been accomplished by hand-clipping, drying, and weighing vegetation from plots of known area. This technique is slow, labor intensive, and destructive. Several methods utilizing remote sensing for non-destructive standing crop estimation were reviewed by Tucker (1980). Others have used double-sampling procedures where hand-clipping was combined with visual weight estimation (Pechanec and Pickford 1937), disk meters (Sharrow 1984), or electronic capacitance meters (Neal and Neal 1981). Success has ranged from poor to excellent. Plant growth stage and plant community type were 2 important factors associated with the accuracy and precision of some of these approaches.

Non-destructive vegetation analysis can be accomplished with a plant canopy analyzer (Welles and Norman 1991) which provides rapid estimations of leaf area index (LAI) and quantifies other characteristics of canopy architecture. This technology has been used to quantify architecture of field crops and to characterize forage utilization intensity on rangeland (Miller-Goodman et al. 1999). Another non-destructive method of measuring vegetation involves visual obstruction. In studies in northeastern Kansas, Robel et al. (1970) found a significant correlation between visual obstruction (VO) and total standing crop. Obstruction measurements were taken by visually sighting towards a round pole that had alternating decimeters painted brown and white. The lowest decimeter mark visible on the pole was recorded as the obstruction measurement. Visual obstruction data are collected and used by several state and federal land management agencies for the purpose of monitoring grazing practices and the status of wildlife habitat; particularly for upland game birds, where density and height of vegetation are important factors (Price 1987, PGTC 1995). The objectives of this study were to quantify the relationship of LAI and VO to standing crop, the relationship of LAI to VO, and the effects of summer stocking rate and grazing pressure on fall LAI and VO on upland range sites in the Nebraska Sandhills. Correspondingly, the potential of using LAI or VO methods in a double-sampling technique to estimate standing crop was evaluated.

Materials and Methods

The study was conducted at the University of Nebraska, Gudmundsen Sandhills Laboratory, 11 km northeast of Whitman, Neb. Soils of the study pastures are Valentine fine sands (mixed mesic Typic Ustipsamment) derived from an eolian sand parent material. Vegetation is dominated by mid and tall grasses including little bluestem, [*Schizachyrium scoparium* (Michx.) Nash], sand bluestem (*Andropogon hallii* Hack.), and prairie sandreed [*Calamovilfia longifolia* (Hook.) Scribn.]. Other common species are hairy grama (*Bouteloua hirsuta* Lag.), sand dropseed [*Sporobolus cryptandrus* (Torr.) Gray], prairie junegrass [*Koeleria macrantha* (Ledeb.) Schult.], switchgrass (*Panicum virgatum* L.), western ragweed (*Ambrosia psilostachya* DC.), and sedges (*Carex* spp.).

Leaf area index (LAI), visual obstruction (VO), and standing crop sampling was conducted in twenty-one, 1-ha pastures in which 7 grazing treatments were replicated 3 times. Treatments were stocking rates of 16, 32, and 48 animal-unit-days (AUD) ha^{-1} in either June or July and an ungrazed control. Treatments resulted in a range of mean standing crop values of 880 to 2,810 kg ha^{-1} in October.

Leaf area index measurements were taken using a LICOR LAI-2000 plant canopy analyzer[1]. Operational theory of this instrument is based on radiation interception and measurements of how quickly radiation is attenuated as it passes through a vegetation canopy (LI-COR Inc. 1991). The probability of radiation interception is related to foliage orientation and is proportional to path length and foliage density (Welles and Norman 1991). A complete sampling sequence first requires a measurement of sky brightness with the sensor held above the canopy followed by 1 or more readings taken below the canopy. The sensor utilizes fisheye optics to project a hemispheric image of the canopy onto 5 silicon detectors that are arranged in concentric rings. A microcomputer processes the data and calculates leaf area index (LAI), leaf mean tilt angle (foliage orientation), and standard errors. Attenuation of diffuse sky radiation is measured simultaneously at 5 zenith angles (7°, 23°, 38°, 53°, and 68°). The ratio of each ring's signals (below to above) is then assumed to be equivalent to the canopy's gap fraction at that ring's viewing angle. By measuring attenuation at several angles from the zenith, foliage orientation information also can be obtained (Welles and Norman 1991).

An important consideration for the sensing optics is some restriction to mask out the operator or the sun. For this study, an opaque cover that restricted the viewing area to 45° was placed on the sensor. Welles and Norman (1991) and Miller-Goodman et al. (1999) also recommended this narrower field of view to correctly integrate gaps and canopy structure that are characteristic of heterogeneous vegetation with large gaps. Our sampling took place on days that ranged from mostly sunny to cloudy. Under sunny conditions, the area surrounding the sensor was shaded with an umbrella because sunlit leaves detected by the sensor would have underestimated LAI.

Equipment used for visual obstruction (VO) measurement was similar in design to that used by Robel et al. (1970). Our equipment consisted of 2 poles (3 cm diameter X 120 cm length) that were connected by a nylon cord fastened at a height of 1 m on each pole. Length of the cord was 4 m. The reading pole was painted in 36 alternating bands (2.54 cm wide) of gray and white. The bands were numbered in ascending order beginning with 1 at the bottom. The procedure for visual obstruction measurement consisted of 1 person holding the reading pole vertically in the center of a 0.25 m^2 quadrat area. A second person, the observer, would place the other pole at a distance of 4 m. Looking from a height of 1 m, the observer would read the number of the lowest band not obstructed by vegetation.

Trial 1

Trial 1 was conducted in October 1995 and 1996. Within each of the 21 pastures, 3 stratified transects were

[1]LI-COR Incorporated, 4421 Superior Street, Lincoln, Neb 68504.

Mention of a trade name or product does not constitute a recommendation or endorsement for use by the University of Nebraska.

established with each transect having 4 randomly selected sampling sites (252 total per year). At each sample site, LAI and VO measurements were taken followed by the centering of a 25 × 100 cm quadrat frame (0.25 m^2) over the sampling point and hand-clipping all vegetation, current- and preceding-year's herbage, to a height of 2 cm. The canopy analyzer measures light attenuation above the 2 cm height. Harvested material was oven-dried at 60°C to a constant weight.

The procedure for leaf area index (LAI) measurements consisted of programming the instrument for an above-canopy calibration reading followed by 3 below-canopy readings (3 LAI measurements). Below-canopy readings were with the sensor on the soil surface at 3 locations (33, 67, and 100 cm) along the 100-cm length of the rectangular quadrat area. The mean of the 3 LAI measurements was considered the LAI for the sample site.

Visual obstruction (VO) readings were made from opposite sides of each sample site perpendicular to the predominant slope. If topography prevented both measurements from being taken in the same vertical plane, the observer would take the second reading in the same horizontal plane from a position less than 180° from the first reading point. The mean of the 2 visual obstruction readings was considered the VO for the sample site.

Trial 2

Trial 2 was conducted in March 1997. Based on the results of trial 1, sampling procedures for LAI and VO measurements were modified and compared with procedures used in trial 1 to determine if improvement could be made in the relationship between leaf area index (LAI) and standing crop or visual observation (VO) and standing crop. The modifications included using a circular 0.25 m^2 plot frame rather than a rectangular quadrat and increasing both the numbers of LAI and VO readings that were used to calculate mean values for each sample site.

For trial 2, 12 sampling sites for LAI, VO, and standing crop measurements were selected in each of 14 pastures (168 total). Methods for LAI estimation included (1) 1 above-canopy and 3 below-canopy readings (as in trial 1) and (2) 1 above-canopy and 8 below-canopy readings. For LAI method 1, the 3 below-canopy readings were taken in a straight line through the center of the circular plot area. For the modified LAI method 2, the 8 below-canopy readings were taken with the sensor placed at an equally-spaced distance around the perimeter of the circular plot area. With this method, the unobstructed view of the LAI sensor was always towards the center of the plot.

Methods for determining VO included (1) 2 readings, as in trial 1, and (2) 4 readings, 1 from each cardinal direction. For both LAI and VO methods, the mean of the multiple readings was used as the LAI or VO value for that sample site. After LAI and VO measurements were taken, vegetation in the plot area was hand-clipped to a height of 2 cm and oven-dried at 60°C to a constant weight.

Regression analysis (SAS Institute Inc. 1985) was used to evaluate the relationships of LAI and VO to standing crop, with standing crop as the dependent variable. Visual obstruction data were multiplied by 2.54 to convert readings to cm. Regression analyses were also used to evaluate the relationship between LAI and VO, and the effects of summer stocking rate (AUD ha^{-1}) on fall LAI and VO. The level of probability selected for significance was $P \leq 0.05$.

Results and Discussion

Leaf Area Index

Collecting leaf area index (LAI) data using the canopy analyzer was relatively rapid averaging less than 2 minutes per sample site when taking 3 below-canopy readings. This included walking time in the 1-ha pastures. Mean LAI recorded during sampling in 1995 and 1996 (trial 1) was 0.97, and ranged from 0.08 to 3.12. Mean yield of standing crop during the 2 years was 148.4 g m^{-2} with a range of 15.2 to 656 g m^{-2}. A significant ($P<0.01$) linear relationship occurred between standing crop and LAI during 1995 and 1996. Year did not affect the relationship between LAI and standing crop ($P>0.05$), therefore, data were pooled across the 2 years. The relationship was poor with only 33% of the variation in standing crop being attributable to LAI (Fig. 1).

The mean LAI recorded during trial 2 was 0.83 (range 0.07 to 2.84) using the 3-reading method and 0.80 (range 0.05 to 3.40) using the 8-reading method. Mean standing crop for trial 2 was 125.2 g m^{-2} with a range of 15.6 to 437.2 g m^{-2}. For the 3-reading method, LAI accounted for 16% more of the variation in standing crop in trial 1 than in trial 2 (Fig. 1 and 2a). The 8-reading method resulted in the strongest relationship between LAI and standing crop (R^2 = 0.59) and was most effective in reducing residual differences when LAI was greater than 1.0 (Fig. 2b).

A significant ($P<0.01$) quadratic relationship between fall LAI and summer stocking rate (0, 16, 32, and 48 AUD ha^{-1}) occurred when LAI data for sample sites pooled within stocking rates (Fig. 3). Year had a significant effect ($P<0.01$), and R^2 values were 0.94 in 1995 and 0.71 in 1996. Higher rates of herbage

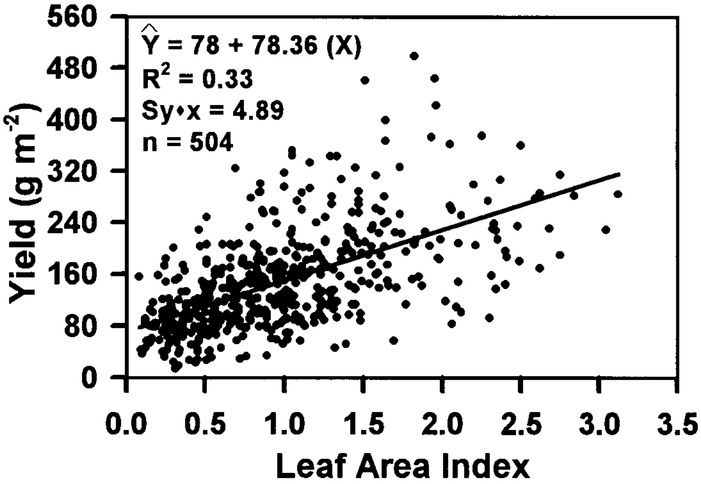

Fig. 1. Relationship between leaf area index (LAI) and standing crop yield in trial 1 during 1995 and 1996. Sy u x is the standard error of the estimate.

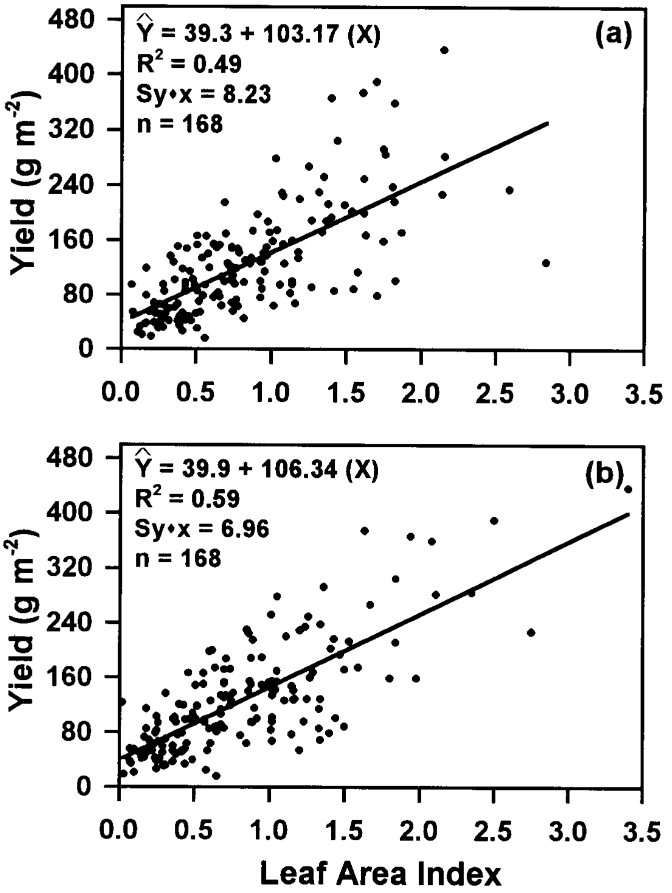

Fig. 2. Relationship between leaf area index (LAI) and standing crop yield (a) using the mean of 3 readings per sample and (b) using the mean of 8 readings per sample in trial 2, 1997. Sy u x is the standard error of the estimate.

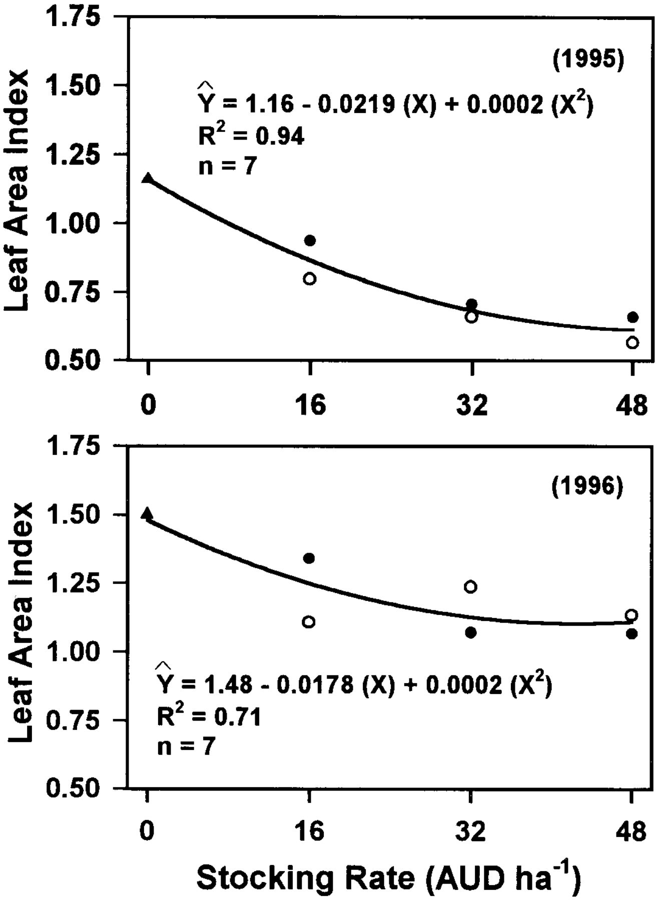

Fig. 3. Effects of stocking rate in June (○) or July (●) on fall leaf area index (LAI) during 1995 and 1996.

production from mid-June to mid-July in 1996 than in 1995 (Cullan 1997), may have caused larger differences between months after light (16 AUD ha^{-1}) and moderate (32 AUD ha^{-1}) stocking rates in respective years. An additional month for plant growth after June grazing (June to October vs. July to October) also contributed variation. Miller-Goodman et al. (1999) reported significant linear relationships (R^2 = 0.95 to 0.99) between change in LAI (pre- and post-grazing) and stocking rate.

Visual Obstruction

The mean visual obstruction (VO) recorded during 1995 and 1996 (trial 1) was 3.6, and the range was from 1.0 to 11.5. There was a significant (P<0.01) linear relationship between VO and standing crop with an 82% greater rate of change in VO per unit change in yield in 1996 than in 1995 (Fig. 4). The relationship was relatively poor with an R^2 value of 0.31 in 1995 and 0.41 in 1996.

During trial 2, mean VO recorded was 2.9 (range 1.0 to 7.5) using the 2-reading method and 3.0 (range 1.0 to 7.3) using the 4-reading method. As in trial 1, a relatively poor linear relationship was observed between VO and standing crop for both methods (Fig. 5). Increasing the number of readings to 4 per sample site accounted for only 8% more of the variance in standing crop than when making 2 readings per site.

Robel et al. (1970) reported an R^2 value of 0.96 when 10 observations per transect were pooled and used to predict standing crop. In contrast, we found pooling observations from 12 sample sites into pasture means did not improve the strength of the relationship between VO and standing crop. Pooling VO data for individual sample sites into stocking rate means resulted in the detection of a significant (P<0.01) quadratic relationship between fall VO and summer stocking rate (Fig. 6). Year had a significant effect (P<0.01), and R^2 values were 0.89 in 1995 and 0.88 in 1996. A similar type of relationship was observed between fall LAI and summer stocking rate (Fig. 3) because of a strong correlation between LAI and VO (r = 0.93 in 1995 and r = 0.71 in 1996). Vegetation type, structure, and density are likely to have a significant affect on VO. The work by Robel et al. (1970) was conducted on several Flint Hills range sites with an average standing crop of about 232 g m^{-2}, 57% more standing crop than during trial 1 and 88% more standing crop than in trial 2 of our study. Vegetation in our study pastures was heterogeneous in terms of basal cover and species composition including short-, mid-, and tall-statured grasses. Robust plants, outside the sampling area clipped for yield, were occasionally located in the line of sight, obstructing the reading pole and providing an over-estimate of VO for herbage harvested inside the sampling area.

Variability in plant type, height, and distribution also can cause a similar type of error when sampling leaf area index (LAI). With minimal canopy cover within the quadrat area, the canopy analyzer optics will sense beyond the boundary of a 0.25 m^2 quadrat. If there was substantial canopy cover in the periphery area, the result would be an over-estimation of LAI for the quadrat area. Increasing quadrat size may have reduced this problem. When hand-clipping for standing crop estimation on the same range type, Brummer et al. (1994) reported that variance was reduced and efficiency improved when quadrat size was increased.

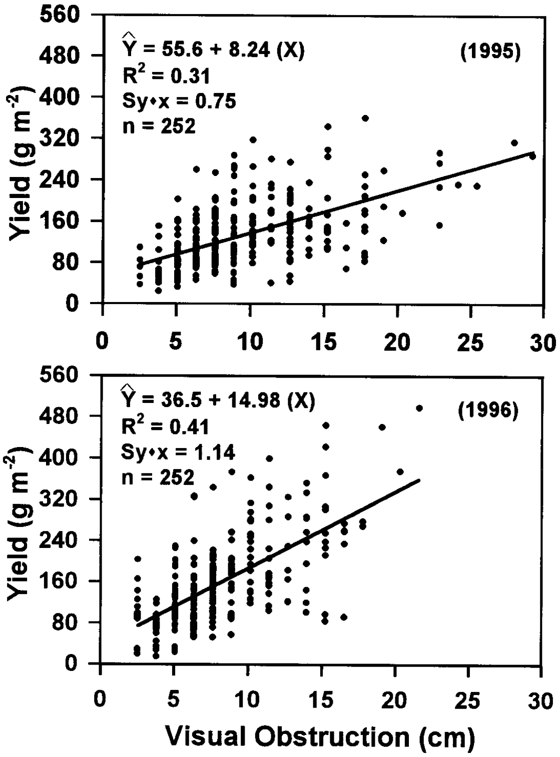

Fig. 4. Relationship between visual obstruction and standing crop yield in trial 1 during 1995 and 1996. SyU x is the standard error of the estimate.

Conclusions

Based on the sampling procedures described, visual obstruction measurements would probably not be useful in a double-sampling technique for prediction of total above-ground herbage standing crop on upland range sites in

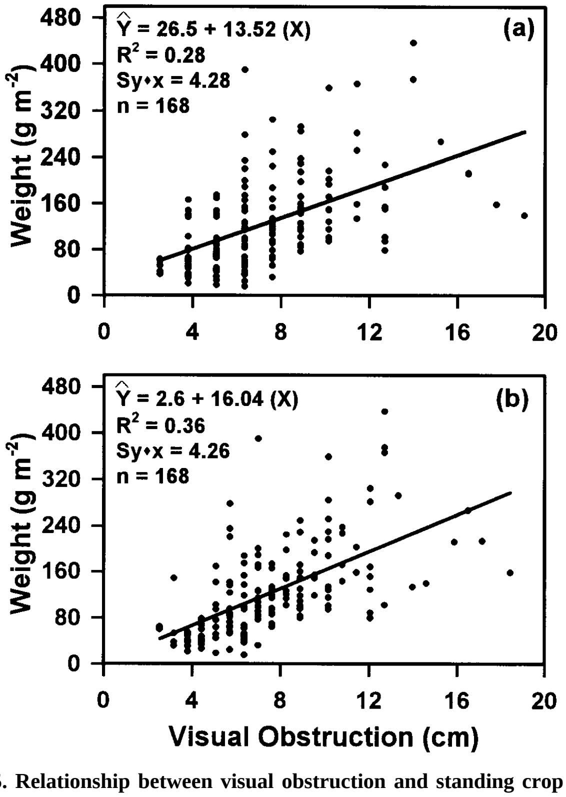

Fig. 5. Relationship between visual obstruction and standing crop yield (a) using the mean of 2 readings per sample and (b) using the mean of 4 readings per sample in trial 2, 1997. SyU x is the standard error of the estimate.

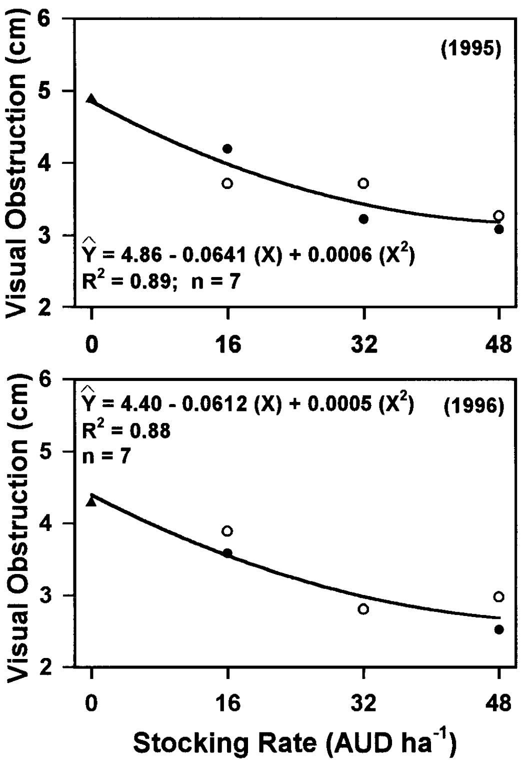

Fig. 6. Effects of stocking rate in June (❍) or July (●) on fall visual obstruction during 1995 and 1996. SyU x is the standard error of the estimate.

the Nebraska Sandhills. Leaf area index and standing crop relationships were generally stronger. Our most successful approach, using 8 below-canopy leaf area index (LAI) readings for a circular 0.25 m^2 plot area, resulted in an R^2 value of 0.59 and a standard error of the estimate of 6.96. However, the strength of this relationship could probably be matched or surpassed using a double-sampling procedure with visual estimates and hand-clipping to estimate yield with lower equipment costs. One disadvantage associated with LAI, visual obstruction (VO), and other indirect sampling methods, is that only the total vegetation weight is estimated. In many situations, it is necessary to distinguish between current- and previous-year's herbage especially when calculating grazing pressure. Additionally, estimates of yield may be needed for individual species or groups.

With replicated pastures, however, canopy analyzer and VO methods can be used to efficiently detect the relative effects of stocking rate treatments. The practical value and/or meaning of this information is important when considering vegetation canopy characteristics and grazing variables, and their association with micro-climate, snow catch, insect populations, or wildlife habitat.

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