Generalized Curves for Gain per Head and Gain per Acre in Rates of Grazing Studies[1]

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A considerable number of degrees-of-grazing studies has been conducted during the past twenty years or more. The purpose of the study here reported was to see if the type of information obtained from the studies was sufficiently consistent to permit the development of a generalized pattern for animal gain under differential rates of stocking. To this end a hodgepodge of data was assembled from publications, progress reports and other sources rather generally available. The contributing studies ranged from Georgia to California and from Texas to North Dakota and represented a wide assortment of livestock, vegetation, climate, management, stocking rates and other variables. It was felt that if such a collection of data should conform to a theoretical function of some type, then this function in all probability must be rather basic and fundamental to the relationship between animal performance and rate of stocking.

Gain per Head Curve

General Form

Information obtained from degrees of grazing studies takes the form indicated in Table 1, insofar as gain per head is concerned. With a few exceptions to be discussed later, the gain per head decreases with increasing stocking rates, but not in a straight line. Cattle on moderately grazed pastures gain more than the arithmetic mean between gains obtained on lightly and heavily grazed pastures. The relationship, if any, must therefore be represented by a curved line. Several plausible curves e.g. logarithmic, exponential, parabolic, were essayed and rejected as not providing realistic fits to the data. The curve shown in Figure 1, however, appeared to give a remarkably good fit. Considering the variety of sources from which these data came and the wide diversity in vegetation, management, experimental procedure, and the complexity of the interaction be-

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Table 1. Average gain per head in some rate-of-stocking studies.

Location	No. Years	Rate of Stocking Light lbs.	Moderate lbs.	Heavy lbs.	Y* lbs.	Reference
Hays, Kans.	9	207	185	130	7.25	(3)
Spur, Tex.	6	148	—	93	5.15	(5)
Mandan, N. D.	17	—	310	230	11.7	(11)
Woodward, Okla. (1)	10	—	301	262	10.5	(9)
Woodward, Okla. (2)	10	400	384	361	13.5	(9)
Alapaha, Geo.	4	161	114	76	6.0	(4)
Sonora, Tex. (1)	5	266	223	172	9.2	(10)
Sonora, Tex. (2)	5	362	274	212	12.2	(10)
Sonora, Tex (3)	5	211	201	165	7.4	Calc.
San Joaquin, Calif. (1)	4	271	281	247	——	(6)
San Joaquin, Calif (2)	4	229	207	155	8.0	(6)
Manitou, Colo.	7	236	222	181	8.3	(7)
Bighorn, Wyo.	3	196	179	160	6.7	(1)
Manhattan, Kans.	6	242	244	222	8.4	(2)

* Value in pounds for each unit of Y used to fit data to the gain per head curve.

tween the biological variables of vegetation and livestock, the approximation of actual data to the theoretical curve seems to be unusual. It is uncommon for biological materials to provide so good a fit to a mathematical function except in growth curves under controlled conditions. But rates of grazing studies using young, growing animals should yield a growth curve of some nature, even though conditions may not be so well controlled as we would like.

The curve as drawn here is a double exponential of the general form $y = 16 - 2^{\frac{2^x}{4}}$. Data from Table 1 were fitted to the curve by simply selecting an appropriate scale for the y values (see table) to account for the wide variation in magnitude of the gains. Slight adjustments to the left or right along the curve were also made, but once one point was fixed the others were also fixed, since the magnitude of x was held constant for all data (Alapaha only excepted). Most of the points so established cluster over the x axis at the points marked as light, moderate, and heavy. A few, however, fall between, and these are of considerable help in extending the curve to the left and right of the well established points.

Points to the Left

Three sets of data fit the curve to the left of the indicated rates of grazing, Figure 2. The Woodward data for summer grazing were obtained from pastures that were intended to be grazed moderately and heavily. The gains per head, however fit the curve a little on the heavy side of light and moderate respectively. This study was conducted for 10 years during the 1940's when conditions were unusually favorable. Those in charge of the experiment frankly admit that during some of these years the intended degrees of use were not obtained, and the moderately grazed pastures were actually close to lightly grazed and the heavily grazed pastures close to moderately grazed. Nevertheless, it is not likely that this was the situation for the average of the whole ten year period. Another explanation is required.

The explanation appears to be in the ecological nature of the vegetation involved. The association is a mixed grass prairie. The most important increasers under use are blue grama and sand dropseed. Both are excellent grasses for the area and provide a substantial amount of high quality forage even under conditions where the taller grasses are much reduced. In the "heavily" grazed pastures, where blue grama and sand dropseed carry the bulk of the grazing load, the nutritional plane is maintained at a high level shoring up the per head gain. Thus, it is evident that the curve is not a stocking rate curve *per se*, but a nutritional curve indicating the relationship between animal performance and the nutritional plane provided at the rates of stocking concerned.

In a similar way the data from yearling grazing at three intensities at Woodward also fit the curve when displaced significantly to the left. This is consistent considering the ecology of the vegetation and also considering the fact that yearlong grazing must be at a lighter rate of stocking than summer grazing. A residue of grass must be left in the fall to carry the animals through the winter. Consequently, the degrees of utilization must be lower in pastures grazed yearlong than in pastures grazed in the summer only.

The data from the Bighorn mountain trial are for only three years, and it is likely that the cumulative effects of the three degrees of use have not yet had time to be fully expressed in vegetative changes. The data are inserted here only because they help to describe the left end of the curve because it would be of interest to see if in future years the values obtained slip down the curve to their proper places. The Bighorn ranges have one feature in common with the Woodward ranges, however, and that is the high nutritive value of the forage. Both areas give very good per head gains, so that similar places on the curve are not altogether unexpected.

Points to the Right

It is difficult to find data to describe the right end of the curve, primarily because the experimenters are very reluctant to graze pastures at rates heavier than those they consider to be al-

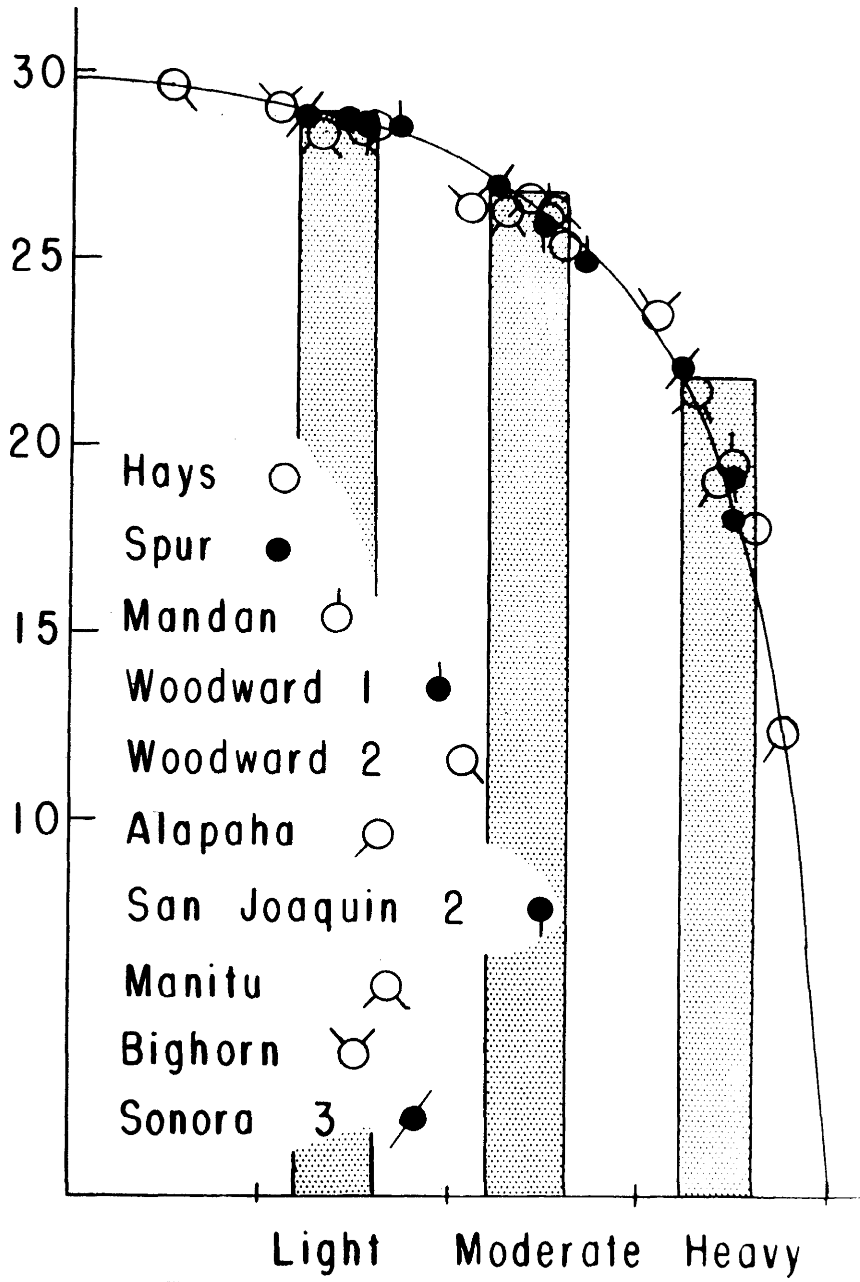

FIGURE 1. Gain per head data fitted to theoretical curve.

ready too heavy. The Georgia data, however, fit the right portion of the curve very closely, Figure 3. It may be that from the vegetational point of view the heavily grazed pastures were not overgrazed, the moderately grazed pastures were properly utilized, etc. But from the nutritional point of view this was obviously not the case. Young, growing animals were on wiregrass pastures from March until October and still gained an average of only 76 pounds per head on the heavily grazed pastures. Nutritionally, the animals were close to starvation whether the vegetation was grazed "heavily" or not. Once again, the curve appears to have validity, but it is a nutritional curve, not a stocking rate curve as such.

The Sonora Data

Most of the data in the center of the curve fit very well, but those obtained from a study near Sonora, Texas seemed to be exceptional. The values for Sonora 2, Table 1, were the only ones in which gain per head of cattle grazed at a moderate rate was lower than the arithmetic mean of the gains from lightly and heavily grazed pastures, Figure 4. In this very interesting study conducted on the Edwards Plateau, the performance of cattle alone was compared to cattle grazed with sheep and with sheep and goats at different stocking rates. The values for Sonora 2 in Table 1 and Figure 4, represent the gains per head of cattle when grazed with sheep and goats. In the same study it was found that the sheep and goats grazed with the cattle at the moderate stocking rate actually gained more per head than at any other rate of stocking. When the gains of the sheep and goats were added to that of the cattle and weighted to give an animal unit gain, the values once again gave a good approximate fit to the curve, Figure 4.

The anomalous data can, therefore, be readily explained on the basis of an interaction between the cattle and the sheep and goats. This still further emphasizes the nutritional basis of the functional relationship graphically represented by the curve.

In Sonora 1, cattle grazed alone gave the poorest fit of any of the data of its kind. Cattle on the moderately grazed pastures did not do as well as they should. Cattle at the same degree of grazing but with sheep and goats in the same pasture gained 50 pounds more per head per season, and nearly 100 pounds per head increase was obtained at the light rate. In this type of vegetation, then, cattle benefit significantly from the presence of sheep and goats. The exact nature of the interaction is probably not known, but presumably the sheep and goats in some way condition the vegetation favorably for the cattle. The advantage was hardly noticeable the first two years of the experiment, so that the benefits were most likely to have been due to changes in botanical composition.

Data that do not Fit

The only data that did not fit the curve at all were those listed as San Joaquin 1, Table 1. These are calf gains, and the calves on lightly grazed pastures gained less than those on moderately grazed pastures. Moreover, when a scale was selected to fit the cattle gains of the moderately grazed pasture to the curve, the gains from the heavily grazed pasture gave a poor fit. This study was conducted for 4 years on a winter annual type range. No explanation is offered at the present time for the poor fit. Data for San Joaquin 2, however, gave an excellent fit. These values were for the same pastures but computing gains of cows and heifers on an animal unit basis.

The Manhattan data presented something of the same problem for gains on lightly stocked ("understocked") pastures. They gave a good fit, however, when moved a full degree of grazing to the left. Again, we do not expect Dr. Anderson to agree that his overstocked pastures were really only moderately grazed, but during the early years of a stocking rate study this may well be the case from a nutritional point of view. In tall grass country, it is quite possible to exploit the considerable reserves of these grasses for a few years. If the overstocked pastures are permitted to reach a buffalograss-little barley sward, we confidently expect the per head gains to drop lower on the curve. It is apparent from the Manhattan and San Joaquin 1 data that understocking can, under certain conditions, decrease per head gains.

Other data are no doubt available that might be used in support of or in contradiction to the validity of the relationship here suggested. For the sake of argument we shall take the position that in normal stocking rate studies, gains per head will decline with increasing stocking rate according to the curve proposed. If we assume the validity of this theorem, then certain corollaries follow.

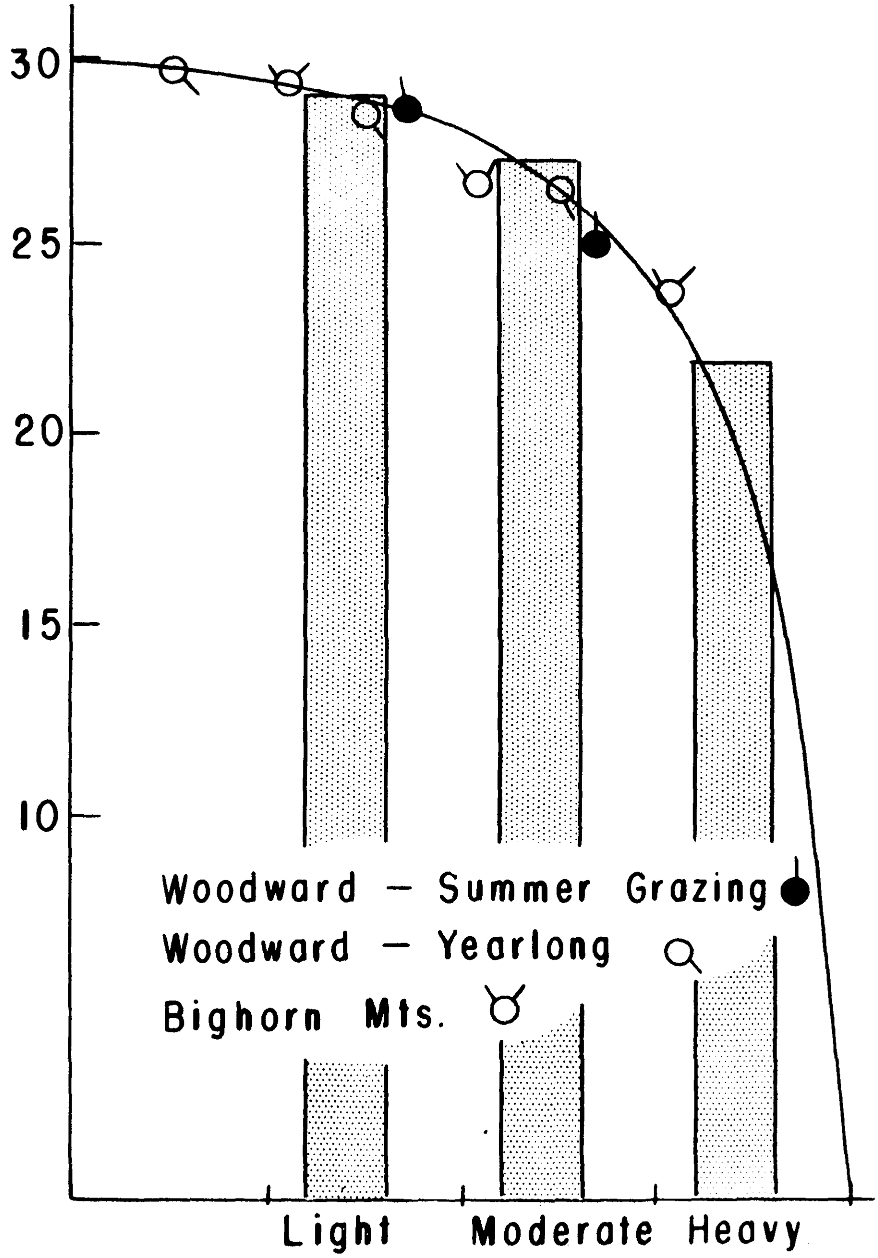

FIGURE 2. Points to the left end of the curve.

Corollary 1:

From the proposed curve for gain per head it follows that one full degree of grazing increment beyond the "heavy" rate will invariably result in loss of weight. As indicated above, the experimenters are reluctant to graze at such degrees of stocking intensity so that there are no data with which to explore the extreme right end of the curve. There are some indications, however, that the corollary is probably correct. In the 8th and 9th years of the Hays study, livestock were removed from the

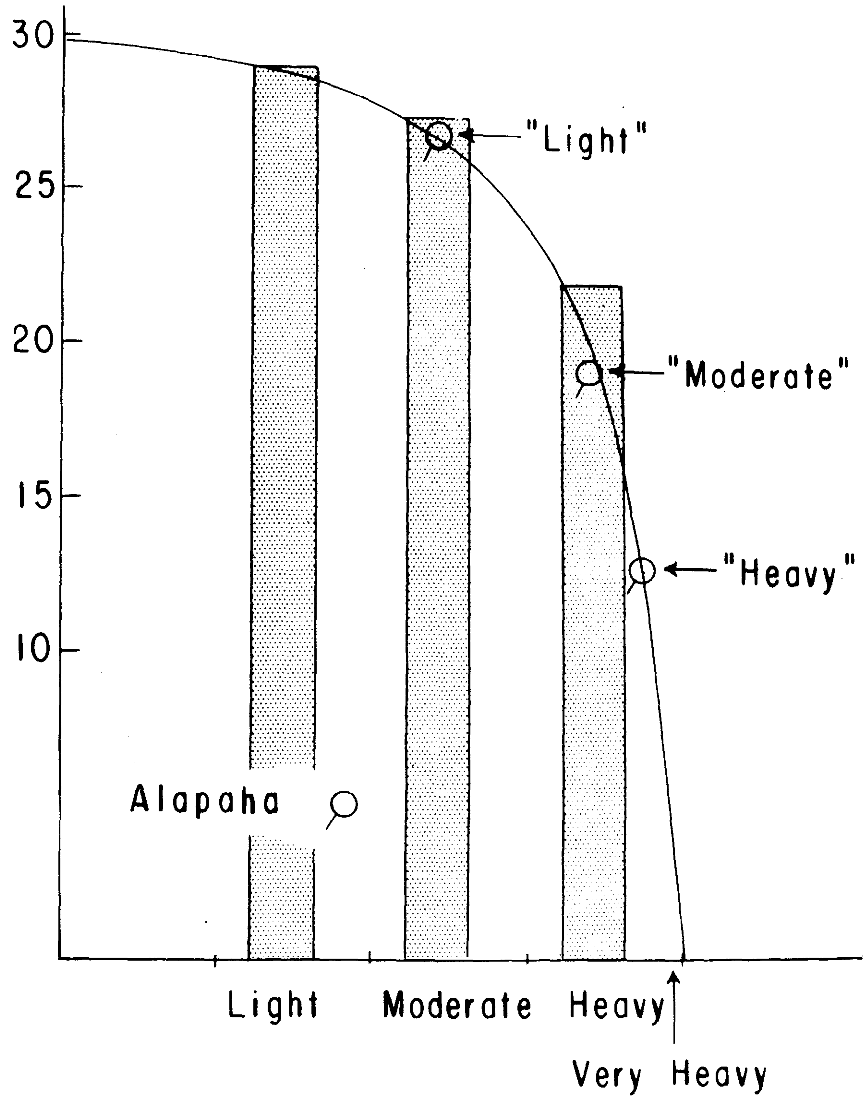

FIGURE 3. Points to the right end of the curve.

heavily stocked pastures for want of forage. In the Woodward study, grazing with steers was discontinued after 10 years, and the degree of grazing study continued with cows. In 1954 and 1955 the cows had to be removed from the heavily grazed pastures or fed hay to prevent undue loss of weight or outright loss by death. Cattle were removed from the heavily grazed pastures in the Manitou study in 1951 due to drouth. It seems evident, then, that a rate of grazing considered "heavy" by those conducting the experiments is indeed close to a peril point. As the curve is actually described, one half of one stocking rate increment beyond "heavy" will bring the livestock to the point of no gain. It is doubtful if this portion of the curve can ever be explored in detail since measurements of both livestock and vegetation to this degree of precision are not possible.

Corollary 2:

From the shape of the curve at the right end, it follows that livestock must either gain weight or lose weight; an equilibrium could not be established by means of rates of stocking, so that an exact balance is maintained without change in weight. The point is perhaps academic but emphasizes the consequences of the extremely rapid decline in per head gains when the stocking rate is on the heavy side of "heavy". In this portion of the curve, the values for y are so much greater than the values of x that an equilibrium would seem to be out of the question. If the grazing intensity was such that the cattle were living from hand to mouth on new growth, a shower might induce gains, a drouth cause loss of weight, but a balance could not be long maintained.

Corollary 3:

The "heavy" rate of grazing will yield a higher gain per unit area than moderate or light. This has generally been found to be the case. Exceptions occur sporadically especially in dry years when "heavily" grazed pastures are in fact very heavily grazed, and the peril point is approached or passed. The higher gain per head at moderate and light stocking rates is not sufficient to offset the smaller area per head at the heavy rate. In fact, grazing rates must be very close to the peril point before per acre gains decrease materially. This is a consequence of the shape of the gain per head curve.

Corollary 4:

Animal gains on heavily grazed pastures should be more variable than those on moderately or lightly grazed pastures. This, again, is due to the shape of the curve in the "heavy" region. The scattering of points in this region in Figure 1 suggests that the corollary is probably correct, but few data so far are suitable for a statistical analysis of this point.

Gain per Acre Curves

Curves for gain per unit area are shown in Figure 5. Gain per acre cannot be expressed as a single curve, but rather by a family of curves with the general

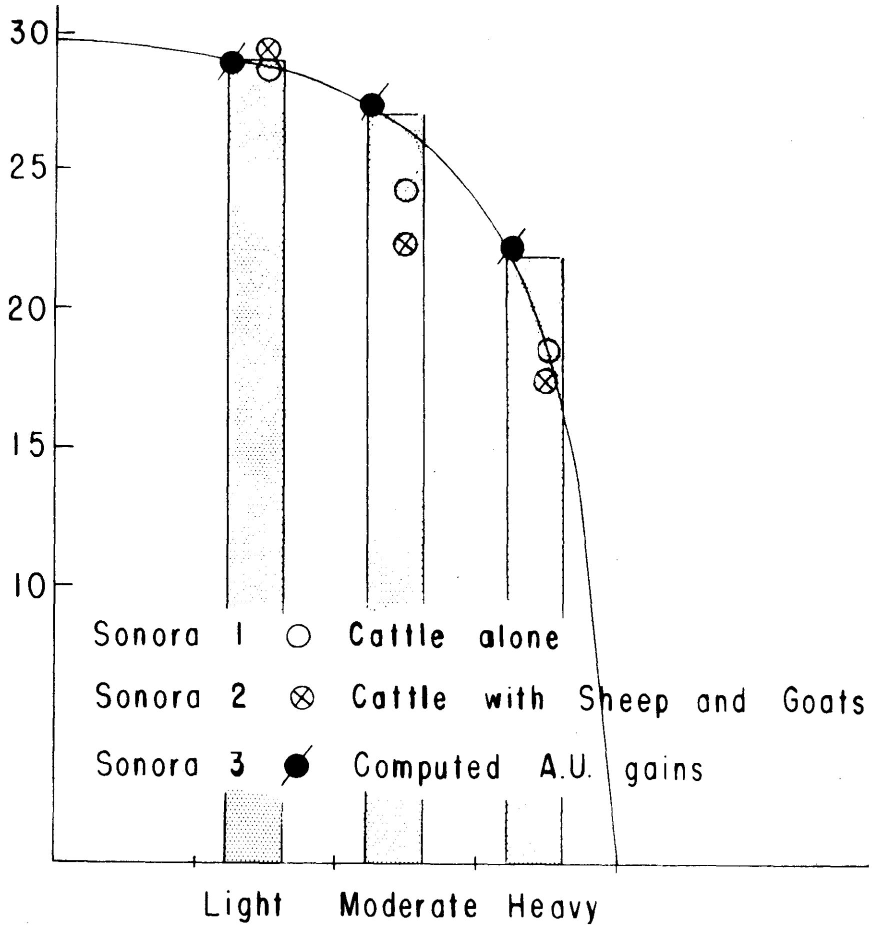

FIGURE 4. Gain per head of cattle and corrected to animal unit gain.

form indicated. There was a considerable variation in experimental design in the several studies. Perhaps the majority of the studies used stocking rate differentials on the order of 1, 1.5, and 2 units of area per head at the heavy, moderate, and light rates, respectively. The Sonora study was on the basis of 1, 2, and 3 units per animal unit at the three rates of grazing. Curves calculated for both types of differential are shown in figure 5. When actual data are used and plotted against a standard differential, the curves take the form indicated in Figure 6. However these values may be plotted, the general form is similar, rising steadily to a peak at the heavy grazing rate and then plunging sharply, crossing the x axis at the same point as the gain per head curve.

Use of the Curves

Interpolation and Estimation

Although considerable care and reservation should be exercised in making interpolations and estimations based on the curves presented, one can visualize situations in which such manipulations could be of very real practical value. Grazing studies of any kind are always expensive. Land, fencing, water, cattle, labor, all add up to a considerable bill. If it were possible to interpolate results for only one degree of grazing, savings of thousands of dollars could often be realized. For example, in the Spur study light and heavy rates of stocking only were used. Both points fell exactly on the line when a suitable scale was used to fit either point. In all probability the results of a moderate degree of grazing trial could be obtained by reading its value (136 lbs.) directly from the curve as accurately as if the trial actually had been conducted for a period of several years. The Mandan figures were for moderate and heavy grazing only. A light degree of use might be projected (336 lbs.) without danger of being very far wrong. Similar interpolations and estimations might be used elsewhere at a substantial saving in research funds.

Such a procedure could hardly be recommended, however, in areas where the ecology of the vegetation was not reasonably well understood, or where no grazing experience was available. On the other hand, if the ecological dynamics of the vegetation is well understood and there is considerable experience with it, and it is possible to state on *a posteriori* grounds that such and such a stocking rate constitutes moderate grazing (or any other degree), then it would seem that degrees of grazing studies are quite unnecessary. Estimated per head and per acre gains based on one degree of use would be adequate.

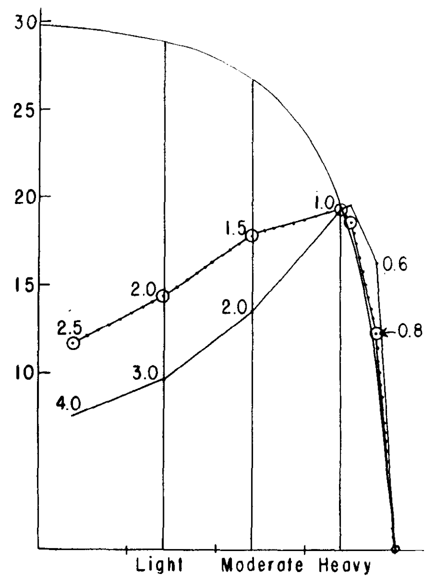

FIGURE 5. Two calculated curves for gain per unit area; pitch depends on stocking rate differentials.

Basic Ecology

A second use of the curves wolud be as an aid to the understanding of the ecological behavior of the vegetation in question under differential usage. As indicated above the per head curve is a functional expression of the nutritional plane provided the livestock. If values are displaced to the left, as in Woodward 1 and Woodward 2, this information is of value in the ecological interpretation of the vegetative changes that took place under the several degrees of utilization. If the values obtained are displaced to the right of expected, as in the Alapaha study, the nutritional value of the forage is clearly reflected. The same is true of the complex of interactions in the Sonora trials, where the values for the moderately grazed pastures were displaced downward from the expected values.

General Interpretation

If the curves are valid, they help to explain in a clear and graphic way some features of rates-of-grazing studies that have not been too clearly understood in the past. They show clearly why it is that the heavy grazing rates persist in giving higher gains per acre even at grazing rates we know to be detrimental. They show that there is very little leeway between maximum gains per acre and no gains at all per acre. Operators who habitually graze heavily may make the most beef per acre and the most profit, but they are also skating on the thinnest ice. With a bad growing season or two, they are the ones who have to take their stock to town and take a whipping at the market place. The operator who habitually grazes his pastures at a moderate rate has considerable leeway in either direction. He is far enough from the peril point that he can weather through most of the bad years in good shape. The operator who habitually grazes lightly (unless he is trying to upgrade his range condition) had better have some additional source of income, for he is not likely to make much out of the livestock business. All of these things have been known and understood in a general way for a long time, but the reasons back of them were not always too clear.

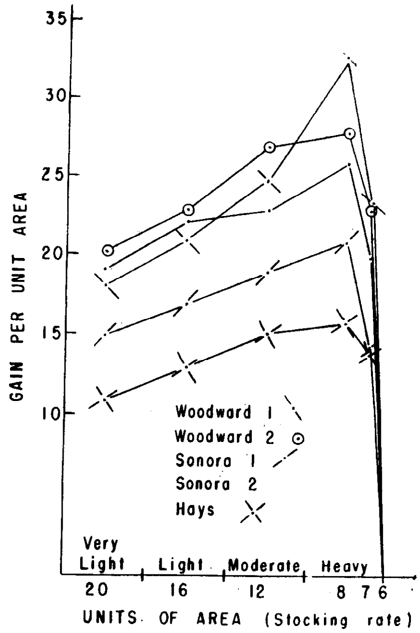

FIGURE 6. Gain data plotted against a standard stocking rate differential: values to the right and left interpolated.

Range Classification

The United States Forest Service has for some time used nine range classes based upon use of primary forage plants in various sections of the western states (Love, 1954). These have been designated as (1) unused, (2) slight, (3) light, (4) moderate, (5) proper, (6) close, (7) severe, (8) extreme, and (9) destructive. This implies a gradual decrease in range condition beyond "close" use. We have attempted a range classification in the Oklahoma tall grass prairie region based on a similar assumption and found it unrealistic. In this area, at least, there is a very quick jump from close use or heavy grazing to destructive grazing. We see little evidence of intermediate classes. This experience would be expected from the curves indicated.

Nor can we clearly detect so many classes to the light side of proper use. Generally speaking, in the Southern Great Plains we seem to have the following main conditions. (a) We have some ranges lightly grazed. These are primarily by nonprofessional ranchers such as oilmen, bankers, lawyers, doctors, etc. These would fit the Soil Conservation Service classification of "excellent". (b) We have some ranges properly used or nearly so. These belong primarily to the larger long-time operators who have learned by experience about what their ranges can and cannot do. In general, they are likely to be grazed moderately or occasionally lightly in the good years and heavily grazed in the bad years. This is a norm of operations in continental climates and is probably the best practical approximation to good or proper use that we can obtain on native rangeland. Such ranges would usually fit the Soil Conservation Service classification of "good". (c) We have very large acreages of range that are by turns heavily grazed and destructively grazed. These are perhaps mainly in the hands of small operators or farmers, but some of the larger ranchers have followed this practice, too. These may be classed as "fair" or "poor", but many such areas have degenerated to the point that to call them native grass ranges is to perpetuate a fiction. Such ranges are the object of serious concern to both action and research agencies in the region. Again, the reason why ranges go from "good" to "bad" so quickly is underscored in the shape of the performance curves offered in this paper.

Conversely, it would appear that if the curves are real and valid, they might be of considerable aid in the development of range classification systems.

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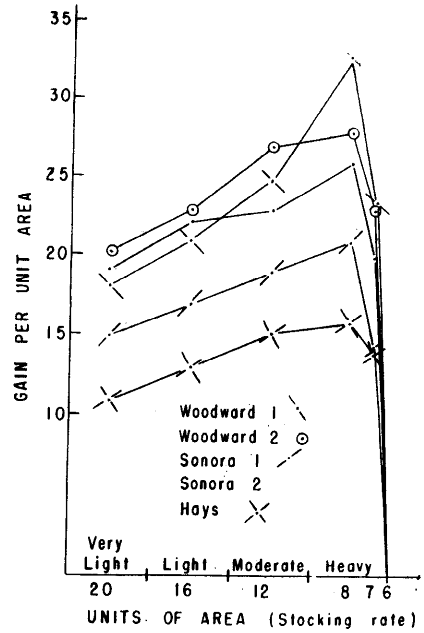

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A Generalization

Progress in science depends ultimately on the development of valid and useful generalizations. "The science and art of grazing land management" has had all too few valid generalizations up to the present time. The one proposed in this paper may not turn out to be valid, but at least is one attempt in that direction.

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