A METHOD OF COMPUTING RESULTS FOR STEER GRAZING STUDIES

Preliminary Draft

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Forward

A great deal of pressure has been brought to bear recently relative to problems in pasture research. The foremost problems are not exactly statistical, but, rather, deal with methods and units of measurement.

On a trip to the U. S. Southern Great Plains Field Station at Woodward, Oklahoma, this spring, the problem of how best to compute the results of put-and-take 1/ experiments with grazing steers. This led to the preparation of a manuscript on the problem, the first draft of which follows these initial remarks.

The basic idea of the proposed method is such that it offers a solution to another problem which perennially arises. Experimental steers are not always representative of any given farmer's steers. Further, the experimental steers in one experiment may be much different from those in another, rendering results, as usually computed, very difficult to compare. A method is thus badly needed for converting the results obtained with one kind of steer to those to be expected with another kind of steer. The method was, therefore, generalized to overcome this problem.

The method appears applicable, not only to beef steers, but also to beef heifers and young dairy animals of either sex.

Certain items necessary for the manuscript are not yet incorporated into it; hence Tables 1 and 3 are not complete. In addition, a discussion of European methods along the same lines has not yet been added. This will be very brief.

1/ Put-and-take experiments are those in which the stocking rate on a given pasture is periodically varied as the season progresses in order to attain a desired degree of utilization.
The manuscript badly needs reworking, especially with a view toward shortening and clarifying it in many places. In this connection, the reactions and suggestions of readers of this first draft will be welcomed.

The manuscript seems appropriate to publish as a Technical Bulletin.
INTRODUCTION

The results of grazing experiments with beef steers are commonly reported in terms of three very practical measures, namely, gain-per-head, acres-per-head and gain-per-acre. The length of the grazing season and the particular time of year involved are, of course, specified. In addition, the genetic make-up and physiological status of the experimental steers are characterized in some way, usually in terms of breed, starting weight, an index of body condition, and approximate age. There are, however, problems which arise, both in the computation of, and in the use of, results reported as above. Two of these problems will be discussed in this paper, and a method for overcoming them will be presented.

The First Problem

The Computation of Results from Put-and-take Experiments:

An increasingly common experimental procedure is to periodically vary the stocking rate on a given pasture as the season progresses. This practice, hereafter referred to as the put-and-take method, allows the investigator to attain a desired degree of forage utilization. For experimental work it seems preferable to the practice of holding stocking rate constant (the constant-number method), because, in the latter, a risk is always run of either overgrazing or undergrazing with respect to the degree of utilization desired. For practical use, however, the results of put-and-take experiments must be expressed as though the constant-number method had been used, if not for the whole of the season, at least for each of the major subdivisions of it. A problem exists as to just how these results should be computed.

The problem is illustrated by the following: One may take as gain-per-head, the average of the season-long gains of those steers which remain on the pasture for
the entire season. As gain-per-acre, one may accept the quantity, sum of the
on-pasture gains of all animals employed divided by the pasture acreage. Finally,
acres-per-head may be computed as (pasture acreage)(days in season)/(steer-days of
grazing). As is well known to research men in the field, the measures so computed
do not satisfy the relation, gain-per-acre = gain-per-head/acres-per-head, unless
the data are from a constant-number experiment. Thus, the method of computation is
not acceptable for put-and-take experiments.

Instead of the above, one might obtain figures which do satisfy the relation.
This can be done by computing one of the three measures from the other two. For
example, gain-per-head might be divided by acres-per-head to arrive at gain-per-acre.
Of the three possible alternatives this method offers, however, there is little
basis for saying which one, if any, gives the true picture. Hence this method is
of uncertain value.

There are some minor variations of the two basic ideas just given. All, how­
ever, lead to the same dilemma. Obviously then, an improved method of computing
the results of put-and-take experiments is needed.

The Second Problem
The Generalization of Experimental Results:

As customarily reported, the results of grazing experiments apply only to the
average steer used in a particular experiment. Although the average experimental
steer may closely approximate the average steer of the average farmer, it will not,
in general, approximate the average steer of any individual farmer. The average
steer of the individual farmer, hereafter referred to as the "farmer's" steer, is
nevertheless, the steer to which the results are to be applied. There is needed,
then, a means for expressing experimental results, not only for the average
experimental steer, but also for each of a variety of "farmer's" steers. This is true whether the constant-number method or the put-and-take method is used as the experimental procedure.

Preliminary Comments

The method to be presented was originally developed as a solution to the put-and-take problem. The idea involved, however, also provides a means of generalizing results. The fundamental basis for the method is the same as that utilized by Knott, Hodgson and Ellington (1934) for expressing the results of grazing experiments with dairy cattle. The performance of the experimental steers is converted to standard food units (total digestible nutrients). These units are then converted back to performance figures for the "farmer's" steer.

The final results are expressed in the usual three measures, gain-per-head, acres-per-head and gain-per-acre. In the case of the average experimental steer from a constant-number experiment, the method yields results identical with those obtained by the usual computations.

The formulae and the data required for the use of the method will be presented first. These will be followed by a numerical example. Finally, a discussion will be given devoting special attention to the magnitude of error involved in the method. Comments will be made regarding research required to improve the method.

The material will be presented as though it is desired to report results on a season-long basis. Modification of the method to yield results for only a part of the season is rather obvious.
THE METHOD

Computation of Gain-per-head

In a constant-number experiment, if expressing results for the average experimental steer, the correct gain-per-head is simply the average of the season-long gains of all of the steers used. In the case of put-and-take experiments, however, it is inadvisable to use all of the animals in computing gain-per-head. The steers which are put on or taken off the pasture during the season usually show a rate of gain somewhat different from that of the other steers, even while on the experimental pasture. Thus, the best figure for gain-per-head for the average experimental steer is the average of the season-long gains of those steers, and only those steers, which remain on the pasture for the whole season.

To arrive at gain-per-head figures for each of a variety of "farmer's" steers, advantage may be taken of the rather wide variation which usually exists among the experimental steers. As will be taken up more fully in the discussion, the experimental steers may be divided into several "farmer's groups". This can be done according to characteristics they had at the start of the experiment. The average steer of a "farmer's group" represents a certain "farmer's" steer. Gain-per-head for each "farmer's" steer represented then, is simply the average of the season-long gains of those steers in the corresponding "farmer's group" which remain on the pasture for the entire season.

Computation of Acres-per-head

To compute acres-per-head the "yield" of the pasture in terms of total digestible nutrients (T.D.N.) is first computed. This is divided into the pasture acreage to obtain the reciprocal of yield-per acre. Next the T.D.N. "requirement"
is computed for each "farmer's" steer referred to at the end of the preceding section. An acres-per-head figure for each "farmer's" steer is then obtained by the formula:

\[ \text{acres-per-head} = \frac{\text{(reciprocal of yield-per-acre)}}{(\text{requirement})} \]

\[ \text{Yield:} \]

The "yield" figure is arrived at by the formula:

\[ "\text{yield}" = a_0 M + b_0 G \]

where

- \( M \) = maintenance units supported by the pasture (in pound-days x 1,000, or for brevity, kilopound-days)
- \( G \) = total gain supported by the pasture (in pounds)
- \( a_0 \) = pounds of T.D.N. required per kilopound-day
- \( b_0 \) = pounds of T.D.N. required per pound of gain.

Appropriate values for the maintenance and gain coefficients, \( a_0 \) and \( b_0 \), are taken from Table 1 of the next section. How to select them is discussed in connection with the table. The values for \( M \) and \( G \) are obtained by formulae given below, using the weight records of all cattle.

Before giving the formulae for \( M \) and \( G \), the following will be noted: In grazing work, animals are usually weighed a number of times during the season. The interval between the initial and second weigh-dates will be referred to as the first period; that between the second and third weigh-dates, as the second period; etc. It will be assumed that there are \( p \) such periods, and that cattle are put on or taken off the pastures only on weigh-dates.
Values for $M$ and $G$ are then given by:

$$
M = \frac{(I_1 + F_1)d_1 + (I_2 + F_2)d_2 + \ldots + (I_p + F_p)d_p}{2,000}
$$

$$
G = (F_1 + F_2 + \ldots + F_p) - (I_1 + I_2 + \ldots + I_p)
$$

In the above formulae, the $I$'s refer to the sums of the body weights at the beginnings of the periods for the particular steers on the pasture during the corresponding periods, the $F$'s refer to the sums of the weights at the ends of the periods for those steers on the pasture during the corresponding periods, and the $d$'s are the lengths of the periods in days.

Requirements:

The "requirement" figure for a "farmer's" steer is given by:

"requirement" = $a \; n + b \; g$

where

$\begin{align*}
    n &= \text{maintenance units required to be supported for the "farmer's" steer} \\
        &= \text{(in kilopound-days)} \\
    g &= \text{gain to be supported for the "farmer's" steer (in pounds).}
\end{align*}$

The coefficients, $a$ and $b$, have the same definition as $a_0$ and $b_0$ in the case of yield, but take somewhat different values for the several "farmer's" steers. Again the appropriate values are selected from Table 1.

The quantities, $n$ and $g$, are computed separately for each "farmer's" steer, by the following formulae:

$$
n = \frac{(I_1 + F_1)d_1 + (I_2 + F_2)d_2 + \ldots + (I_p + F_p)d_p}{2,000n}
$$

$$
g = \frac{F_p - I_1}{n}
$$
The i's and the f's have the same meanings as the I's and F's in the formulae for M and G. Here, however, they are the sums of the body weights of those steers which are in a particular "farmer's group" and which remain on the pasture the entire season. Note that \( i_2 = f_1, i_3 = f_2, \) etc., whereas, in general, \( I_2 \neq F_1, I_3 \neq F_2, \) etc. The d's are the same as in the formulae for \( H, \) and \( n \) is the number of steers in the "farmer's group". The quantity, \( g, \) is, of course, the gain-per-head figure for the "farmer's" steer discussed in the previous section.

Modification if supplements are fed:

If supplements are fed to the grazing steers, the computations of "yield" and "requirement" proceed exactly as above. Before using these two quantities to compute acres-per-head, however, they are adjusted downward. One simply subtracts from the "yield" the total T.D.N. supplied by supplement to all animals during the experiment, and subtracts from the "requirement" the total supplemental T.D.N. which a single steer consumes. The modified "yield" and "requirement" figures are then used to arrive at acres-per-head.

It should be noted that this approach can not safely be used to predict what might happen under a rate of supplemental feeding different from that used in the experiment. Although this might give quite good results for acres-per-head, it could lead to large errors in gain-per-head and gain-per-acre. This is because supplements may markedly affect rate of gain.
Computation of Gain-per-acro

Gain-per-acre is computed simply as gain-per-head divided by acres-per-head. This is done separately for each "farmer's" steer, using the appropriate pair of gain-per-head and acres-per-head figures.

Values for the Maintenance and Gain Coefficients

Values for the maintenance and gain coefficients, \( a \) and \( b \), are shown in Table 1. The maintenance coefficients are given as a function of average body weight (i.e., proportional to the seven-eights power of weight) for both good native ranges and good tame pastures. The gain coefficients are given as a function of age of steer and type of pasture.

Table 1. Maintenance and gain coefficients, \( a \) and \( b \), for computing "yield" of a pasture and "requirement" of a "farmer's" steer.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance coefficients: calves &amp; yearlings: Long yearlings &amp; 2-yr. olds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kilogram-day</td>
<td>Calves &amp; yearlings</td>
<td>2-yr. olds</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>300</td>
<td>12.0</td>
<td>10.0</td>
</tr>
<tr>
<td>400</td>
<td>11.6</td>
<td>9.7</td>
</tr>
<tr>
<td>500</td>
<td>11.3</td>
<td>9.4</td>
</tr>
<tr>
<td>600</td>
<td>11.0</td>
<td>9.2</td>
</tr>
<tr>
<td>700</td>
<td>10.8</td>
<td>9.0</td>
</tr>
<tr>
<td>800</td>
<td>10.6</td>
<td>8.8</td>
</tr>
<tr>
<td>900</td>
<td>10.4</td>
<td>8.7</td>
</tr>
<tr>
<td>1,000</td>
<td>10.3</td>
<td>8.6</td>
</tr>
<tr>
<td>1,100</td>
<td>10.2</td>
<td>8.5</td>
</tr>
<tr>
<td>1,200</td>
<td>10.1</td>
<td>8.4</td>
</tr>
</tbody>
</table>
There is no special problem in selecting the values of $b_0$ for the computation of "yield" and of the $b$'s for the "requirements" of the several "farmer's" steers. To select values for $a_0$ and the $a$'s, however, the table must be entered at the appropriate average body weight.

The average body weight for "yield" is given by

\[
\frac{1,000M}{\text{total steer-days of grazing}}
\]

where $M$ is the number of maintenance units supported by the pasture as computed previously.

For each of the "farmer's" steers the average weights are obtained as

\[
\frac{1,000m}{\text{days in season}}
\]

where $n$ is the number of maintenance units required to be supported for the appropriate "farmer's" steer.

With the above figures, one may enter the table to arrive at the values for the maintenance constants. Interpolation is probably not necessary in view of the experimental errors due to other sources, especially between-pasture and between-year variability. Rounding the above average weights to the closest 100 pounds is thus satisfactory.

In the event one uses, on the same pasture, steers which fall in both age classes, one computes the maintenance units, gain and "yields" separately for the two groups. The two "yield" figures are then added together to arrive at "yield" for the pasture.
NUMERICAL EXAMPLE

For the numerical example, a set of data obtained in grazing work at the U. S. Southern Great Plains Field Station was selected. Yearling Hereford steers were used in the study, and the pasture was 107 acres in size. The data are shown in Table 2, arranged for computation. Those steers which were on pasture the entire season ("permanent" steers) are classified according to "farmer's groups". The cattle which were put on or taken off during the season ("add" steers) are not grouped according to kind of steer, but rather according to starting and take-off time.
Table 2. Experimental data. The observed weights at the several dates with sums needed for computations.

<table>
<thead>
<tr>
<th>Farmers cr.</th>
<th>Body weight in pounds on</th>
</tr>
</thead>
<tbody>
<tr>
<td>starting</td>
<td></td>
</tr>
<tr>
<td>time group: number: Grade: Apr. 15: Apr. 30: May 31: June 30: July 31: Aug. 31: Sept. 30</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Grand line</td>
<td>F line</td>
</tr>
<tr>
<td>Totals</td>
<td></td>
</tr>
</tbody>
</table>

Animals on pasture in period: 20: 20: 22: 22: 34: 34
Gain-per-head

These figures are easily obtained from the subtotals for the "farmer's groups" and the total for all "permanent" cattle given in Table 2. For example in the case of the average experimental steer, gain-per-head is \[
\frac{15,230 - 8,819}{20} = 320.6 \text{ pounds.}
\]

Acres-per-head

Yield:

From the grand total lines (the i and F lines) of Table 2 one first computes the maintenance and gain units supported by the pasture, as follows:

\[
M = \frac{(0.019+9,605)(15)+(9,605+11,135)(31)+(12,235+13,095)(30)+\ldots+(24,605+25,732)(20)}{2,000}
\]

\[= 2,754 \text{ kilopound-days} \]

\[G = (9,605 + 11,135 + 13,095 + \ldots + 25,732) - (0.019 + 9,605 + 12,235 + \ldots + 24,605) \]

\[= 7,052 \text{ pounds.} \]

To select a maintenance coefficient the average weight is next computed as

\[
\frac{(1,000)(2,754)}{(20)(15) + (20)(31) + (22)(30) + \ldots + (34)(20)} = 645.
\]

Rounding to the closest 100 pounds, the appropriate maintenance coefficient from Table 1 is, then, 11.0, and the correct gain coefficient is 1.3.
Thus, "yield" is

\[ (11.0)(2.754) + (1.3)(7.052) = 40,502 \text{ lbs of T.D.N.} \]

and the reciprocal of yield-per-acre is

\[ \frac{107}{40,502} = 0.002642 \text{ acres per lb. T.D.N.} \]

**Requirements:**

To compute "requirements" one uses the subtotals for the various "farmer's groups" and the total for all "permanent" steers. The proper gain units are, of course, the gain-per-head figures previously obtained. Corresponding values for the maintenance units must also be computed. For example, the figure for maintenance units per head for the average experimental steer is computed from the "permanent" subtotal line as

\[
m = \frac{(8,819 + 9,605)(15) + (9,605 + 11,135)(31) + \ldots + (14,695 + 15,230)(20)}{(2,000)(20)}
\]

\[ = 104.5 \text{ kilopound-days.} \]

The figure for gain units for the same steer is the gain-per-head previously obtained, i.e.,

\[
g = \frac{15,230 - 8,819}{20} = 320.6 \text{ pounds.} \]

The maintenance coefficients are selected from Table 1 for the appropriate average weights. In the case of the average experimental steer, the average weight is

\[
\frac{(1,000)(104.5)}{15 + 31 + \ldots + 20} = 630 \text{ pounds.} \]
The proper maintenance coefficient for the average experimental steer is thus 11.0 and the gain coefficient 1.3.

The "requirements" are computed for each "farmer's" group by the proper formula. In the case of the average experimental steer the "requirement" is

\[(11.0)(104.5) + (1.3)(320.6) = 1,566 \text{ lbs. of T.D.N.}\]

**Acres-per-head:**

Multiplication of the several "requirement" figures by the reciprocal of yield-per-acre previously obtained, results in the appropriate set of figures for acres-per-head. For the average experimental steer the value is

\[(.002642)(1,566) = 4.14 \text{ acres-per-head}\]

**Gain-per-acre**

Gain-per-acre, of course, is simply gain-per-head divided by acres-per-head.

In the case of the average experimental steer this is

\[
\frac{320.6}{4.14} = 77.4 \text{ lbs. per acre.}
\]

**Summary of Results**

The results of the computations just completed, along with factors characterizing the several "farmer's" steers and the average experimental steer, are shown in Table 3. For actual publication most of the data in Table 3 should be presented. This point will be discussed again later.
Table 3. Summary of computations and results

For pasture "yield"

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Supported:</td>
<td>Acroge: yield-per-acre</td>
</tr>
<tr>
<td>Mainte:-:</td>
<td>Weight: Gain: Average: For: For:</td>
</tr>
<tr>
<td>nance: G: Average:</td>
<td>For: For: Yield: Acres:</td>
</tr>
<tr>
<td>units: units:</td>
<td>T.D.N.: lbs. T.D.N.:</td>
</tr>
<tr>
<td>weight: maintenance:</td>
<td>gain:</td>
</tr>
<tr>
<td>kilolb:-:</td>
<td>kilolb. lb.</td>
</tr>
<tr>
<td>days: lbs:</td>
<td>kilolb.: lb.</td>
</tr>
<tr>
<td>:</td>
<td>days</td>
</tr>
</tbody>
</table>

For the several "farmer's" steers and the average experimental steer

<table>
<thead>
<tr>
<th>Required/head:</th>
<th>Coefficients used: Require: Practical results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer's: Average:</td>
<td>Gain: Acres: gain</td>
</tr>
<tr>
<td>group: initial: initial: nance: Gain: Average: For: For: head: per: per: per:</td>
<td></td>
</tr>
<tr>
<td>:</td>
<td>days: kilolb: lb.</td>
</tr>
<tr>
<td>1:</td>
<td>day:</td>
</tr>
<tr>
<td>2:</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Average:</td>
<td>441: 104.5: 320.6: 630: 11.0: 1.3: 1,556: 321: 4.14: 77.4</td>
</tr>
</tbody>
</table>
DISCUSSION

There seems little reason to question the method presented for arriving at gain-per-head for the several "farmer's" steers. Likewise little comment need be made as to the procedure employed for computing gain-per-acre. It is obvious that, if the gain-per-head and acres-per-head figures are correct, gain-per-acre must be the quotient of the former divided by the latter. It is appropriate, however, to go into the matter of forming the "farmer's" groups in more detail, and to discuss rather critically the procedure for computing acres-per-head.

Formation of the "Farmer's" Groups

The presentation of results for each of a variety of "farmer's" steers seems an important aspect of the present method. Obviously, maintenance requirements and rates of gain vary with the size and condition of steers and perhaps with breed. The principal effects of age are probably associated with size unless age varies widely. Formation of groups according to initial body weight and condition, and according to breed seems thus to be warranted. A refined classification is not justified, however, because of other experimental errors. The class intervals on weight need not be narrower than 100 pounds, and it is necessary to consider only two or three condition classes. Further, the extent of grouping should be governed in part by the total number of steers. Each group should probably have at least 4 to 6 animals in it. The wider the variation among animals, however, the smaller the groups that can be tolerated. It is not necessary that a certain number of animals for any one class be present in any one pasture any one year. In experiments which are replicated and/or run for several years, a substantial number of animals will fall in each class over the several replications and/or the several years.
Because the method is just being proposed, little experience on how refined a classification to use is yet available. Certainly classification is warranted, but, until experience accumulates, the investigator will have to use prudence in forming the "farmer's" groups.

Discussion of Method for Acres-per-head

In the method for computing acres-per-head, questions can be raised concerning several matters. Among these are the choice of scale and the method of calculation for the maintenance units. More important, however, are the effects of inaccuracies in the maintenance and gain coefficients, and how these coefficients were determined.

Regarding the choice of scale for maintenance units, the predominance of evidence (Brody, 1945; Kleiber, 1932) indicates that the resting maintenance requirement of animals, in general, varies as weight to a power less than one, probably near the three-fourths power. Hence, one might criticize the use of weight instead of weight to some power for computing maintenance units. Expenditure for exercise in grazing would tend to place the exponent between three-fourths and one.

The strongest argument in favor of using a power of one is ease of computation. A sum of weights is obviously much easier to compute than is a sum of powers of weights. That the resulting error is of no consequence, is easy to show. For the range of weights involved, usually will be about one per cent, and certainly less than two per cent.

The computational formulae for maintenance units provide estimatos of areas under growth curves. In using formulae it is assumed, however, that the growth curves are linear between weigh-dates. Since this is not strictly true, small errors are introduced. Such errors for the maintenance units used in arriving at
"yield" and for the maintenance units used in determining "requirement" are, however, in the same direction and almost of the same relative magnitude. Thus, in computing acres-per-head, the errors almost completely cancel, introducing a final error of only a fraction of a per cent.

Before entering into a discussion of the effects of inaccuracies in the maintenance and gain coefficients on the acres-per-head figure, it is necessary to point out that two types of inaccuracies are involved. One has to do with the general level of the coefficients, e.g., what is the effect of having all the maintenance coefficients ten per cent too high or too low? The second has to do with the relative values of the coefficients for different kinds of steers; e.g., what is the difference if the maintenance coefficients vary in proportion to one power of weight instead of another?

It should be pointed out, further, that inaccuracies in the maintenance coefficients are more serious than inaccuracies of the same relative size in the gain coefficients. This is because, as was evident in the numerical example, the energy utilized for maintenance is the major part, about three-fourths, of the total energy consumed.

Effect of inaccuracies in the general level of the coefficients:

The effect of inaccuracies in the general level of the coefficients is easily demonstrated by applying various values to a given set of experimental data and noting the magnitudes of the changes in the final measures of interest. The results of such computations are shown in Table 4. The data of the numerical example are used, with the results expressed for the average experimental steer.
Table 4. The effect on *acres-per-head* and *gain-per-acre* of errors in the general level of the maintenance and gain coefficients.

<table>
<thead>
<tr>
<th>Coefficients used</th>
<th>Requirement</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>For maintenance</td>
<td>For gain</td>
<td>Pasture for yield</td>
<td>average steer per head per acre</td>
<td></td>
</tr>
<tr>
<td>8.0</td>
<td>.9</td>
<td>29,099</td>
<td>1,124</td>
<td>4.13</td>
</tr>
<tr>
<td>8.0</td>
<td>1.3</td>
<td>32,240</td>
<td>1,253</td>
<td>4.16</td>
</tr>
<tr>
<td>8.0</td>
<td>2.5</td>
<td>41,662</td>
<td>1,638</td>
<td>4.21</td>
</tr>
<tr>
<td>11.0</td>
<td>1.3</td>
<td>40,502</td>
<td>1,566</td>
<td>4.14</td>
</tr>
<tr>
<td>11.0</td>
<td>2.5</td>
<td>49,924</td>
<td>1,951</td>
<td>4.18</td>
</tr>
<tr>
<td>13.0</td>
<td>.9</td>
<td>42,669</td>
<td>1,647</td>
<td>4.11</td>
</tr>
</tbody>
</table>

It is seen that marked variations in the maintenance and gain coefficients, and even in their ratio, have only negligible effects on the values for *acres-per-head* and *gain-per-acre*. Assuming that any pair of values other than those taken from Table 1 (11.0 and 1.3) are correct, the use of those from Table 1 leads to errors of less than 2 per cent. Obviously, then, inaccuracies as regards the general level of the coefficients are of no consequence. This is because the errors in "yield" and the errors in "requirement" essentially cancel in arriving at *acres-per-head*.

The effect of inaccuracies in the relative values of the coefficients for different kinds of steers:

A given "farmer's" steer may be considerably smaller or larger than the average experimental steer. Hence the energy required for maintenance per kilogram-day is somewhat different from that for the average experimental steer. Similarly the composition of the gains in weight may differ somewhat, so that the T.D.N. represented by a pound of gain may vary. If the maintenance and gain coefficients do not allow for these differences errors will be incurred.
In the case of the maintenance coefficient, the effect of relative inaccuracies may be examined by using the maintenance coefficient for the average experimental steer as a base, and varying it, for smaller and larger "farmer's" steers, in accordance with different powers of body weight. Similarly the gain coefficient for the average experimental steer can be used as a base, and its value varied.

The results of such computations are shown in Table 5. For this purpose there were used simulated "farmer's" steers which deviate rather extremely from the average experimental steer as regards size, but which fall in the same general age group (calves and yearlings). The particular powers of body weight used, and the range of gain coefficients employed, were chosen on the basis of studies discussed in the next section.

Table 5. The effect on results of errors in the basis for relating the maintenance coefficient to body weight, and of errors in the coefficients for gain, for different kinds of "farmer's" steers.

<table>
<thead>
<tr>
<th>Required per head</th>
<th>Coefficients</th>
<th>Basis for</th>
<th>For</th>
<th>Acres</th>
<th>Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>lbs. kilolb-1</td>
<td>power of T.D.N.</td>
<td>lbs.</td>
<td>per head</td>
<td>per acre</td>
<td></td>
</tr>
<tr>
<td>Initial weight</td>
<td>Average experimental steer:</td>
<td>441</td>
<td>104.5</td>
<td>320.6</td>
<td>630</td>
</tr>
<tr>
<td>Small &quot;farmer's&quot; steer: from Table 1:</td>
<td></td>
<td>252</td>
<td>66.9</td>
<td>230.0</td>
<td>400</td>
</tr>
<tr>
<td>Varying maintenance basis:</td>
<td></td>
<td>3/4</td>
<td>12.3</td>
<td>1.3</td>
<td>1,122</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>11.0</td>
<td>1.3</td>
<td>1,035</td>
</tr>
<tr>
<td>Varying gain coefficient:</td>
<td></td>
<td>7/8</td>
<td>11.6</td>
<td>1.0</td>
<td>1,006</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/8</td>
<td>11.6</td>
<td>1.6</td>
<td>1,144</td>
</tr>
<tr>
<td>Large &quot;farmer's&quot; steer: from Table 1:</td>
<td></td>
<td>557</td>
<td>133.8</td>
<td>410.0</td>
<td>800</td>
</tr>
<tr>
<td>Varying maintenance basis:</td>
<td></td>
<td>3/4</td>
<td>10.2</td>
<td>1.3</td>
<td>1,898</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.0</td>
<td>11.0</td>
<td>1.3</td>
<td>2,005</td>
</tr>
<tr>
<td>Varying gain coefficient:</td>
<td></td>
<td>7/8</td>
<td>10.6</td>
<td>1.0</td>
<td>1,828</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7/8</td>
<td>10.6</td>
<td>1.6</td>
<td>2,074</td>
</tr>
</tbody>
</table>
The three-fourths and unit powers of weight appear to be definite limits of a possible range. Hence it is clear that, in using the figures of Table 1, the maximum error due to the choice of a wrong exponent for relating maintenance to weight is less than 5 per cent. Assuming that the range of gain coefficients is reasonable, the errors associated with the gain coefficients of Table 1 are of the same order. Thus, in the case of rather extreme "farmer's" steers, the total maximum error is about 10 per cent. Smaller errors will occur with "farmer's" steers more similar to the average experimental steer than those used in the illustration. It is felt that errors will usually be about five per cent, but little evidence can be given to support such a conclusion.

Even if an error of 10 per cent is present, it is nevertheless worthwhile to compute separate results for each "farmer's" steer. An error of such size is certainly less important than the 25 per cent difference in acres-per-head which exists between the average experimental steer and either of the "farmer's" steers. In the simulated data little difference between the "farmer's" steers and the average experimental steer exists as regards gain-per-acre. In actual data, however, this might not be the case. It depends on the gain-per-head figures observed for "farmer's" steers in the particular experiment.

Derivation of the Maintenance and Gain Coefficients

It is evident from the preceding sections that high accuracy regarding the general level of the constants is not needed to give accurate figures for acres-per-head and gain-per-acre. Accuracy with respect to how the coefficients are changed for various "farmer's" steers is of more importance, but again is not critical. It may be argued on general principles, however, that the coefficients should be ascertained as accurately as possible. In addition some workers might
wish to compare the T.D.N. "yields" of grazed pastures with yields of hay or some other crop, even though the computation of "yield" is intended only as an intermediate step in the present procedure.

**Gain coefficients:**

To arrive at the gain coefficients, the slaughter data of Haecker (1920) and Moulton, Trowbridge and Haigh (1922), as presented by Arnsby and Moulton (1925), served as the basis. Arnsby and Moulton tabulated the energy content of the gains of beef steers during various growth periods. For the present purposes these were converted to T.D.N. on the basis that 1 therm of Net Energy for body increase is equivalent to 1.10 pounds of T.D.N. in the form of roughage. This conversion factor is based on figures cited by Brody (1945).

In the above data, cattle 10 to 20 months old, and fed either for "scanty growth" or for "full growth without appreciable fattening" (data of Moulton, *et al*), showed T.D.N. equivalents of .9 to 1.6 pounds per pound of gain, with an average at about 1.3. This average was considered to represent the gain coefficient for calves and yearlings on native range. For cattle of the same age and either "kept in normal condition" (data of Haecker) or "full fed from birth" (data of Moulton, *et al*), the T.D.N. equivalents per pound of gain ranged from 1.5 to 3.3 with an average about 2.3. The gain coefficient for calves and yearlings on tame pasture was considered to be halfway between the latter average and the previous one, 1.3. Thus, 1.8 was adopted.

Cattle 20 to 30 months old and on the lower feeding levels showed T.D.N. equivalents of 1.4 to 3.2 with an average about 2.0. This was accepted as the gain coefficient for long yearlings and two-year olds on native range. The heavier fed cattle of the same age showed T.D.N. equivalents of 2.0 to 4.0 with
an average at 2.5. Since the composition of the gain in older cattle is not very
dependent on feeding level, 2.5 was adopted as the gain coefficient for long
yearlings and two-year olds on tame pasture. Further support for the figure, 2.5,
is presented below.

Maintenance coefficients — general levels:

To arrive at maintenance coefficients the problem was attacked in two parts;
first, the assessment of general level, and second, the determination of the
manner in which the coefficients should vary with body weight. In view of the
fact that high accuracy for the coefficients is not required for the method, the
details of how the figures were obtained will not be given. The procedures will
be outlined, however, in order that those who might wish to use the T.D.N. yields
for comparative purposes may judge their value.

A lower limit for the maintenance coefficients was obtained using the data of
Haecker as summarized by Morrison (1936). These data were analyzed by a method
similar to the algebraic partition method of Brody (1945). For steers in the
neighborhood of 1,000 pounds, a figure of 0.0 was obtained for the maintenance
coefficient and one of 2.6 for the gain coefficient. The maintenance coefficient
is essentially the same as that used by Morrison (1940) and that found by Brody
(1945), as well as others, for dairy cows weighing 1,000 pounds. It is also not
far from the figure given for beef steers by Armsby and Moulton (1926), using the
data of Moulton et al, previously referred to. The gain coefficient is in agree­
ment with the figure of 2.5 for older steers on tame pastures, previously presented.

It seems only logical to assume that the maintenance figure, 0.0, is too low,
since it was determined on "dry-lot" steers. One would expect the figure to be
higher on pastures, even on good tame pastures, because of the exercise necessary
to gather food.
To arrive at more reasonable figures for the maintenance coefficients under grazing conditions, the following procedure was used. Brody (1945) gives the energy requirement for basal metabolism of beef steers. He also gives the energy requirement (above maintenance) per pound body weight per mile for walking in the case of steers. This factor is apparently independent of speed. One might reasonably assume that the maintenance requirement on pasture is divisible into two main parts, that for basal metabolism and that for walking. Further it might be assumed that the distance walked is proportional to total energy consumed, inversely proportional to the density of daily grazable energy on the pasture, and inversely proportional also to the width of "swath" which a grazing animal "cuts". Reasonable limits, such as 1 to 2 feet, may be set on the width of "swath". Approximate ranges of values for total energy consumed and for T.D.N. density are easily arrived at. Using these and Brody's figures for basal metabolism and energy required in walking (converted to T.D.N.), and the previously determined figures for gain, it is possible, by iterative procedures, to arrive at an estimate of the T.D.N. consumed by a steer of given weight. The figure varies somewhat, of course, with width of "swath". In the case of native ranges, the maintenance coefficients indicated for 1,000-pound steers by this procedure varied from 9.2 and 12.0. Hence the more-or-less arbitrary figure of 10.6 was adopted. Similar computations for tame pastures indicated that the maintenance coefficients for 1,000-pound steers varied from 8.0 and 9.6, and the figure 8.8 was adopted.

To check the above figures, another approach was taken. The premise of this approach was that one should add to the basic figure for "dry-lot" steers,

\[ 1 \text{ therm net energy for maintenance} = 0.87 \text{ pounds of T.D.N. in the form of roughage}. \]
3.0, an amount for extra exercise involved in the grazing process. Shippard (1921) and Cary (1927) give estimates of distance "traveled" by grazing steers on native ranges. The values given are roughly 2 to 5 miles per day. These represent only the major movements of the cattle, such as going to and from water and changing grazing grounds. The milling around while grazing was not included and neither were night movements in one case. In addition, grazing involves many little items of work expenditure not necessary in the dry lot. These observations and considerations led to the adoption of a figure of 7 miles for native ranges and one or two miles for tame pastures. Using the conversion factors for energy of walking, previously referred to, maintenance coefficients of 8.6 for tame pastures and 10.1 for native ranges were thus obtained. Since these were not seriously different from those previously decided upon, i.e., 8.6 and 10.6, the latter were retained.

There is a possibility that the adopted maintenance coefficient for native range is in error by as much as 10 per cent, and the one for tame pasture, in error by 5 per cent. The figures adopted for the gain coefficient appear to have similar errors. As has previously been illustrated these errors are of no importance in computing acres-per-head and gain-per-acre. T.D.N. "yields" are, however, subject to these errors, totalling 10 to 15 per cent. This should be remembered if reporting figures for T.D.N. "yield".

Maintenance coefficients - relation to body weight:

The manner in which the maintenance coefficients should be related to body weight was attacked as follows: It is well established that basal metabolism and resting maintenance vary as the three fourths power of weight. On the other hand, energy used in the exercise of grazing is essentially proportional to
weight. Therefore, in grazing animals, maintenance must vary as weight to some power intermediate to three-fourths and one.

To estimate the correct exponent for grazing experiments, advantage was taken of the findings with regard to exercise discussed above. On the average for native ranges and tame pastures considered together, about half of the energy needed for maintenance went to basal metabolism and half to exercise. Using the 50-50 partition, then, and the appropriate coefficients for basal metabolism and exercise, it was found that the "working" maintenance for various size steers was closely approximated by relating it to powers of weight ranging from .85 to .90. Hence, the seven-eights power was adopted as the basis for relating the maintenance coefficients to weight.

Research needed to improve the method:

The first criticism which comes to mind, regarding the proposed method, is that the values assigned for the maintenance and gain coefficient were not arrived at on a sound experimental basis. Hence, they are subject to considerable unknown error. It was demonstrated, however, that this criticism can be dismissed if reporting final results in terms of gain-per-head, acres-per-head, and gain-per-acre. If reporting results in terms of T.D.N. per acre, however, the criticism holds.

Because it might sometimes be advisable to report T.D.N. yields, research is needed in order to establish the constants more certainly. Slaughter studies on grazing animals under a wide variety of conditions offer one approach to ascertain the composition of gains and hence the T.D.N. required per pound.
of gain. Studies to learn the amount of "exercise" taken by grazing animals would be of great help in arriving at working maintenance. Exercise is a function not only of yield per unit area per unit time, but probably also of size and topography of pasture. Thus, the working maintenance will vary with these factors, and, in a way, will be a function of results. This complication could be managed, however, by appropriate mathematical procedures. The algebraic partition method could be used to great advantage, if methods of estimating the actual types and amounts of forage consumed were developed. Improved digestibility-ratio methods seem to offer the best possibilities for this approach.

Comments on the design of grazing experiments as related to the method:

A second criticism of the method is that the computation of results for steers other than the average experimental one is not justified, even though the maintenance and gain coefficients necessary to do so could be assumed to be known without error. Such a criticism is based on the experience that larger steers may consume more of the coarser materials on the pasture than do smaller steers, may digest all of the forage more efficiently, and, thus, may obtain more nutrients per acre than smaller ones. If this is true, the proposed procedure tends to overestimate acres-per-head somewhat in the case of the larger "farmer's" steers, and underestimate acros-per-head in the case of the smaller ones. Opposite effects on gain-per-acre occur. Estimates of gain-per-head are not affected, because they are computed solely from the observed behaviour of the appropriate steers.

The errors just mentioned will not be serious if the "farmer's" steers are not greatly different from the average experimental steer. But if, say,
yearlings and two-year olds, are run together on the same pastures, the errors might be considerable. This does not mean, however, that uniformity of steers is desirable. Rather the experiment should be so designed that, despite heterogeneity, the errors are kept small.

Ideally one should use a variety of "farmer's" steers sufficiently wide to represent the area of practice to which the results are to be applied. In addition, a "standard" steer could well be represented in all grazing experiments, so that results may be compared from time to time and experiment to experiment over a wide variety of conditions.

The "standard" and various "farmer's" steers represented may form a quite heterogeneous group. In order to circumvent the errors due to varying utilization, then, the different kinds of steers should be divided into two or more major groups, which are placed on separate pastures. In the case of tame pastures this point may not be critical at all, but in native ranges it would seem to be important.

Nature of errors in the method and remarks on statistical analysis:

The errors associated with the method, as discussed in this paper, are in the nature of biases. The usual random errors also will be present in any experimental data. These are principally due to animal variations other than those taken into account, and to between-pasture variability which attributable to differences in soil, botanical composition, stand, etc. The latter errors are 10 to 25 per cent on a per pasture basis. These unavoidable errors are, thus, usually, more important than any due to the deficiencies of the method.

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1/ The standard steer could be represented, for example, by a group of yearling Hereford steers, varying in initial weight from 350 to 450 pounds with an average at about 400, and limited to a certain range and average as regards body condition.

2/ Unpublished data at the North Carolina Station.
A statistical analysis of gain-per-head is possible in either replicated or non-replicated experiments. Since, however, each pasture provides only a single figure for each "farmer's" steer with regard to acres-per-head, gain-per-acre, and T.D.N. yield, a statistical analysis of these is possible only in replicated experiments, unless one is interested in only comparing different "farmer's" steers.

Usage with animals other than steers:

The present method was developed with steer grazing studies in mind. There seems to be no reason, however, that the same method, with the same maintenance and gain coefficients, can not be used satisfactorily for work with beef heifers and young dairy animals of either sex. It is recommended, therefore, for these classes of animals as well.

Reporting results:

Future research will no doubt make necessary some changes in the maintenance and gain coefficients given here. This being the case, it seems advisable to publish more data than just gain-per-head, acres-per-head, and gain-per-acre for the average experimental and various "farmer's" steers. In addition, the maintenance units and gain units supported by the pasture, and those required to be supported for each "farmer's" steer should be reported along with the maintenance and gain coefficients used. The experimental steers and the various "farmer's" groups should be also adequately described (See Table 3). The publication of such figures would allow recomputation of results with improved coefficients when such become available.
Summary

A method for computing the results from steer grazing experiments is presented. It was especially developed for studies in which the "put-and-take" method of handling the animals is used. If a variety of steers are used in the trial, it also allows interpretation in terms of steers ("farmer's" steers), which differ considerably from the average experimental steer. The procedure is recommended for work with beef heifers and young dairy animals as well as with steers.

Results are computed as gain-per-head, acres-per-head and gain-per-acre, for each of a variety of "farmer's" steers, as well as for the average experimental steer. Each gain-per-head figure is computed directly from the gains of appropriate groups of the experimental animals. The acres-per-head figures are arrived at indirectly. This is accomplished by first computing the T.D.N. "yield" of the pasture, and the T.D.N. "requirements" of the various "farmer's" steers. The acres-per-head figures are then calculated as (pasture acreage)(requirement)/(yield). The gain-per-acre figures are obtained as (gain-per-head)/(acres-per-head).

It is shown that the inherent errors (biases) of the method are negligible for acres-per-head and gain-per-acre. These two measures as well as gain-per-head are, of course, subject to the usual random experimental errors.

The primary purpose of the method is not to arrive at the T.D.N. "yield" of a pasture, although such a figure is computed as an intermediate step. This figure is subject to bias of unknown direction which may be as large as 10 or 15 per cent. If the T.D.N. "yield" is used to compare pastures with some other crop, then, its relatively high error, which is superimposed on the usual random experimental error, should be taken into account.
Literature Cited

Armsby, H. P., and C. R. Moulton. 1925. The Animal as a Conv


