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SAMPLE NUMBERS FOR FORAGE PRODUCTION DETERMINATIONS[1]

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Range scientists and technicians constantly are confronted with the problem of determining the number of samples necessary to attain a given degree of accuracy in forage production measurements. This is due to the variability that occurs in vegetation because of changes in the soil, plant species, or physiographic differences--such as slopes, exposure, etc.--and the habits of the animals grazing on the area.

Literature on the variability of native vegetation is limited. Pechanec (1941) reported a coefficient of variation for forage production of 20 per cent for the sagebrush-grass ranges of Idaho. He also reported (1940) coefficients of variation of 64 per cent for arrowleaf balsamroot and 103 per cent for tapertip hawksbeard, with other species as high as 141 per cent. Davies (1931) in Australia reported forage yields of natural vegetation with a coefficient of variation of 32.5 per cent. Beruldsen and Morgan (1934), also working in Australia with pastures composed of ryegrass, Kentucky bluegrass, cocksfoot, and clovers, reported similar variations in forage production. Hanson (1934) reported a coefficient of variation of 27.8 per cent for the mixed prairie of North Dakota. Neven (1945) found a coefficient of variation of 23.7 per cent for bluegrass pastures of Illinois. Costello and Kipple (1939) state that no relationship exists between the size of vegetational type and the number of samples needed for any given degree of accuracy on the ranges of Colorado and Wyoming.

Formulae for the determination of sample numbers are important to the investigator since no tables appear in the literature showing the number of samples necessary for a given degree of accuracy. Hanson (1934) and Neven (1945) have used the formula $N = S^2(p\bar{x})^2$ to calculate the number of samples necessary to achieve the accuracy of p (percentage of the mean). The odds are 2 to 1 that the population mean lies within the desired limit (p) in the above formula. Any estimates calculated by the use of this formula would err in one-third of the cases. Pechanec (1941) states that the sampling error of the estimated forage yield of a section of sagebrush-grass range was 18 per cent. He further states that the odds are 2 to 1 that the actual forage yield of the section of land was within 18 per cent of the estimate. Experimental work in other fields has shown that odds of at least 19 to 1 or 99 to 1 should be used.

Other formulae are available that permit the investigator to obtain estimated sample numbers that are more reliable than those used by Pechanec. Such formulae are shown by Snedecor (1946).

1. $N = t^2s^2/(\bar{x} - m)^2$
2. $N = (100)^2t^2s^2/p^2\bar{x}^2$
3. $N = t^2C^2/p^2$
4. $C^2 = (100)^2s^2/\bar{x}^2$

N = number of required samples	p = desired limits in per cent of the mean
t = the value of students	C = coefficient of variation
s = the standard deviation	100 = one hundred per cent
$\bar{x}$ = sample mean	m = population mean

In most range work these formulae provide an estimate of the number of samples required for a given degree of accuracy in the measurements made on any set of values. These formulae are applicable to forage production and botanical composition data.

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The first formula lends itself readily to determinations of the number of samples necessary to set a desired limit around the sample mean. Suppose that an area of range land has been sampled to determine the forage yield and that 300 samples were used, and that the standard deviation was 100 pounds per acre, and the desired limits around the mean were 50 pounds per acre ($\bar{x}$ - m), and the mean was 400 pounds per acre. For a sample as large as 300, a t value of 2.6 is a close enough approximation to the one per cent level of significance. Therefore, $N = (2.6)^2\ (100)^2/(50)^2$ and N = 27.04 is an indication of the number of samples necessary to measure the production to within 50 pounds per acre of the mean when the standard deviation is 100 pounds per acre with odds of 99 to 1 that the population mean falls within the limits set around the sample mean. This formula can be used in terms of the coefficient of variation and the limits should then be expressed as a percentage of the mean. Thus the second formula becomes of value to the investigator.

$$N = (100)^2 t^2 s^2 / p^2 \bar{x}^2$$

$$N = 27.04$$

Under the conditions of the above problem, the limits of 50 pounds per acre were equal to 12.5 per cent of the mean. Substitution in the above formula gives the same value for N as in the first formula. Thus the statement may be made that 28 samples (any fraction must be counted as a whole) are necessary to determine the production within 12.5 per cent of the mean. The formula may be simplified if the coefficient of variation has been calculated.

Therefore, $N = t^2 C^2/p^2$ (Formula 3).

Values of N required for a known size of the mean and standard deviation have been calculated. They are shown in Table I. Data calculated from Formula 2 indicate that 400 samples are necessary when the standard deviation is equal to the mean and that 100 samples are necessary to measure the forage production when the standard deviation is equal to one-half of the mean with an accuracy of 10 per cent at the .05 level of significance. Table II shows the calculated values for N at a limit of one per cent of the mean and at P .05.

Tables I and II permit the investigator who has a knowledge of the size of the mean and standard deviation to determine the number of samples needed without calculating the actual figures. These tables also serve to emphasize the need for using methods which will reduce the variability which occurs naturally in native vegetation. Sampling within a vegetational type may reduce the amount of variability with which the experimenter must contend. Thus, it lessens the amount of work that must be done for any desired degree of accuracy for the type, but may increase the total amount of work if the area being sampled contains more than one vegetational type when the area of each type is not known nor easily measured. The influence of vegetational type on the sampling needed for any given degree of accuracy is shown in Table III in which two vegetational types have been measured and the mean and standard deviations determined for each type. On the basis of the formulae given in the preceding pages, 129 samples are necessary to sample each area separately--that is, the sum of the samples necessary to sample type A plus the number of samples necessary to sample type B. One hundred and twelve samples are necessary to sample the total area of A plus B as calculated by the given formula. These data indicate that it would require fewer samples to consider the two vegetational types as one and not two. However, if the information shown above already is known and the area covered by each can be determined, then the number of samples required for estimating the mean at some given limit is considerably smaller than the sum of the required numbers for each area or the two areas as one.

Let c be the fraction of the total area covered by Little Bluestem (Area A) and 1-c the fraction of Improved Pasture (Area B). Then if $\bar{x}_1$ is the mean for A samples and $\bar{x}_2$ is the mean for B samples, the estimated mean for the total area will be $\bar{x} = c\bar{x}_1 + (1-c)\ \bar{x}_2$ and the variance of $\bar{x}$ will be

$$V_{\bar{x}} = \frac{c^2 \sigma_1{}^2}{n_1} + \frac{(1-c)^2\ \sigma_2{}^2}{n_2}$$

where $\sigma_1{}^2$ is the variance of A samples, $\sigma_2{}^2$ is the variance of B samples, n_1 is the number of A samples and n_2 is the number of B samples.

It is recognized that making n_1 and n_2 equal would seldom result in the most efficient use of time, labor, and money in studying forage production. Likewise, the type which contributes most to the total should be estimated best if the most efficient use of labor is to be made. The problem then is to determine the optimum ratio of n_1 and n_2. This may be done as follows:

Let the total number of samples to be taken be N and let a signify the fraction of these to be of type A, then,

$$n_1 = aN$$

$$n_2 = (1-a)N$$

$$\text{and } V_{\bar{x}} = \frac{c^2\sigma_1{}^2}{aN} + \frac{(1-c)^2\sigma_2{}^2}{(1-a)N}$$

Now find the value of a that makes $V_{\bar{x}}$ as small as possible with any fixed number (N) of samples. This may be done as follows: Equate the derivative of $V_{\bar{x}}$ with respect to a to zero and solving for a. This derivative is:

$$\frac{dV_{\bar{x}}}{da} = \frac{-c^2\sigma_1{}^2N}{a^2N^2} + \frac{(1-c)^2\sigma_2{}^2N}{(1-a)^2N^2}$$

Setting it equal to zero, we have:

$$\frac{-c^2\sigma_1{}^2N}{a^2N^2} + \frac{(1-c)^2\sigma_2{}^2N}{(1-a)^2N^2} = 0$$

Multiply by N:
$$\frac{-c^2\sigma_1{}^2}{a^2} + \frac{(1-c)^2\sigma_2{}^2}{(1-a)^2} = 0$$

Transfer first term to the right side:

$$\frac{(1-c)\sigma_2{}^2}{(1-a)^2} = \frac{c^2\sigma_1{}^2}{a^2}$$

Taking the square root:

$$\frac{(1-c)\sigma_2}{1-a} = \frac{c\sigma_1}{a}$$

Solve for a:
$$a = \frac{c\sigma_1}{c\sigma_1 + (1-c)\sigma_2}$$

Now substitute $c = .62$, $\sigma_1 = 413$, and $\sigma_2 = 220$

Then $a = .75$

Thus, the optimum distribution of samples is ¾ to Type A, and ¼ to Type B. Now if the mean is to be estimated within 10 per cent with 95 per cent assurance (P = .05) $V_{\bar{x}}$ must equal $(.1\bar{x}/t)^2$. Set them equal and the following calculations provide the number of samples necessary for estimating the mean production.

$$V_{\bar{x}} = \frac{c^2\sigma_1{}^2}{aN} + \frac{(1-c)^2\sigma_2{}^2}{(1-a)N} = \frac{(.1)^2\bar{x}^2}{t^2}$$

Substituting numerical values:

$$\frac{(.62)^2\ (413)^2}{.75N} + \frac{(.38)^2\ (220)^2}{.25N} = \frac{(.01)\ (923)^2}{4}$$

Solve for N:

N = 54.2, which should be estimated at 55 when the numbers are rounded.

Thus, N being equal to 55, we have achieved a considerable saving in the number of samples required to achieve a given degree of accuracy. In this case, 55 represents a reduction in the number of required samples of approximately 60 per cent as compared with sampling the areas A and B as one area and a reduction of 57.4 per cent in the numbers required for separate sampling where the mean production and variance of the two areas are considered separately.

As long as the relative sizes of sub-areas are known, sampling by type will always be more efficient if the means for the types differ. As the differences grow greater, more will be gained from sampling by types. If the magnitude of the sub-areas is not known, then one is confronted with the problem of determining whether measuring them will be less costly than the extra samples required for equal precision when sampling is completely random. As the differences in strata means increase, the information derived may be less accurate to allow estimates from stratified sampling to be better than estimates obtained with equal cost under a program of random sampling.

Sampling by vegetational type allows for wider application of the results within the same general climatic and edaphic area. The sampling of areas with an artificial boundary that does not follow changes in the vegetation does not permit the wide use of the results and their application to other areas because other areas will not contain the vegetational types in the same proportions as in the experimental area. Thus, results obtained by sampling vegetational types are applicable over a greater range of area than are the results obtained by sampling artificial units, such as pastures. This does not mean that vegetation should be sampled on the smallest type available but that the sampling should be based on the vegetational type that is present over a wide area, and that it should not be limited to areas bounded by artificial boundaries such as fences.

Many investigators wish to set limits of a certain size around the mean. This may be done by the use of the first formula, where (x - M) is equal to the limits desired. Calculations based on this formula are shown in Table IV.

A certain amount of regularity in the table permits the formulation of two rules:

1. If the limit desired is 50 per cent of the standard deviation, 16 samples are required.
2. If the limit desired is 25 per cent of the standard deviation, 64 samples are required.

Table IV is of less value than Table I and Table II to the investigator who fails to recognize that the limits expressed are not in terms of a certain percentage of the mean, but are in relation to the size of the standard deviation. Thus, the investigator must determine the desired limits in relation to the mean before using Table IV. Hodgson (1942), Lommasson (1942), and Rhoads (1945) have attempted to measure forage yields in terms of animals, or they have tried to devise methods whereby the forage production could be estimated.

The reason that studies that have tried to use clipping data to estimate animal consumption have not been successful is apparent in Table V. An accuracy of one per cent at P .01 or P.05 is deemed to be greater than can be obtained by clipping samples. Yet, when this accuracy is applied to clipping data, the error on 640 acres may be as high as 23 animal unit grazing days when the forage production is only 100 pounds per acre. When the average forage production is 2,000 pounds per acre, the number of grazing days in error may be as high as 457. On a section of land that will carry one animal unit on 10 acres, this is an error of 7.14 grazing days for each of the 64 animal units on the pasture. If a five per cent limit of the mean were used, the error per animal unit may be as high as 35.73 grazing days. A limit of 10 per cent has often been accepted as a reasonable limit. When this limit is applied to a section of land with an average forage production of 1,400 pounds per acre, the error may be as high as 3,200 animal unit grazing days or 50 grazing days per animal unit, if the pasture will carry one animal unit on 10 acres.

These calculations would indicate that a one per cent error is necessary if the number of grazing days on a pasture were to be calculated from clipping data. Table II shows the number of samples necessary to obtain this accuracy in clipping measurements. Often, the investigator is unable to take the number of samples indicated in Table II. The only recourse is to take as many samples as possible and to use the data to calculate his actual limits and interpret his data in terms of the limits which were obtained.

Even if an investigator uses the estimated number of samples necessary for desired limits, he should always calculate the actual limits obtained in his measurements. This may be done by the formulae used for the calculation of the sample size.

While important, the random errors considered here may not be as important as errors resulting from the possibilities (1) that what the animal harvests may be different from that which is harvested with the clipper, or (2) that due to qualitative variation in forage (*i.e.*, 28 pounds) may not truly represent an animal unit grazing day.

SUMMARY

Formulae and tables are listed for the calculation of the number of samples needed to measure forage production within desired limits. These tables enable the investigator to determine sample size without calculating.

Data are given to indicate the amount of error that occurs when desired limits of accuracy are applied to clipping data and the results are evaluated in terms of animal unit grazing days. The one per cent error of the mean at P .05 was judged most desirable for critical work on grazing capacity.

Stratification of range areas on the basis of natural vegetative units is advocated as increasing the value of data obtained by clipping in relation to their application to similar range areas and to reduce the amount of labor and money required for a given degree of accuracy.

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Table I. The Number of Samples Required to Determine Forage Production to an Accuracy Within 10 Per Cent of the Mean Production. Formula 2. (P.05 = 2.00).

Ave. prod. (lbs. /acre)	Standard deviation (pounds per acre)											
	50	100	150	200	250	300	350	400	450	500	550	600
100	100	400	900	1,600	2,500	3,600	4,900	6,400	8,100	10,000	12,100	14,400
150	45	178	400	712	1,112	1,600	2,178	2,845	3,600	4,445	5,378	6,400
200	25	100	225	400	625	900	1,225	1,600	2,025	2,500	3,025	3,600
250	16	64	144	256	400	576	784	1,024	1,296	1,600	1,936	2,304
300	12	45	100	178	278	400	545	712	900	1,112	1,345	1,600
350	9	33	74	131	205	294	400	523	662	817	988	1,176
400	7	25	57	100	157	225	307	400	507	625	757	900
450	5	20	45	80	124	178	242	317	400	494	598	712
500	4	16	36	64	100	144	196	256	324	400	484	576
600	3	12	25	45	70	100	137	178	225	278	337	400
700	3	10	19	33	52	74	100	131	166	205	247	294
800	2	7	15	25	40	57	77	100	127	157	190	225
900	2	5	12	20	31	45	61	80	100	124	150	178
1,000	1	4	9	16	25	36	49	64	81	100	121	144
1,100	1	4	7	14	21	30	41	53	67	83	100	120
1,200	1	3	7	12	18	25	35	45	57	70	85	100
1,300	1	3	6	10	15	22	29	38	48	60	72	86
1,400	1	3	5	9	13	19	25	33	42	52	62	74
1,500	1	2	4	8	12	16	22	29	36	45	54	64
1,600	1	2	4	7	10	15	20	25	32	40	48	57
1,700	1	2	4	6	9	13	17	23	29	35	42	50
1,800	1	2	3	5	8	12	16	20	25	31	38	45
1,900	1	2	3	5	7	10	14	18	23	28	34	40
2,000	1	1	3	4	7	9	13	16	21	25	31	36
2,200	1	1	2	4	6	8	11	14	17	21	25	30
2,400	1	1	2	3	5	7	9	12	15	18	22	25
2,600	1	1	2	3	4	6	8	10	12	15	18	22
2,800	1	1	2	3	4	5	9	9	11	13	16	19
3,000	1	1	1	2	3	4	6	8	9	12	14	16
3,200	1	1	1	2	3	4	5	7	8	10	12	15
3,400	1	1	1	2	3	4	5	6	8	9	12	13
3,600	1	1	1	2	2	3	4	5	7	8	10	12
3,800	1	1	1	2	2	3	4	5	6	7	9	10
4,000	1	1	1	1	2	3	4	4	6	7	8	9

These values of N may be converted to the odds of 99:1 by multiplying by 1.69.

$$(P.01)^2/(P.05)^2 = (2.6)^2/(2)^2 = 1.69.$$

Table II. The Number of Samples Required to Determine Forage Production Within an Accuracy of One Per Cent of the Mean Production. Formula 2. (0 .05).

Avg. prod. (lbs. /acre)	Standard deviation (pounds per acre)											
	50	100	150	200	250	300	350	400	450	500	550	600
100	10,000	40,000										
150	4,445	17,778	40,000									
200	2,500	10,000	22,500	40,000								
250	1,600	6,400	14,400	25,600	40,000							
300	1,112	4,445	10,000	17,778	27,778	40,000						
350	817	3,266	7,347	13,060	20,409	29,388	40,000					
400	625	2,500	5,625	10,000	15,625	22,500	30,625	40,000				
450	494	1,976	4,445	7,903	12,347	17,780	24,200	31,609	40,000			
500	400	1,600	3,600	6,400	10,000	14,400	19,600	25,600	32,400	40,000		
600	278	1,112	2,500	4,445	6,945	10,000	13,612	17,778	22,500	27,778	33,612	40,000
700	205	817	1,837	3,266	5,103	7,347	10,000	13,062	16,531	20,409	14,694	29,388
800	157	625	1,407	2,500	3,907	5,625	7,657	10,000	12,657	15,625	18,907	22,500
900	124	494	1,112	1,976	3,087	4,445	6,050	7,902	10,000	12,346	14,939	17,787
1,000	100	400	900	1,600	2,500	3,600	4,900	6,400	8,100	10,000	12,100	14,400
1,100	83	331	744	1,323	2,067	2,976	4,050	5,290	6,695	8,265	10,000	11,901
1,200	70	278	625	1,112	1,737	2,500	3,403	4,445	5,625	6,945	8,403	10,000
1,300	60	237	533	947	1,480	2,131	2,900	3,787	4,793	5,918	7,148	8,521
1,400	52	205	460	817	1,276	1,837	2,500	3,266	4,133	5,103	6,174	7,347
1,500	45	178	400	712	1,112	1,600	2,178	2,845	3,600	4,445	5,378	6,400
1,600	40	157	352	625	977	1,407	1,915	2,500	3,165	3,907	4,727	5,625
1,700	35	139	312	554	866	1,246	1,696	2,215	2,803	3,461	4,187	4,983
1,800	31	124	278	494	772	1,112	1,513	1,976	2,500	3,087	3,735	4,445
1,900	28	111	250	444	693	998	1,358	1,773	2,244	2,771	3,352	3,989
2,000	25	100	225	400	625	900	1,225	1,600	2,025	2,500	3,025	3,600
2,200	21	83	186	331	517	744	1,013	1,323	1,674	2,067	2,500	2,976
2,400	18	70	157	278	435	625	851	1,112	1,407	1,737	2,101	2,500
2,600	15	60	134	237	370	533	725	947	1,199	1,480	1,790	2,131
2,800	13	52	115	205	319	460	625	817	1,034	1,276	1,544	1,837
3,000	12	45	100	178	278	400	545	712	900	1,112	1,345	1,600
3,200	10	40	88	157	245	352	479	625	792	977	1,182	1,407
3,400	9	35	78	139	217	312	424	554	701	866	1,047	1,246
3,600	8	31	70	124	193	278	379	494	625	772	934	1,112
3,800	7	28	63	111	174	250	340	444	561	693	838	998
4,000	7	25	57	100	157	225	307	400	507	625	757	900

These values of N may be converted to the odds of 99:1 by multiplying by 1.69.

$$(P.01)^2/(P.05)^2 = (2.6)^2/(2)^2 = 1.69.$$

Table III. The Influence of Widely Divergent Means and Standard Deviation on the Number of Samples Necessary for an Accuracy of 10 Per Cent of the Mean at P .05.

Vegetational type	Mean (lbs. per acre)	Standard deviation (lbs. per acre)	Number of samples necessary for 10 per cent error at P.05
A. Little Bluestem (ungrazed)	1,188	413	48
B. Improved Pasture (heavily grazed)	490	220	81
C. A plus B	923	488	112

Table IV. The Size of Sample Necessary for Determination of the Forage Production Within Desired Limits of Mean with a Known Standard Deviation. p .05.

Limits (lbs. /acre)	Standard Deviation (pounds per acre)									
	50	100	150	200	250	300	350	400	450	500
25	16	64	144	256	400	576	784	1,024	1,296	1,600
50	4	16	36	64	100	144	196	256	324	400
100	1	4	9	16	25	36	49	64	81	100
150	1	2	4	7	11	16	22	28	36	44
200	1	1	2	4	6	9	12	16	20	25
250	1	1	1	3	4	6	8	10	13	16
300	1	1	1	2	3	4	5	7	9	11

Table V. The Amount of Error in Forage Production Measurements in Terms of Animal Unit Grazing Days per Section of Land (640 acres) in Relation to the Mean Production and the Desired Accuracy of Sampling. (28 pounds of dry matter per day per animal unit).

Average forage production (lbs/acre)	Accuracy desired (per cent of the mean forage production per section)				
	Animal unit grazing days				
	1	5	10	15	20
100	23	114	229	343	457
200	46	229	457	686	914
300	69	343	686	1,029	1,371
400	91	457	914	1,371	1,829
500	114	571	1,143	1,714	2,286
600	137	686	1,371	2,057	2,743
700	160	800	1,600	2,400	3,200
800	183	914	1,829	2,743	
900	206	1,029	2,057	3,086	
1,000	229	1,143	2,286	3,429	
1,200	274	1,371	2,743		
1,400	320	1,600	3,200		
1,600	366	1,829			
1,800	411	2,057			
2,000	457	2,286			
2,200	503	2,514			
2,400	549	2,743			
2,600	594	2,971			
2,800	640	3,200			
3,000	686				
3,200	731				
3,400	777				
3,600	823				
3,800	869				
4,000	914				