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Effect of sample size and method of sampling pig weights on the accuracy of estimating the mean weight of the population

Abstract

Producers have adopted marketing strategies such as topping to help cut economic losses at the processing plant. Even though producers are implementing these strategies, they are still missing target weights and receiving substantial discounts. To assess this situation, we must first determine the accuracy of sampling methods producers use to estimate the mean weight of the population. The standard sampling procedure that has been adapted by many producers is to weigh a subsample of pigs in multiple pens (i.e., 5 pigs from 6 pens). Using a computer program developed in R (R Foundation for Statistical Computing, Vienna, Austria), we were able to generate 10,000 sample means for different sampling procedures on 3 different datasets. Using this program we evaluated taking: (1) a completely random sample of 10 to 200 pigs from the barn, (2) an increasing number of pigs per pen from 1 to 15 or the entire pen, and (3) increasing the number of pens until all pens had been sampled in the 3 separate datasets. This allowed us to provide tables for producers to decide on the sampling method and size necessary to achieve an acceptable estimation of pig weight in the barn. The analysis indicated that the number of pigs can be decreased by increasing the number of pens; however, the confidence interval (range in which 95% of weight estimates would fall) was still as high as 23 lb (242 to 265 lb) when only 30 pigs were sampled. Increasing the number of pens reduced the range between the upper and lower confidence interval, but not enough to make increasing pen sample size a practical means of estimating mean pig weight of the barn. Other methods of analysis must be designed to improve the accuracy of estimating pig mean weight in a facility other than random sampling of pigs within the barn.; Swine Day, Manhattan, KS, November 17, 2011

Keywords

Swine Day, 2011; Kansas Agricultural Experiment Station contribution; no. 12-064-S; Report of progress (Kansas State University. Agricultural Experiment Station and Cooperative Extension Service); 1056; Swine; Finishing pig; Mean estimation; Sample size

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C B. Paulk, G L. Highland, Michael D. Tokach, Jim L. Nelssen, Robert D. Goodband, Joel M. DeRouchey, and Steven S. Dritz

Effect of Sample Size and Method of Sampling Pig Weights on the Accuracy of Estimating the Mean Weight of the Population¹

C. B. Paulk, G. L. Highland², M. D. Tokach, J. L. Nelssen, S. S. Dritz³, R. D. Goodband, and J. M. DeRouchey

Summary

Producers have adopted marketing strategies such as topping to help cut economic losses at the processing plant. Even though producers are implementing these strategies, they are still missing target weights and receiving substantial discounts. To assess this situation, we must first determine the accuracy of sampling methods producers use to estimate the mean weight of the population. The standard sampling procedure that has been adapted by many producers is to weigh a subsample of pigs in multiple pens (i.e., 5 pigs from 6 pens). Using a computer program developed in R (R Foundation for Statistical Computing, Vienna, Austria), we were able to generate 10,000 sample means for different sampling procedures on 3 different datasets. Using this program we evaluated taking: (1) a completely random sample of 10 to 200 pigs from the barn, (2) an increasing number of pigs per pen from 1 to 15 or the entire pen, and (3) increasing the number of pens until all pens had been sampled in the 3 separate datasets. This allowed us to provide tables for producers to decide on the sampling method and size necessary to achieve an acceptable estimation of pig weight in the barn. The analysis indicated that the number of pigs can be decreased by increasing the number of pens; however, the confidence interval (range in which 95% of weight estimates would fall) was still as high as 23 lb (242 to 265 lb) when only 30 pigs were sampled. Increasing the number of pens reduced the range between the upper and lower confidence interval, but not enough to make increasing pen sample size a practical means of estimating mean pig weight of the barn. Other methods of analysis must be designed to improve the accuracy of estimating pig mean weight in a facility other than random sampling of pigs within the barn.

Key words: finishing pig, mean estimation, sample size

Introduction

Swine producers must meet the processing plant's requirements for specific weights of pigs as well as weight ranges to avoid economic penalties. Pig weights within a population contain natural variability. In attempts to reduce these economic penalties, producers have adopted marketing practices such as topping, or marketing the heaviest pigs several weeks before the expected barn closeout; however, little evaluation of the accuracy of these marketing procedures has taken place. Because pig BW typically approximates a normal distribution, subsampling methods to predict the average weight of pigs in the barn can be used to model distributions of BW within the barn, but inad-

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equated data exist on the precision of subsampling methods. Therefore, we developed a method to determine the precision and bias of pig mean weight estimates for varying sample sizes and sampling methods.

Procedures

A total of 3 datasets (A, B, and C) were used to evaluate sample size and method of sampling on the precision of estimating the pig mean weight of the barn. The first method of sampling tested was a completely random sample of the barn, disregarding pen arrangements. Samples of different sizes were taken (10, 20, 30, etc.). The second method of sampling tested was comparing the number of pigs (1 to 15 pigs or the entire pen) sampled from an increasing number of pens until the various number of pigs had been selected from all of the pens.

Dataset A was derived from Groesbeck et al., 2007⁴. For dataset A (Figure 1), there was a total of 1,260 pigs with 23 to 28 pigs per pen and a total of 48 pens. The mean, median, standard deviation, and CV of the population were 253.0 lb, 254 lb, 32.8 lb, and 13.0%, respectively. Datasets B and C were obtained from research trials conducted by Elanco Animal Health. Notably, a portion of the heaviest and lightest pigs were removed from the barn prior to starting the studies for experimental design purposes, which could lead to a reduction in the variation of the barn. For dataset B (Figure 2), there was a total of 1,696 pigs with 16 to 23 pigs per pen and a total of 84 pens. The mean, median, standard deviation, and CV of the population were 275.0 lb, 277 lb, 27.1 lb, and 9.8%, respectively. For dataset C (Figure 3), there was a total of 950 pigs with 19 to 21 pigs per pen and a total of 48 pens. The mean, median, standard deviation, and CV of the population were 209.6 lb, 209 lb, 19.4 lb, and 9.3%, respectively.

A program was coded using R to demonstrate the error that varying sample sizes and methods of selecting pig weights to sample have on the estimation of the mean weight of the population. For the first method of sampling, the program was designed to take a completely random sample of the designated sample size, disregarding pen arrangements, and calculate the mean of this sample. The program then conducts this sampling technique 10,000 times, generating 10,000 sample means for each sample size (10, 20, 30, etc.) by randomly selecting the desired number of pig weights from the population. The 10,000 sample means for each sample size are sorted from least to greatest, and a 95% confidence interval (CI) is generated by selecting the 9,751st observation, the upper CI, and the 250th observation, the lower CI. The distances between the upper and lower CI represent the range of the mean estimations. Figures 4, 5, and 6 display a reference line for the upper and lower CI, and the line drawn down the middle represents the mean of the population. A similar code was conducted using R for the second method, but the second sampling method tested the sampling error among a varying number of pigs within varying numbers of pens, with 1 to 15 pigs or the entire pen sampled from 1 to all of the pens. Figures 7, 8, and 9 represent the range between the upper and lower limits associated with the varying number of pigs per pen and varying numbers of pens, and the following Tables (2, 3, and 4) list the range values.

⁴ Groesbeck, G. N., G. Armbruster, M. D. Tokach, R. D. Goodband, J. M. DeRouchey, and J. L. Nelssen. 2007. Influence of Pulmotil, Tylan, and Paylean on pig growth performance and weight variation. *Am. Assoc. Swine Vet. Proc.*, pp. 235-238.

Results and Discussion

It is important to note that the random samples were generated using a computer program, that samples taken from the barn are not truly random, and that bias can be generated. When increasing the sample size of a completely random sample from 10 to 200 pigs, the range between the upper and lower CI was reduced when estimating the mean (Figures 4, 5, and 6) for all 3 datasets. A majority of the improvement in the precision of the estimation occurred when the sample size was increased from 10 to 90 pigs (Table 1). The difference in accuracy of sample size between the different datasets is also important to note. This could result from the difference in the standard deviation of each dataset along with the distribution of each dataset (Figures 1, 2, and 3). Any removal of lightweight pigs prior to starting pigs on test may have altered the variation of pigs within the dataset, which may be particularly evident in datasets B and C.

As both the number of pigs and the number of pens were increased when sampling, the range or distance between the upper and lower CI decreased (Figures 7, 8, 9 and Tables 2, 3, and 4). For the barn with the most variation, increasing the number of pens sampled while keeping the total number of pigs sampled constant led to a reduction in range between the upper and lower CI (Table 5). For dataset A, when sampling 15 pigs from 2 pens the estimated range between the upper and lower CI was 32 lb, but when sampling 1 pig from 30 pens the range between the upper and lower CI was to be 23.1 lb. Therefore, increasing the number of pens used when sampling the barn can improve the range between the upper and lower CI by 28%; however, this improvement was not observed in datasets B and C. The decreased variation in datasets B and C due to allotment for experimental design purposes allowed for a smaller effect or no effect on the range by increasing the number of pens sampled. Because dataset A is typical for a commercial barn and no negative effects were observed from increasing the number of pens on datasets B and C, taking a random sample from an increasing number of pens is recommended when estimating the mean of the barn.

In conclusion, sample size, method, variation, and distribution of pigs within a barn can substantially affect the precision of estimating the mean weight of all pigs in the barn. Producers should take this into consideration when weighing pigs prior to topping to make marketing decisions. Finding ways to improve the ability to accurately estimate the mean weight of pigs without drastically increasing workload could provide great benefits for producers in making marketing decisions.

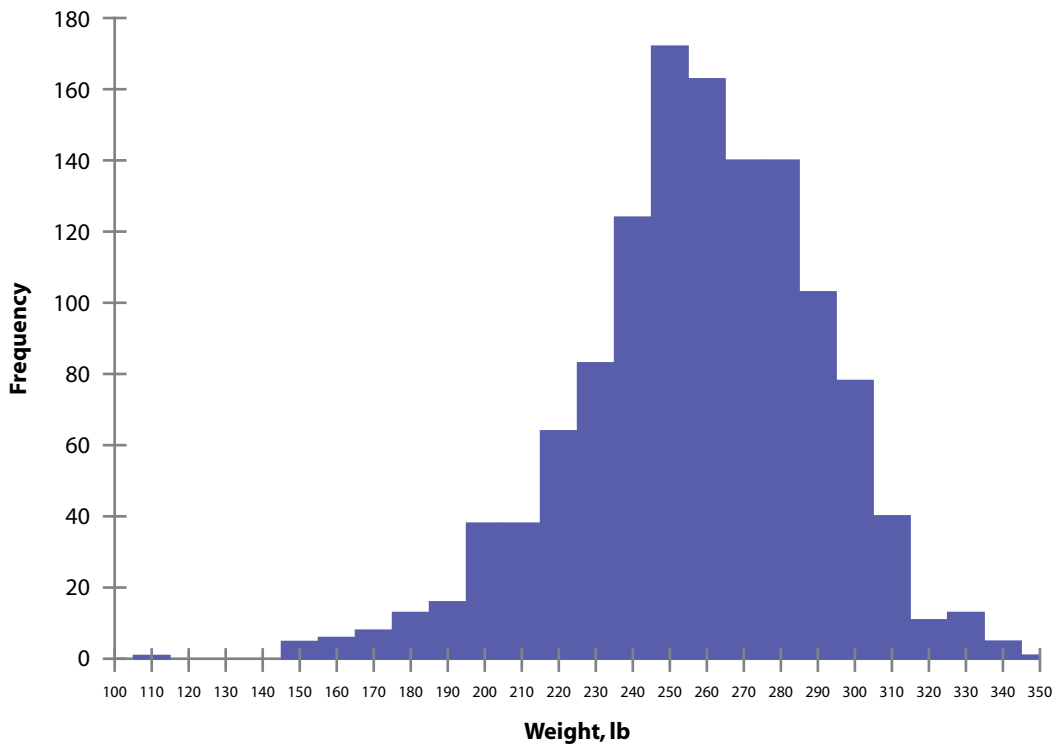


Figure 1. Histogram of dataset A. A total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) with 23 to 28 pigs per pen and a total of 48 pens.

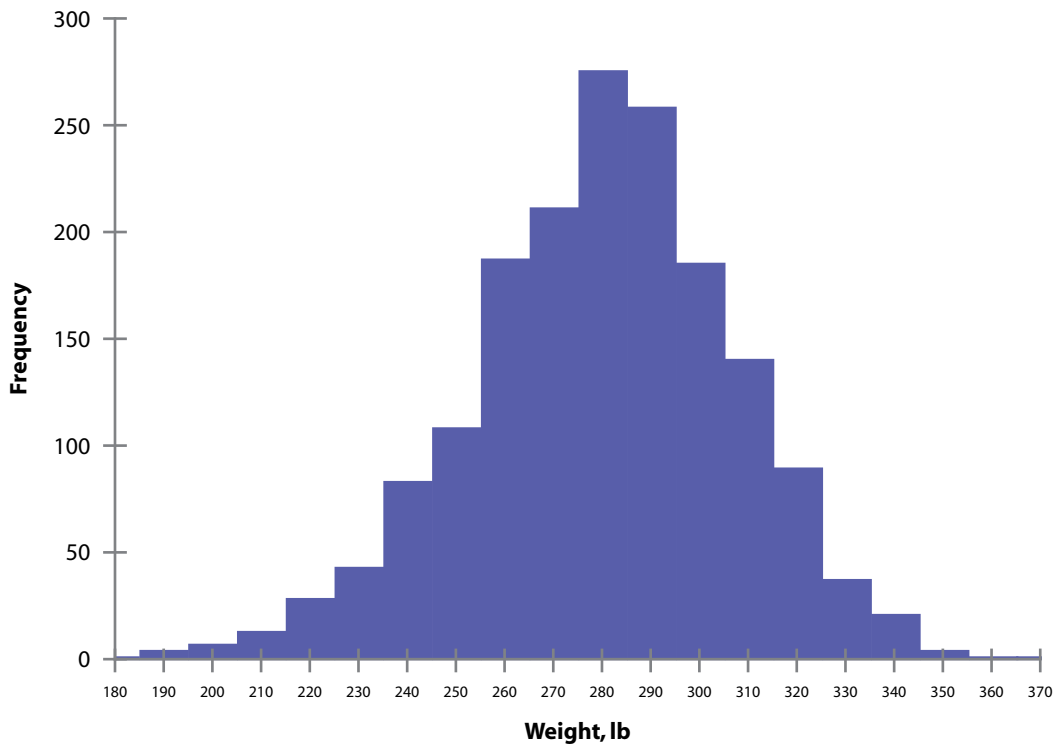


Figure 2. Histogram of dataset B. A total of 1,696 pigs (mean = 275.0 lb, median = 277 lb, standard deviation = 27.1 lb, and CV = 9.84%) with 16 to 23 pigs per pen and a total of 84 pens.

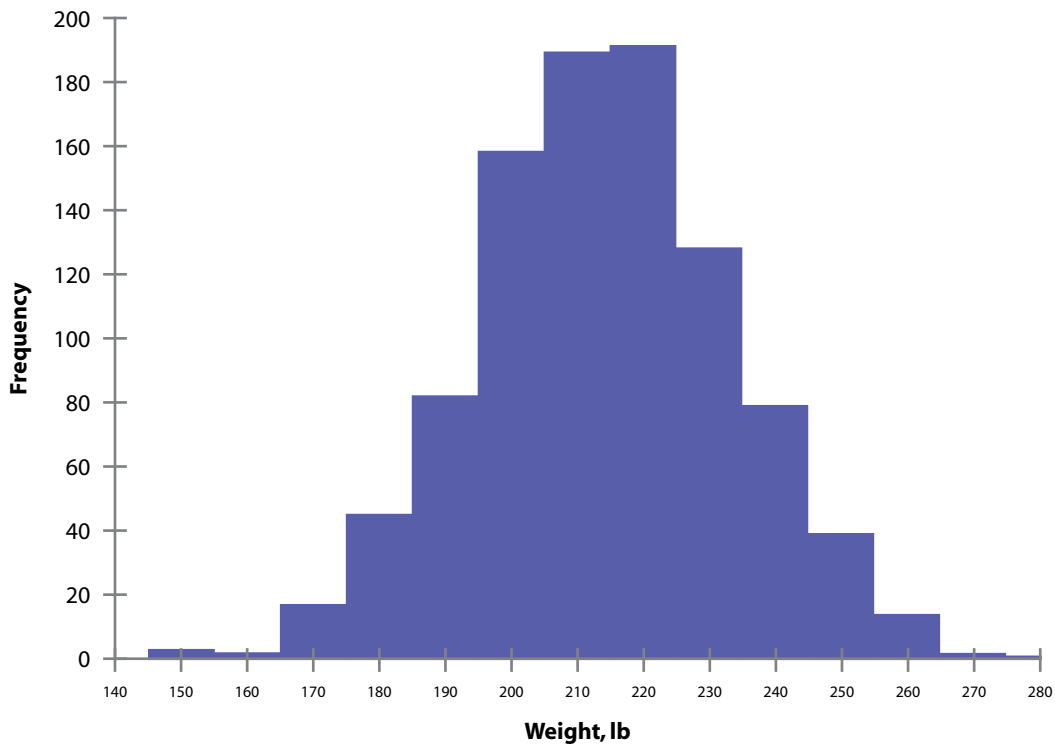


Figure 3. Histogram of dataset C. A total of 950 pigs (mean = 209.6 lb, median = 209 lb, standard deviation = 19.4 lb, and CV = 9.26%) with 19 to 21 pigs per pen and a total of 48 pens.

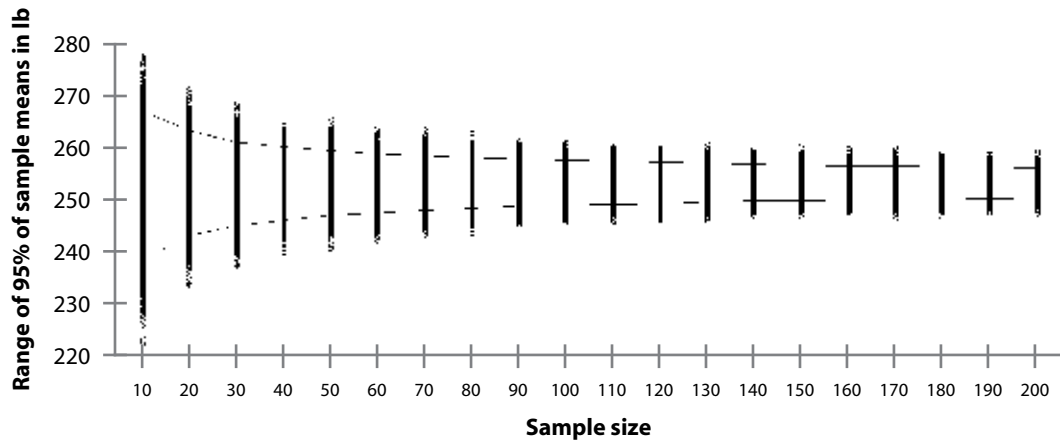


Figure 4. For dataset A, individual pig weights were collected on a total of 1,260 pigs (actual population weight = 253.0 lb and CV = 12.98%) with 23 to 28 pigs per pen. The datasets were then analyzed by taking random samples, disregarding pen arrangements, of different sample size (10, 20, 30, etc.) and calculating the mean. This was completed 10,000 times for each sample size. Each point represents the mean calculated for the respective sample. Reference lines representing the 95% confidence interval have been drawn, and the center line represents the actual population mean.

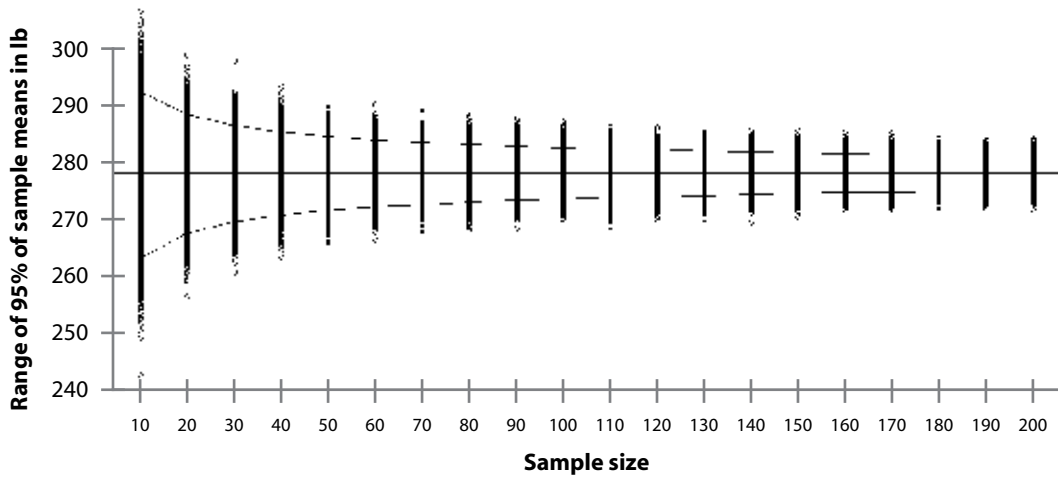


Figure 5. For dataset B, individual pig weights were collected on a total of 1,696 pigs weighed (actual population weight = 275.0 lb and CV = 9.84%) with 16 to 23 pigs per pen. The datasets were then analyzed by taking random samples, disregarding pen arrangements, of different sample size (10, 20, 30, etc.) and calculating the mean. This was completed 10,000 times for each sample size. Each point represents the mean calculated for the respective sample. Reference lines representing the 95% confidence interval have been drawn, and the center line represents the actual population mean.

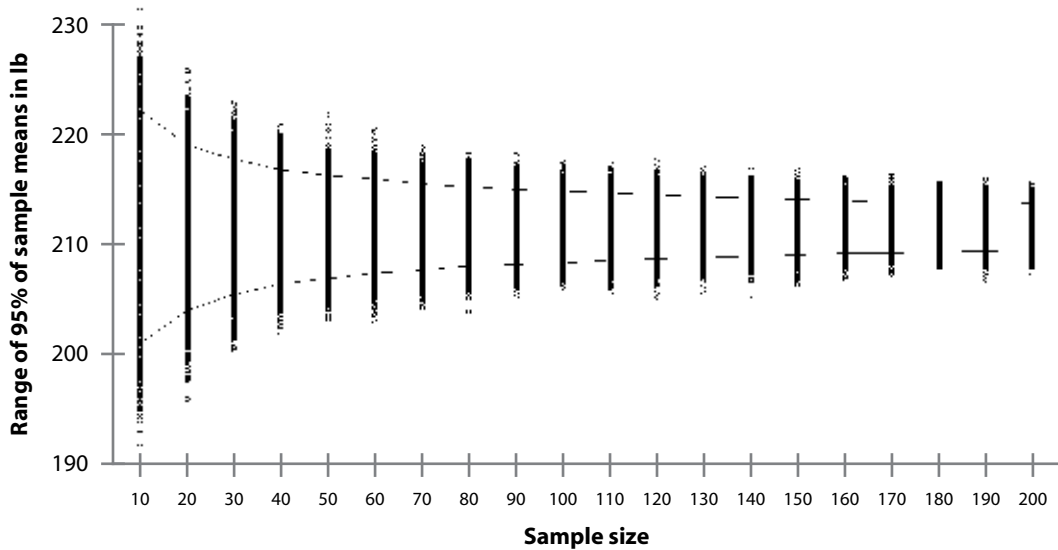


Figure 6. For dataset C, individual pig weights were collected on a total of 950 pigs weighed (Actual population weight = 209.6 lbs and CV = 9.26%) with 16 to 23 pigs per pen. The datasets were then analyzed by taking random samples, disregarding pen arrangements, of different sample size (10, 20, 30, etc.) and calculating the mean. This was completed 10,000 times for each sample size. Each point represents the mean calculated for the respective sample. Reference lines representing the 95% confidence interval have been drawn, and the center line represents the actual population mean.

Table 1. The mean upper confidence interval (CI), lower confidence interval, and range of estimates when taking a completely random sample of 30, 60, 90, or 120 pigs from dataset A, B, or C

Sampling method	Mean of 10,000 simulations	Upper CI	Lower CI	Range
Dataset A ¹				
30 pigs	253.0	264.2	241.2	22.95
60 pigs	252.9	261.0	244.7	16.25
90 pigs	253.0	259.4	246.6	12.83
120 pigs	253.0	258.6	247.2	11.36
Dataset B ²				
30 pigs	275.2	284.7	265.4	19.30
60 pigs	275.0	281.6	268.3	13.28
90 pigs	275.0	280.5	269.7	10.81
120 pigs	275.0	279.8	270.3	9.44
Dataset C ³				
30 pigs	209.6	216.4	202.7	13.73
60 pigs	209.6	214.5	204.9	9.58
90 pigs	209.6	213.3	205.7	7.61
120 pigs	209.5	212.8	206.3	6.48

¹ A total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) with 23 to 28 pigs per pen and a total of 48 pens.

² A total of 1,696 pigs (mean = 275.0 lb, median = 277 lb, standard deviation = 27.1 lb, and CV = 9.84%) with 16 to 23 pigs per pen and a total of 84 pens.

³ A total of 950 pigs (mean = 209.6 lb, median = 209 lb, standard deviation = 19.4 lb, and CV = 9.26%) with 19 to 21 pigs per pen and a total of 48 pens.

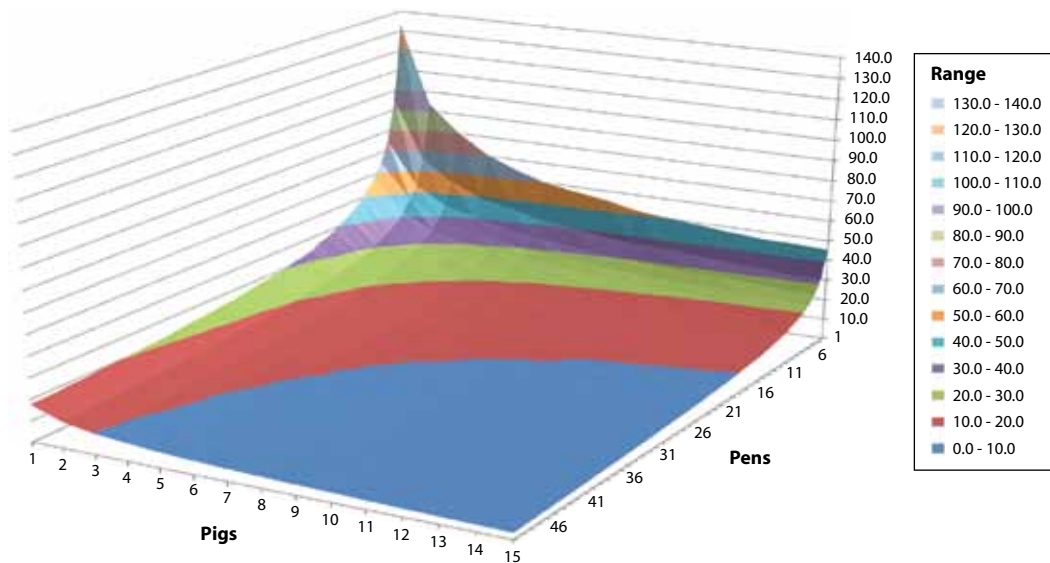


Figure 7. For dataset A, individual pig weights were collected on a total of 1,260 pigs (actual population weight = 253.0 lb and CV = 12.98%) with 23 to 28 pigs per pen. The dataset was analyzed by estimating the overall mean using different sampling methods. These methods explored different numbers of pigs selected within pens, and total number of pens sampled. This was completed 10,000 times for each sampling method and the range or difference between the upper and lower confidence interval was calculated. Each point on this graph shows the range between the upper and lower confidence interval, represented in pounds.

Table 2. The range between the upper and lower confidence interval for varying pigs and pen as presented in Figure 7 (dataset A)¹

Pens, n	Number of pigs from each pen															Entire pen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	133.0	93.3	80.2	70.5	64.4	59.8	57.3	55.1	51.8	50.4	48.9	47.4	46.3	46.0	45.5	35.8
2	94.8	65.6	55.6	49.1	46.0	42.2	40.4	38.3	36.8	36.5	35.2	34.2	33.4	32.2	32.0	28.1
3	74.7	53.3	44.6	40.8	37.5	34.6	32.5	31.2	29.9	28.8	28.4	27.9	26.9	26.3	25.8	22.9
4	64.4	47.6	39.3	35.2	32.2	29.5	28.5	26.9	25.6	24.6	24.3	23.8	23.3	22.8	22.2	19.7
5	58.2	41.6	34.5	30.7	28.7	26.6	25.1	23.9	23.0	22.2	21.4	20.9	20.6	20.3	19.7	17.3
6	53.2	37.8	31.6	28.6	26.0	24.2	23.0	22.1	21.0	20.5	19.6	19.0	18.3	18.3	18.0	15.9
7	48.4	35.0	29.4	26.2	23.6	22.0	21.0	20.1	19.2	18.7	17.8	17.4	17.1	16.5	16.8	14.2
8	45.7	32.9	27.6	24.0	22.2	20.6	19.4	18.7	18.0	17.2	16.9	16.1	15.9	15.6	15.0	13.2
9	42.7	30.7	25.9	22.7	20.5	19.2	18.0	17.4	16.7	16.1	15.7	15.0	14.9	14.7	14.2	12.3
10	40.7	29.3	24.6	22.0	19.6	18.5	17.5	16.5	15.5	15.0	14.5	14.3	14.1	13.6	13.4	11.7
11	38.4	27.6	23.0	20.5	18.5	17.4	16.6	15.5	15.1	14.4	13.9	13.3	13.2	12.9	12.5	10.8
12	36.6	26.4	22.0	19.7	17.7	16.6	15.2	14.5	14.1	13.8	13.2	12.9	12.4	12.2	11.8	10.3
13	35.6	25.8	21.0	18.7	17.2	15.7	14.8	14.2	13.6	12.8	12.6	12.2	11.9	11.7	11.1	9.7
14	33.2	24.7	20.3	17.8	16.2	14.8	14.3	13.2	12.8	12.4	12.1	11.7	11.3	11.2	10.7	9.1
15	32.2	23.5	19.3	17.2	15.9	14.4	13.7	13.1	12.4	12.0	11.4	11.1	10.8	10.5	10.5	8.7
16	31.6	22.8	18.9	17.1	15.1	13.9	13.0	12.4	11.8	11.5	11.0	10.6	10.4	10.2	9.9	8.5
17	30.9	22.1	18.2	16.2	14.8	13.4	12.6	11.8	11.5	10.9	10.4	10.3	10.0	9.8	9.5	8.0
18	29.3	21.6	17.7	15.5	14.0	13.0	12.4	11.4	11.0	10.7	10.1	9.8	9.7	9.3	9.0	7.6
19	29.1	20.6	17.3	15.1	13.6	12.6	11.8	11.3	10.6	10.2	9.5	9.4	9.3	8.9	8.7	7.3
20	28.1	20.2	16.7	14.5	13.2	12.4	11.5	10.8	10.3	10.0	9.6	9.1	8.9	8.6	8.5	7.1
21	27.8	19.8	16.4	14.1	12.8	11.9	11.1	10.5	10.0	9.3	9.1	9.0	8.5	8.2	8.1	6.9
22	26.9	19.5	15.7	13.7	12.5	11.5	10.6	10.1	9.6	9.1	8.9	8.6	8.4	8.0	7.8	6.4
23	26.3	18.6	15.4	13.5	12.1	11.0	10.5	9.9	9.3	9.0	8.7	8.2	8.0	7.8	7.5	6.1
24	25.6	18.2	15.1	13.2	11.7	11.0	10.2	9.5	9.0	8.7	8.2	8.1	7.8	7.4	7.3	6.0

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Table 2. The range between the upper and lower confidence interval for varying pigs and pen as presented in Figure 7 (dataset A)¹

Pens, n	Number of pigs from each pen															Entire pen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
25	25.1	18.0	14.6	12.9	11.5	10.6	9.8	9.5	8.8	8.4	8.1	7.8	7.5	7.3	7.0	5.6
26	24.8	17.6	14.5	12.5	11.3	10.3	9.7	9.1	8.6	8.2	7.8	7.5	7.4	7.0	6.8	5.4
27	24.0	17.6	14.2	12.3	11.0	10.0	9.4	8.8	8.3	8.0	7.6	7.4	7.1	6.9	6.6	5.3
28	23.7	16.8	14.0	12.0	10.7	9.9	9.1	8.7	8.1	7.8	7.4	7.0	6.8	6.6	6.4	5.0
29	23.2	16.6	13.3	11.7	10.4	9.5	8.8	8.2	7.8	7.5	7.1	6.9	6.5	6.4	6.2	4.8
30	23.1	16.4	13.0	11.5	10.5	9.2	8.7	8.2	7.7	7.3	7.0	6.8	6.5	6.3	5.9	4.5
31	22.5	15.8	13.0	11.0	10.1	9.2	8.4	7.9	7.4	7.2	6.8	6.5	6.1	6.1	5.8	4.3
32	22.1	15.7	12.6	10.9	9.9	8.9	8.2	7.8	7.2	6.8	6.4	6.3	6.1	5.8	5.6	4.2
33	21.5	15.4	12.5	10.7	9.7	8.8	8.1	7.6	7.0	6.7	6.5	6.2	5.9	5.6	5.4	3.9
34	21.3	15.1	12.1	10.6	9.4	8.7	8.0	7.3	6.9	6.5	6.2	5.9	5.7	5.4	5.2	3.7
35	20.9	14.7	12.0	10.5	9.4	8.4	7.7	7.3	6.7	6.4	6.2	5.8	5.5	5.3	5.0	3.6
36	20.5	14.3	11.8	10.1	9.0	8.3	7.6	7.1	6.6	6.2	5.8	5.6	5.3	5.1	4.9	3.5
37	20.6	14.5	11.7	10.0	8.9	8.0	7.5	6.9	6.3	6.0	5.7	5.5	5.2	5.0	4.7	3.2
38	19.9	14.2	11.3	9.7	8.7	7.9	7.2	6.7	6.2	5.8	5.5	5.2	5.0	4.8	4.6	3.0
39	19.7	14.1	11.4	9.6	8.5	7.7	7.1	6.5	6.1	5.7	5.4	5.1	4.9	4.7	4.4	2.9
40	19.6	13.7	11.4	9.4	8.4	7.5	6.8	6.3	5.9	5.5	5.2	4.9	4.7	4.4	4.2	2.6
41	19.4	13.4	10.8	9.3	8.2	7.4	6.7	6.3	5.8	5.4	5.1	4.8	4.5	4.3	4.0	2.4
42	18.8	13.3	10.8	9.1	8.0	7.1	6.7	6.0	5.7	5.2	5.0	4.7	4.4	4.1	3.9	2.2
43	18.8	13.1	10.4	9.0	7.8	7.1	6.4	5.9	5.5	5.1	4.9	4.6	4.3	4.0	3.7	2.0
44	18.6	12.7	10.3	8.9	7.9	7.0	6.3	5.7	5.4	5.0	4.7	4.3	4.1	3.9	3.7	1.8
45	18.2	12.9	10.2	8.7	7.8	6.7	6.2	5.7	5.3	4.8	4.5	4.2	3.9	3.6	3.5	1.5
46	17.9	12.4	10.2	8.7	7.3	6.7	6.1	5.5	5.2	4.7	4.4	4.1	3.8	3.5	3.4	1.2
47	17.8	12.5	9.9	8.4	7.4	6.5	6.0	5.3	5.0	4.5	4.3	4.0	3.6	3.4	3.2	0.8
48	17.8	12.4	9.8	8.4	7.2	6.5	5.8	5.4	4.9	4.6	4.2	3.8	3.5	3.3	3.0	0.0

¹ Colors match the color scheme in Figure 7, representing a range of 10 lb for each color.

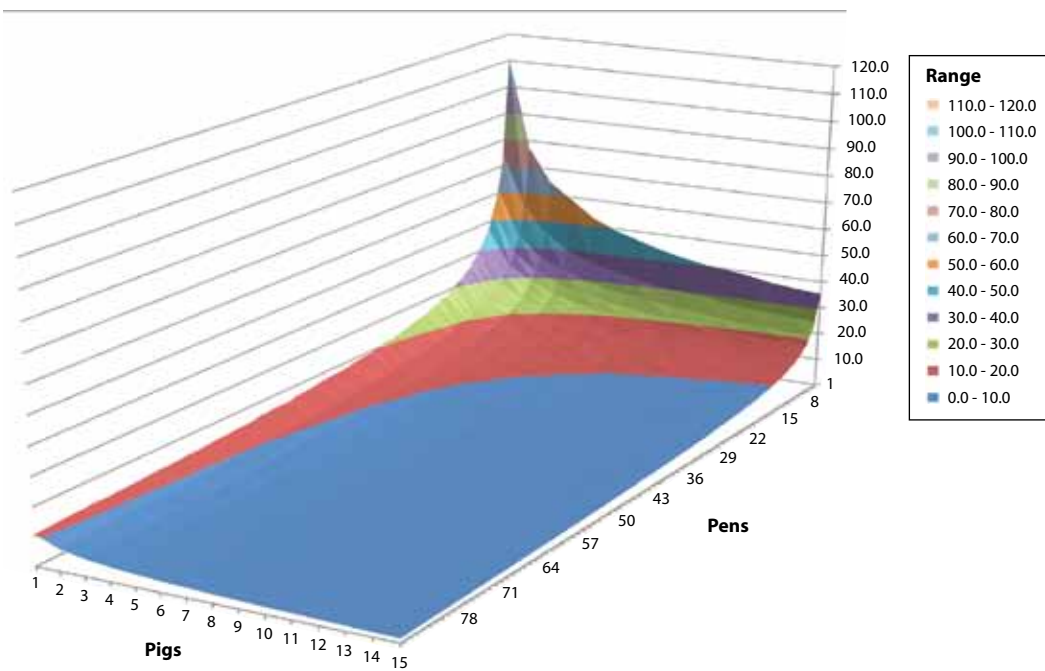


Figure 8. For dataset B, individual pig weights were collected on a total of 1,696 pigs weighed (actual population weight = 275.0 lb and CV = 9.84%) with 16 to 23 pigs per pen. The dataset was analyzed by estimating the overall mean using different sampling methods. These methods explored different numbers of pigs selected within pens, and total number of pens sampled. This was completed 10,000 times for each sampling method and the range or difference between the upper and lower confidence interval was calculated. Each point on this graph shows the range between the upper and lower confidence interval, represented in pounds.

Table 3. The range between the upper and lower confidence interval for varying pigs and pen as presented in Figure 8 (dataset B)¹

Pens, n	Number of pigs from each pen															Entire pen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	111.0	77.0	64.7	58.8	52.8	49.2	46.6	44.0	42.1	40.5	39.6	38.4	36.8	36.1	35.4	32.07
2	74.5	55.3	46.2	39.9	36.9	34.5	32.6	30.9	30.1	29.3	28.0	27.2	26.5	26.1	25.2	23.77
3	61.0	44.2	36.9	33.2	30.0	28.0	26.7	25.8	24.4	23.8	23.0	22.1	21.8	21.2	20.9	19.40
4	53.8	38.1	32.3	28.5	26.4	24.4	22.8	21.7	21.1	20.7	19.6	19.0	18.4	18.5	17.7	16.88
5	47.0	34.1	29.0	25.4	23.0	21.6	20.6	19.7	18.9	18.1	17.7	17.0	16.8	16.6	16.0	14.81
6	43.7	31.5	26.4	23.2	21.2	19.8	18.9	18.0	17.1	16.6	16.1	15.5	15.3	14.8	14.5	13.48
7	40.1	28.6	24.2	21.4	19.9	18.3	17.0	16.6	15.6	15.2	14.8	14.4	14.0	13.8	13.4	12.55
8	37.6	27.1	22.8	20.0	18.3	17.0	15.9	15.0	14.5	14.2	13.7	13.2	12.9	12.7	12.7	11.53
9	35.0	25.6	21.5	19.1	17.5	16.0	15.4	14.6	13.9	13.1	13.0	12.6	12.2	12.0	11.6	11.00
10	33.4	24.5	19.7	17.8	16.1	15.1	14.3	13.7	13.1	12.7	12.1	12.0	11.6	11.3	11.0	10.06
11	31.7	23.2	19.0	17.0	15.6	14.3	13.7	13.1	12.4	12.1	11.5	11.0	10.9	10.7	10.5	9.80
12	30.8	22.1	18.2	15.8	14.8	13.9	13.1	12.4	11.7	11.7	11.1	10.8	10.4	10.2	10.0	9.22
13	29.2	21.2	17.7	15.6	14.2	13.1	12.7	11.6	11.4	10.7	10.5	10.3	9.8	9.8	9.5	8.79
14	27.6	20.4	16.7	15.1	13.5	13.0	12.1	11.4	10.9	10.4	10.1	9.9	9.5	9.4	9.2	8.42
15	27.6	19.6	16.1	14.3	13.0	12.2	11.6	10.9	10.5	10.0	9.6	9.4	9.1	9.0	8.7	8.00
16	26.3	19.1	15.8	14.1	12.6	11.8	10.9	10.3	9.8	9.5	9.6	9.0	9.0	8.6	8.4	7.83
17	25.5	18.7	15.3	13.5	12.3	11.4	10.6	10.1	9.7	9.3	8.9	8.7	8.6	8.2	8.1	7.46
18	24.5	17.9	14.9	13.2	11.9	10.9	10.4	9.8	9.4	9.0	8.6	8.5	8.2	8.0	7.8	7.20
19	24.2	17.6	14.5	12.5	11.5	10.8	9.9	9.4	9.1	8.9	8.5	8.3	8.0	7.8	7.5	6.93
20	23.5	16.9	13.8	12.1	11.0	10.3	9.9	9.1	8.8	8.5	8.3	7.9	7.7	7.4	7.3	6.82
21	23.0	16.4	13.7	12.0	10.9	10.0	9.5	9.0	8.5	8.2	8.0	7.7	7.6	7.2	7.1	6.57
22	22.4	16.0	13.4	11.7	10.7	9.7	9.3	8.9	8.2	8.0	7.7	7.4	7.3	7.0	7.0	6.19
23	21.9	15.7	13.1	11.5	10.3	9.6	9.0	8.5	8.1	7.8	7.6	7.1	7.1	7.0	6.7	6.10
24	21.2	15.7	12.7	11.2	10.2	9.4	8.8	8.3	7.9	7.5	7.3	7.0	6.8	6.8	6.7	5.93
25	20.8	15.0	12.3	10.7	10.0	9.3	8.6	8.0	7.8	7.3	7.1	6.8	6.8	6.5	6.4	5.80
26	21.0	14.8	12.2	10.6	9.6	8.9	8.2	7.9	7.6	7.3	7.0	6.8	6.5	6.4	6.2	5.61
27	20.3	14.5	12.0	10.4	9.4	8.7	8.2	7.8	7.4	7.0	6.9	6.6	6.5	6.2	6.0	5.37
28	19.9	14.3	11.6	10.2	9.4	8.5	8.0	7.6	7.1	6.9	6.6	6.4	6.2	6.0	5.8	5.25

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continued

Table 3. The range between the upper and lower confidence interval for varying pigs and pen as presented in Figure 8 (dataset B)¹

Pens, n	Number of pigs from each pen															Entire pen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
29	19.1	13.9	11.5	9.9	9.0	8.4	7.8	7.3	7.0	6.7	6.5	6.3	6.0	5.9	5.8	5.18
30	19.2	13.5	11.3	9.9	9.0	8.1	7.6	7.3	6.9	6.5	6.3	6.1	5.9	5.7	5.6	5.09
31	18.7	13.6	11.1	9.5	8.7	7.9	7.4	7.0	6.8	6.4	6.1	6.0	5.9	5.6	5.4	4.91
32	18.6	13.0	10.9	9.3	8.6	7.7	7.3	7.0	6.6	6.4	6.0	5.8	5.7	5.6	5.3	4.78
33	18.0	12.8	10.8	9.4	8.4	7.7	7.3	6.8	6.4	6.2	5.8	5.8	5.5	5.4	5.2	4.71
34	17.6	12.6	10.4	9.1	8.2	7.7	7.0	6.7	6.3	6.0	5.8	5.6	5.5	5.3	5.0	4.60
35	17.5	12.8	10.4	9.0	8.1	7.4	7.0	6.5	6.2	6.0	5.7	5.4	5.2	5.1	5.0	4.48
36	17.6	12.3	10.1	8.8	8.0	7.4	6.6	6.4	6.0	5.9	5.6	5.3	5.2	5.0	4.9	4.30
37	17.3	12.1	9.9	8.5	7.9	7.2	6.6	6.3	6.0	5.6	5.5	5.2	5.1	4.9	4.7	4.29
38	17.2	12.0	9.8	8.7	7.7	7.0	6.5	6.2	5.8	5.6	5.4	5.1	5.0	4.7	4.8	4.07
39	16.7	11.7	9.7	8.5	7.6	7.0	6.4	6.1	5.8	5.4	5.3	5.1	4.9	4.7	4.6	4.01
40	16.5	11.6	9.5	8.3	7.5	6.8	6.5	6.0	5.8	5.4	5.2	5.0	4.8	4.7	4.4	3.96
41	16.2	11.4	9.5	8.1	7.3	6.8	6.3	5.9	5.6	5.3	5.1	4.9	4.6	4.6	4.5	3.83
42	16.1	11.3	9.3	8.2	7.3	6.7	6.1	5.9	5.3	5.2	5.0	4.8	4.5	4.3	4.2	3.79
43	15.9	11.3	9.2	7.9	7.1	6.6	6.1	5.7	5.4	5.1	4.9	4.6	4.5	4.4	4.2	3.63
44	15.3	10.9	9.1	7.8	7.0	6.4	5.9	5.6	5.2	5.0	4.8	4.6	4.4	4.3	4.1	3.55
45	15.3	10.7	9.0	7.5	6.9	6.3	5.9	5.4	5.1	4.9	4.7	4.4	4.3	4.2	4.0	3.46
46	15.3	10.8	8.8	7.6	7.0	6.1	5.7	5.4	5.1	4.8	4.6	4.4	4.2	4.1	4.0	3.41
47	15.3	10.6	8.8	7.5	6.7	6.1	5.6	5.3	5.0	4.8	4.5	4.3	4.1	4.0	3.9	3.29
48	15.0	10.6	8.5	7.4	6.7	6.0	5.5	5.2	4.8	4.7	4.5	4.2	4.1	4.0	3.8	3.20
49	15.1	10.3	8.5	7.4	6.5	6.0	5.3	5.1	4.8	4.6	4.3	4.2	4.0	3.9	3.7	3.18
50	14.4	10.4	8.5	7.3	6.4	5.8	5.4	5.0	4.8	4.6	4.2	4.0	3.9	3.8	3.6	3.15
51	14.2	10.3	8.3	7.1	6.4	6.0	5.4	5.0	4.7	4.4	4.2	4.0	3.8	3.7	3.6	3.02
52	14.2	9.9	8.2	7.0	6.3	5.7	5.2	4.9	4.6	4.4	4.1	3.9	3.8	3.6	3.5	2.91
53	14.2	9.9	8.0	7.0	6.1	5.6	5.2	4.8	4.6	4.2	4.0	3.9	3.7	3.6	3.3	2.93
54	13.9	9.9	8.0	6.9	6.1	5.6	5.1	4.8	4.5	4.2	4.0	3.8	3.6	3.5	3.3	2.79
55	13.7	9.7	8.1	6.8	6.1	5.5	5.1	4.6	4.4	4.1	3.9	3.7	3.6	3.4	3.3	2.68
56	13.9	9.6	7.8	6.9	6.0	5.4	5.0	4.5	4.3	4.1	3.9	3.7	3.5	3.4	3.2	2.67

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continued

Table 3. The range between the upper and lower confidence interval for varying pigs and pen as presented in Figure 8 (dataset B)¹

Pens, n	Number of pigs from each pen															Entire pen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
57	13.6	9.6	7.7	6.6	6.0	5.3	4.9	4.6	4.2	4.0	3.9	3.5	3.4	3.2	3.1	2.55
58	13.4	9.3	7.8	6.6	5.9	5.3	4.8	4.5	4.2	3.9	3.7	3.5	3.3	3.2	3.0	2.50
59	13.3	9.4	7.5	6.5	5.8	5.2	4.7	4.5	4.1	3.8	3.6	3.5	3.2	3.2	3.0	2.47
60	13.1	9.2	7.6	6.2	5.7	5.1	4.7	4.4	4.1	3.8	3.6	3.5	3.2	3.1	2.9	2.39
61	13.1	9.2	7.3	6.3	5.6	4.9	4.6	4.2	4.1	3.7	3.5	3.3	3.1	3.0	2.9	2.32
62	12.9	9.0	7.3	6.2	5.6	4.9	4.6	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.8	2.22
63	12.9	9.0	7.3	6.3	5.5	4.9	4.5	4.2	3.9	3.7	3.4	3.2	3.0	2.9	2.8	2.19
64	12.6	9.0	7.0	6.2	5.4	4.9	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.7	2.10
65	12.7	8.9	7.0	6.2	5.4	4.8	4.4	4.0	3.8	3.5	3.3	3.2	2.9	2.8	2.6	2.02
66	12.6	8.8	7.0	6.0	5.3	4.8	4.4	4.0	3.7	3.4	3.2	3.0	2.8	2.7	2.5	1.96
67	12.6	8.7	7.0	5.9	5.2	4.6	4.3	3.9	3.6	3.3	3.2	2.9	2.8	2.7	2.5	1.87
68	12.3	8.6	7.0	5.8	5.2	4.6	4.2	3.8	3.7	3.4	3.1	2.9	2.7	2.6	2.4	1.82
69	12.1	8.4	6.9	5.9	5.1	4.5	4.2	3.8	3.6	3.3	3.1	2.8	2.7	2.5	2.4	1.78
70	12.1	8.5	6.7	5.7	5.0	4.5	4.1	3.7	3.5	3.3	3.0	2.8	2.6	2.5	2.3	1.67
71	12.0	8.4	6.7	5.8	5.1	4.4	4.1	3.7	3.4	3.1	2.9	2.8	2.6	2.5	2.2	1.59
72	11.9	8.3	6.6	5.6	5.0	4.4	4.0	3.6	3.4	3.2	2.9	2.7	2.5	2.4	2.2	1.53
73	11.7	8.3	6.5	5.6	4.9	4.4	3.9	3.6	3.3	3.1	2.9	2.6	2.5	2.3	2.1	1.45
74	11.7	8.4	6.7	5.6	4.9	4.3	3.9	3.7	3.3	3.1	2.8	2.6	2.4	2.3	2.1	1.37
75	11.9	8.0	6.5	5.5	4.9	4.3	3.9	3.6	3.2	2.9	2.7	2.5	2.3	2.2	2.0	1.31
76	11.8	8.1	6.4	5.4	4.8	4.2	3.8	3.4	3.1	2.9	2.7	2.5	2.3	2.1	1.9	1.24
77	11.5	7.9	6.3	5.5	4.7	4.2	3.8	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.14
78	11.6	8.0	6.3	5.3	4.7	4.1	3.7	3.4	3.1	2.7	2.6	2.4	2.2	2.0	1.8	1.06
79	11.4	8.0	6.3	5.3	4.6	4.0	3.7	3.3	3.0	2.8	2.5	2.3	2.1	2.0	1.8	0.94
80	11.4	7.8	6.1	5.2	4.6	4.1	3.6	3.3	3.0	2.7	2.5	2.2	2.1	1.9	1.7	0.84
81	11.2	7.7	6.1	5.2	4.5	4.0	3.6	3.2	2.9	2.7	2.4	2.2	2.0	1.8	1.7	0.71
82	11.0	7.7	6.1	5.0	4.5	3.9	3.5	3.1	2.8	2.7	2.4	2.2	1.9	1.8	1.6	0.58
83	10.8	7.6	6.0	5.2	4.4	3.9	3.5	3.1	2.8	2.6	2.3	2.1	1.9	1.7	1.5	0.39
84	10.9	7.6	5.9	5.0	4.3	3.8	3.4	3.1	2.8	2.5	2.3	2.1	1.8	1.6	1.5	0.00

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¹ Colors match the color scheme in Figure 8, representing a range of 10 lb for each color.

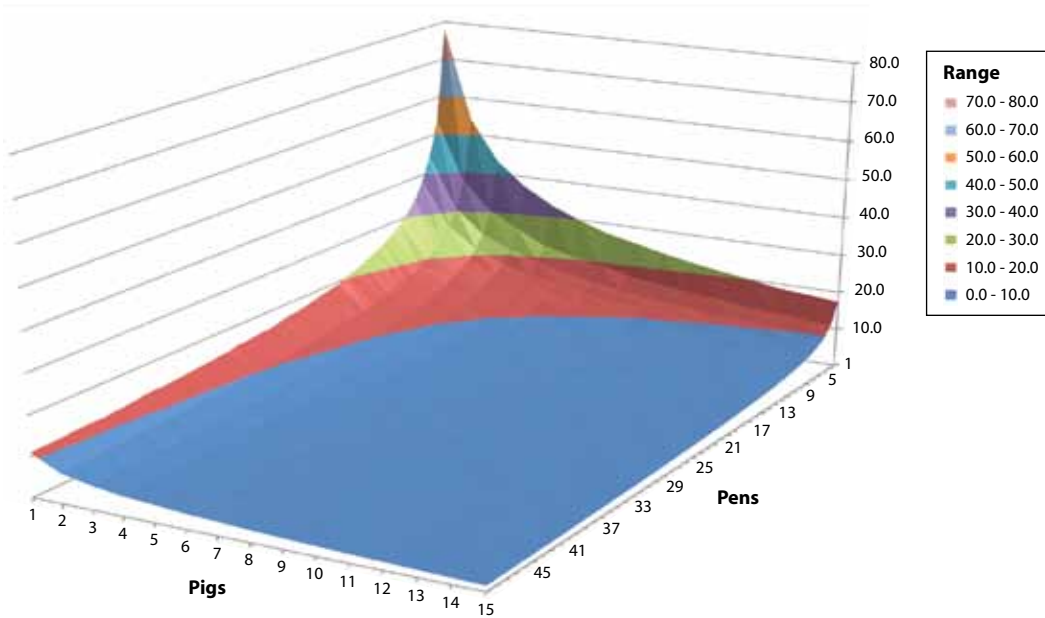


Figure 9. For dataset C, individual pig weights were collected on a total of 950 pigs weighed (actual population weight = 209.6 lb and CV = 9.26%) with 16 to 23 pigs per pen. The dataset was analyzed by estimating the overall mean using different sampling methods. These methods explored different numbers of pigs selected within pens, and total number of pens sampled. This was completed 10,000 times for each sampling method and the range or difference between the upper and lower confidence interval was calculated. Each point on this graph shows the range between the upper and lower confidence interval, represented in pounds.

Table 4. The range between the upper and lower confidence interval for varying pigs and pen as presented in Figure 9 (dataset C)¹

Pens, n	Number of pigs from each pen															Entire pen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
1	78.0	54.0	43.3	37.3	33.0	29.8	27.3	25.6	23.9	22.4	21.2	20.1	18.8	18.1	17.4	14.1
2	53.5	37.8	30.3	26.4	22.6	20.8	19.4	17.5	16.5	15.7	14.8	13.8	13.2	12.5	12.0	9.7
3	44.3	30.7	24.6	21.3	18.9	17.1	15.5	14.3	13.4	12.6	11.7	11.2	10.6	10.0	9.6	7.7
4	38.3	26.6	21.4	18.1	16.3	14.9	13.2	12.4	11.7	10.9	10.2	9.7	9.0	8.7	8.2	6.7
5	33.8	23.8	19.1	16.5	14.8	13.1	11.8	11.3	10.1	9.6	9.1	8.7	8.2	7.7	7.3	6.0
6	31.0	21.8	17.8	15.0	13.3	12.1	11.0	10.1	9.1	8.9	8.2	7.7	7.4	7.0	6.7	5.3
7	28.6	19.8	16.3	13.9	12.4	10.9	10.2	9.4	8.6	8.1	7.6	7.2	6.8	6.3	6.1	4.9
8	26.9	18.9	15.0	13.0	11.5	10.3	9.3	8.8	8.0	7.5	7.1	6.6	6.3	6.0	5.7	4.5
9	25.4	17.6	14.3	12.1	10.9	9.7	8.8	8.1	7.6	7.1	6.6	6.1	5.9	5.5	5.3	4.2
10	24.1	16.9	13.5	11.6	10.1	9.1	8.4	7.6	7.2	6.6	6.1	6.0	5.6	5.3	5.0	3.9
11	23.0	16.2	12.8	11.0	9.6	8.8	7.9	7.3	6.8	6.4	5.9	5.6	5.2	5.0	4.7	3.7
12	21.9	15.3	12.1	10.4	9.2	8.3	7.5	6.9	6.4	6.0	5.6	5.3	5.0	4.8	4.5	3.5
13	21.0	14.7	11.8	9.9	8.9	8.0	7.3	6.6	6.3	5.7	5.5	5.1	4.8	4.4	4.2	3.3
14	20.4	14.2	11.3	9.6	8.5	7.7	7.0	6.4	5.9	5.5	5.1	5.0	4.5	4.3	4.1	3.1
15	19.3	13.3	10.9	9.4	8.1	7.4	6.6	6.2	5.8	5.4	4.9	4.7	4.3	4.1	3.9	2.9
16	18.8	13.2	10.6	9.0	7.9	7.2	6.5	6.0	5.6	5.1	4.8	4.5	4.1	4.0	3.8	2.9
17	18.4	12.6	10.2	8.7	7.6	6.9	6.3	5.8	5.3	4.9	4.6	4.3	4.0	3.8	3.6	2.7
18	17.8	12.6	10.1	8.6	7.3	6.8	6.1	5.5	5.1	4.8	4.5	4.3	3.9	3.7	3.4	2.6
19	17.3	12.2	9.7	8.3	7.1	6.5	5.9	5.4	4.9	4.6	4.3	4.1	3.8	3.5	3.3	2.5
20	16.8	11.8	9.5	8.0	7.1	6.4	5.7	5.3	4.8	4.5	4.1	3.8	3.7	3.4	3.2	2.3
21	16.6	11.5	9.3	7.9	6.9	6.0	5.5	5.0	4.7	4.4	4.1	3.8	3.5	3.3	3.1	2.3
22	16.0	11.1	9.0	7.7	6.6	6.0	5.5	5.0	4.6	4.2	3.9	3.7	3.4	3.2	3.0	2.2
23	15.4	10.9	8.8	7.4	6.5	5.9	5.3	4.9	4.4	4.1	3.8	3.6	3.3	3.1	2.9	2.1
24	15.3	10.8	8.7	7.3	6.4	5.7	5.2	4.8	4.4	4.0	3.7	3.5	3.3	3.0	2.8	2.0
25	15.1	10.4	8.3	7.1	6.3	5.6	5.0	4.6	4.3	3.9	3.6	3.3	3.1	2.9	2.7	1.9
26	14.8	10.3	8.2	7.0	6.1	5.4	5.0	4.5	4.1	3.7	3.5	3.3	3.1	2.9	2.7	1.8
27	14.8	10.1	8.1	6.9	5.9	5.3	4.8	4.3	4.0	3.7	3.4	3.2	3.0	2.8	2.6	1.8
28	14.1	9.9	7.8	6.7	5.9	5.1	4.7	4.4	3.9	3.6	3.4	3.2	2.9	2.7	2.5	1.7

continued

Table 4. The range between the upper and lower confidence interval for varying pigs and pen as presented in Figure 9 (dataset C)¹

Pens, n	Number of pigs from each pen															Entire pen
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
29	14.0	9.7	7.7	6.5	5.8	5.1	4.7	4.3	3.9	3.5	3.3	3.1	2.8	2.6	2.4	1.6
30	13.6	9.6	7.5	6.5	5.6	5.0	4.5	4.2	3.8	3.5	3.2	3.0	2.7	2.5	2.3	1.6
31	13.5	9.2	7.4	6.4	5.6	4.9	4.4	4.1	3.7	3.4	3.1	2.9	2.6	2.5	2.3	1.5
32	13.3	9.2	7.4	6.3	5.5	4.9	4.4	4.0	3.6	3.3	3.1	2.9	2.6	2.4	2.2	1.4
33	13.1	8.9	7.3	6.2	5.4	4.7	4.2	3.9	3.6	3.2	3.0	2.8	2.6	2.3	2.2	1.4
34	12.9	8.9	7.2	6.0	5.4	4.6	4.2	3.8	3.5	3.2	2.9	2.7	2.5	2.3	2.1	1.3
35	12.6	8.9	7.0	5.8	5.3	4.5	4.1	3.7	3.4	3.1	2.8	2.6	2.4	2.2	2.0	1.2
36	12.8	8.5	6.9	5.8	5.1	4.6	4.1	3.7	3.4	3.1	2.8	2.6	2.4	2.2	2.0	1.1
37	12.6	8.6	6.8	5.8	4.9	4.4	4.1	3.6	3.3	3.0	2.8	2.5	2.3	2.1	2.0	1.1
38	12.1	8.3	6.8	5.6	4.9	4.4	3.9	3.6	3.3	2.9	2.7	2.5	2.3	2.0	1.9	1.0
39	11.9	8.2	6.6	5.6	4.9	4.3	3.8	3.5	3.2	2.9	2.6	2.4	2.2	2.0	1.8	1.0
40	11.8	8.2	6.5	5.5	4.8	4.2	3.8	3.4	3.2	2.8	2.6	2.4	2.2	2.0	1.7	0.9
41	11.4	8.0	6.4	5.5	4.7	4.2	3.8	3.4	3.1	2.8	2.5	2.3	2.1	1.9	1.7	0.8
42	11.6	7.9	6.4	5.4	4.7	4.1	3.7	3.3	3.0	2.8	2.5	2.2	2.1	1.9	1.7	0.8
43	11.5	7.8	6.2	5.3	4.6	4.0	3.6	3.3	3.0	2.7	2.5	2.2	2.0	1.8	1.6	0.7
44	11.5	7.8	6.1	5.2	4.5	4.0	3.6	3.2	2.9	2.6	2.4	2.2	2.0	1.8	1.6	0.6
45	11.2	7.6	6.2	5.2	4.5	4.0	3.5	3.2	2.8	2.6	2.3	2.1	1.9	1.8	1.5	0.5
46	11.1	7.6	6.0	5.1	4.3	3.9	3.5	3.1	2.8	2.6	2.3	2.1	1.9	1.7	1.5	0.4
47	11.1	7.5	6.0	5.0	4.4	3.9	3.4	3.1	2.7	2.5	2.3	2.0	1.8	1.6	1.4	0.3
48	11.0	7.4	5.9	4.9	4.4	3.7	3.4	3.0	2.7	2.4	2.2	2.0	1.8	1.6	1.4	0.0

¹ Colors match the color scheme in Figure 9, representing a range of 10 lb for each color.

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Table 5. The resulting mean, upper confidence interval (CI), lower CI, and range when sampling a varying number of pigs and pens to give a total sample size of 30 pigs

Sampling method	Mean of 10,000 simulations	Upper CI	Lower CI	Range
Dataset A ¹				
15 pigs from 2 pens	253.2	268.6	236.6	32.0
10 pigs from 3 pens	253.1	267.1	238.4	28.8
6 pigs from 5 pens	253.1	266.0	239.4	26.6
5 pigs from 6 pens	253.0	265.6	239.7	26.0
3 pigs from 10 pens	253.1	265.2	240.7	24.6
2 pigs from 15 pens	253.1	264.7	241.2	23.5
1 pig from 30 pens	253.0	264.3	241.2	23.1
Dataset B ²				
15 pigs from 2 pens	275.3	288.3	263.1	25.2
10 pigs from 3 pens	275.4	287.7	263.9	23.8
6 pigs from 5 pens	275.3	286.2	264.6	21.6
5 pigs from 6 pens	275.4	285.9	264.7	21.2
3 pigs from 10 pens	275.3	285.2	265.5	19.7
2 pigs from 15 pens	275.3	285.1	265.5	19.6
1 pig from 30 pens	275.4	284.9	265.7	19.2
Dataset C ³				
15 pigs from 2 pens	209.5	215.9	203.9	12.0
10 pigs from 3 pens	209.6	215.9	203.4	12.6
6 pigs from 5 pens	209.6	216.1	203.0	13.1
5 pigs from 6 pens	209.6	216.3	203.0	13.3
3 pigs from 10 pens	209.5	216.2	202.7	13.5
2 pigs from 15 pens	209.6	216.2	202.9	13.3
1 pig from 30 pens	209.6	216.4	202.8	13.6

¹ A total of 1,260 pigs (mean = 253.0 lb, median = 254 lb, standard deviation = 32.8 lb, and CV = 12.98%) with 23 to 28 pigs per pen and a total of 48 pens.

² A total of 1,696 pigs (mean = 275.0 lb, median = 277 lb, standard deviation = 27.1 lb, and CV = 9.84%) with 16 to 23 pigs per pen and a total of 84 pens.

³ A total of 950 pigs (mean = 209.6 lb, median = 209 lb, standard deviation = 19.4 lb, and CV = 9.26%) with 19 to 21 pigs per pen and a total of 48 pens.