# THE PHOSPHORUS REQUIREMENTS OF DAIRY HEIFERS[1]

By J. G. ARCHIBALD, *assistant research professor of chemistry*, and E. BENNETT, *research assistant, Massachusetts Agricultural Experiment Station*[2]

## INTRODUCTION

An earlier paper[3] in this journal dealt with the calcium requirements of growing dairy heifers. Since that report was published an investigation of phosphorus requirements has been conducted along the same general lines.

## EXPERIMENTAL ANIMALS

One pure-bred and seven high-grade Holstein-Friesian heifers were used. They were divided into two groups designated as the high-phosphorus and low-phosphorus groups. Table 1 shows their history. Unfortunately, two of them (both in the same group) had to be disposed of when their experimental period was about half completed.

TABLE 1.—*History of the heifers in the phosphorus-requirement tests*

| Group | Heifer no. | Born | Age at commencement of experiment | First calf delivered | Age at first calving |
|---|---|---|---|---|---|
| | | | *Days* | | *Days* |
| High-phosphorus ration | 162 | Aug. 29, 1929 | 181 | Nov. 28, 1931 | 821 |
| | 175 | Jan. 10, 1930 | 114 | June 26, 1932 | 898 |
| | 190 | Apr. 12, 1931 | 159 | Sept. 18, 1933 | 890 |
| | 192 | Apr. 10, 1931 | 161 | Aug. 29, 1933 | 872 |
| Average | | | 154 | | 870 |
| Low-phosphorus ration | [1] 163 | Aug. 31, 1929 | 179 | No calf | |
| | [1] 168 | Dec. 16, 1929 | 128 | do | |
| | 191 | Apr. 12, 1931 | 159 | Aug. 11, 1933 | 852 |
| | 193 | Apr. 1, 1931 | 170 | Aug. 19, 1933 | 871 |
| Average | | | [2] 165 | | 862 |

[1] Reacted to the tuberculin test, Feb. 9, 1931; slaughtered Feb. 16, 1931.
[2] Average age of the two that calved.

## NATURE OF THE RATIONS

The basal ration was composed of:

Mixed hay (low in phosphorus).
Dried beet pulp.
Grain mixture { 8 parts corn meal. / 1 part corn gluten meal. / 1 part blood flour.

This combination resulted in a ration quite low in phosphorus. For the high-phosphorus group it was supplemented with requisite

[1] Received for publication Mar. 4, 1935; issued August 1935. Contribution no. 188 of the Massachusetts Agricultural Experiment Station.
[2] The advice and suggestions of Dr. J. B. Lindsey, former head of the Department of Chemistry at this station, are acknowledged and appreciated.
[3] LINDSEY, J. B., ARCHIBALD, J. G., and NELSON, P. R. THE CACLIUM REQUIREMENTS OF DAIRY HEIFERS. Jour. Agr. Research 42: 883–896, 1931.

amounts of rice bran, a product relatively high in phosphorus. The additional amounts of other nutrients furnished by the rice bran were offset for the low group by slightly larger amounts of the basal ration.

The proportions of the several ingredients fed to the two groups at varying ages are shown in table 2. The slightly larger average daily feed intake by the high-phosphorus group is due to the fact that these animals, as a group, were slightly heavier from start to finish than those in the low-phosphorus group.[4]

The hay fed was designedly as low in phosphorus as could be purchased locally. It was grown on farms in the vicinity of the experiment station, was cut late, and came from run-out fields. The beet pulp was fed to give the ration greater palatability and also to furnish calcium. The grain mixture provided adequate amounts of protein and energy and was very low in phosphorus. The composition of the feeds is shown in table 3.

TABLE 2.—*Average daily feed consumption of heifers by groups and ages*

| Group and age | Hay | Beet pulp | Grain mixture | Rice bran | Total daily intake |
|---|---|---|---|---|---|
| High-phosphorus: | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Calves | 5.63 | 0.99 | 3.12 | 0.99 | 10.73 |
| Yearlings | 9.00 | 1.28 | 3.50 | 1.10 | 14.88 |
| 2-year-olds | 11.55 | 1.88 | 3.88 | 1.88 | 19.19 |
| Low-phosphorus: | | | | | |
| Calves | 5.94 | .99 | 3.36 | ---------- | 10.29 |
| Yearlings | 9.09 | 1.35 | 3.77 | ---------- | 14.21 |
| 2-year-olds | 12.72 | 1.94 | 3.98 | ---------- | 18.64 |

[4] The method of feeding previous to placing the heifers on the experimental rations at about 5 months of age was the same for all individuals.

TABLE 3.—*Minimum, maximum, and average composition of feeds used in the experiments*

| Different lots | Feed | Moisture | | | Dry matter basis of— | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total ash | | | Crude protein | | | Crude fiber | | | Ether extract | | | Calcium | | | Phosphorus | | | Magnesium | | |
| | | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average | Minimum | Maximum | Average |
| *Number* | | *Pct.* | *t.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| 7 | Hay | 9.12 | 10.56 | 10.10 | 3.93 | 6.30 | 4.98 | 5.10 | 7.32 | 6.44 | 29.85 | 33.53 | 31.83 | 1.84 | 2.35 | 2.06 | 0.448 | 0.638 | 0.511 | 0.095 | 0.169 | 0.134 | 0.136 | 0.285 | 0.185 |
| 6 | Dried beet pulp | 8.03 | 11.31 | 9.74 | 2.50 | 5.47 | 3.52 | 9.56 | 12.44 | 10.73 | 16.13 | 21.06 | 19.22 | .09 | .52 | .36 | .636 | .807 | .724 | .071 | .094 | .082 | .265 | .353 | .312 |
| 4 | Grain mixture | 11.83 | 13.27 | 12.53 | 1.47 | 2.94 | 2.37 | 22.57 | 25.34 | 23.85 | 1.85 | 2.23 | 1.98 | .88 | 4.59 | 2.86 | .014 | .131 | .081 | .273 | .392 | .335 | .118 | .160 | .141 |
| 5 | Rice bran | 8.70 | 9.47 | 9.13 | 10.73 | 12.82 | 11.76 | 13.15 | 15.05 | 14.19 | 9.42 | 10.73 | 10.03 | 12.69 | 17.78 | 14.31 | .043 | .131 | .082 | 1.519 | 1.746 | 1.611 | .698 | .858 | .757 |

The high-phosphorus ration supplied about one and two-thirds times as much of that element as did the low-phosphorus ration. Other constituents were kept as nearly on a par as possible (table 4). Intake of digestible protein per unit of body weight was practically identical for both groups throughout, but the high-phosphorus group received an average amount of total digestible nutrients per unit of weight slightly greater than did the low-phosphorus group. This was due to a somewhat higher content of fat in the rice bran than was anticipated. Analyses on record give the average crude fat content of rice bran as about 10 percent; the samples taken during this experiment averaged 14.3 percent.

TABLE 4.—*Daily intake of total and digestible nutrients by heifers, per 100 pounds live weight*

| Age | Group | Dry matter | Crude protein | Crude fiber | Nitrogen-free extract | Fat | Calcium | Phosphorus | Digestible protein | Total digestible nutrient |
|---|---|---|---|---|---|---|---|---|---|---|
| | | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| Calves | High-phosphorus | 2.10 | 0.27 | 0.43 | 1.25 | 0.077 | 0.0085 | 0.0072 | 0.17 | 1.51 |
| | Low-phosphorus | 1.96 | .26 | .39 | 1.18 | .048 | .0082 | .0040 | .16 | 1.35 |
| Yearlings | High-phosphorus | 1.67 | .20 | .36 | .97 | .052 | .0067 | .0050 | .12 | 1.14 |
| | Low phosphorus | 1.80 | .21 | .40 | 1.07 | .041 | .0075 | .0034 | .13 | 1.22 |
| 2-year-olds | High-phosphorus | 1.66 | .18 | .37 | .97 | .055 | .0065 | .0045 | .10 | .91 |
| | Low phosphorus | 1.58 | .17 | .36 | .93 | .037 | .0069 | .0026 | .10 | 1.05 |
| Weighted averages for the duration of the experiment. | High-phsophorus | 1.78 | .22 | .38 | 1.04 | .058 | .0071 | .0055 | .13 | 1.22 |
| | Low-phosphorus | 1.71 | .21 | .37 | 1.02 | .040 | .0072 | .0033 | .13 | 1.16 |

## RESULTS OF METABOLISM BALANCE TRIALS

Seventy-seven metabolism balance trials were carried out, 42 with the high-phosphorus group and 35 with the low-phosphorus group. It should be borne in mind that these metabolism-balance periods were not continuous, but were conducted at frequent intervals for 10-day periods throughout the course of the investigation. The experimental and analytical procedure was identical with that described in the earlier publication.[5] The progress of the work has been accelerated somewhat by the addition of two more metabolism stalls, thus making it possible to have four heifers on trial at one time. Figure 1 shows the general arrangement of the stalls.

[5] LINDSEY, J. B., ARCHIBALD, J. G., and NELSON, P. R. See footnote 3.

Methods of analysis were as follows:

For nitrogen the Kjeldahl method described in the following publication: ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS, OFFICIAL AND TENTATIVE METHODS OF ANALYSIS . . . Compiled by the committee on editing methods of analysis. Ed. 3, 593 pp., illus. Washington, D.C. 1930.

For calcium and magnesium the method of McCrudden modified for use with materials of this nature: MCCRUDDEN, F. H., THE QUANTITATIVE SEPARATION OF CALCIUM AND MAGNESIUM IN PRESENCE OF PHOSPHATES AND SMALL AMOUNTS OF IRON DEVISED ESPECIALLY FOR THE ANALYSIS OF FOODS, URINE AND FECES. Jour. Biol. Chem. 7:83-100. 1910.

For phosphorus the colorimetric method described in the following publication: FISKE, C. H., and SUBBAROW, Y. THE COLORIMETRIC DETERMINATION OF PHOSPHORUS. Jour. Biol. Chem. 66: 387-389. 1925

The frequency with which individual heifers were used as members of the high-phosphorus and low-phosphorus groups was as follows: High-phosphorus group—heifers 162 and 175, 16 times; heifer 190, 4 times; heifer 192, 6 times. Low-phosphorus group—heifer 163, 8 times; heifer 168, 4 times; heifer 191, 11 times; heifer 193, 12 times. The uneven distribution of trials between individuals was due in the first place to the loss of nos. 163 and 168 early in their yearling period, and to a subsequent effort to even up the number of trials for the two

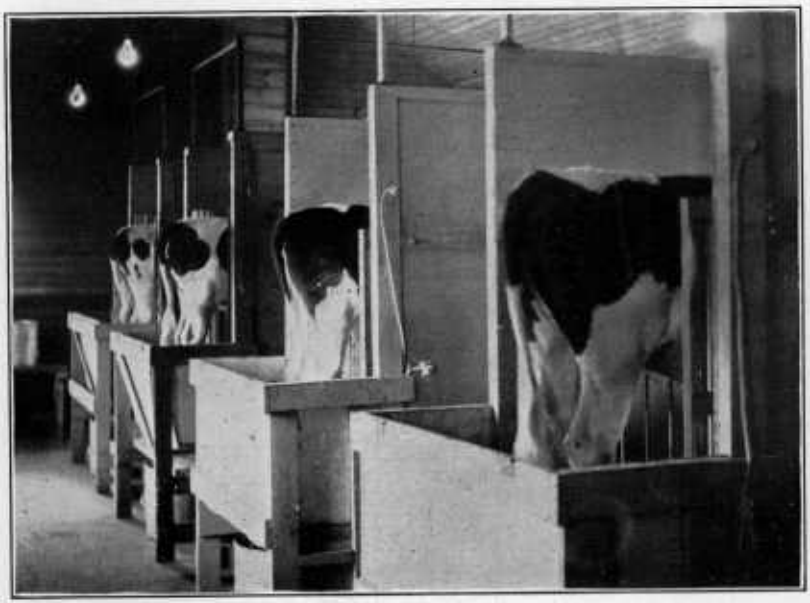

FIGURE 1.—Arrangement of metabolism stalls used in the experiments.

groups by using nos. 191 and 193 considerably more than nos. 190 and 192.

The detailed balance records for the individual heifers are given in table 5 and the data are summarized in table 6. The values in this table were obtained by taking the average of all trials for a given age of all individuals in the group. The probable error of these averages was determined by means of Bessel's formula, viz.,

$$P.E._m = 0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}.$$

TABLE 5.—*Detailed balance record for each heifer in the high- and low-phosphorus metabolism experiments, 1930–33*

HIGH-PHOSPHORUS GROUP

| Heifer no. | Age | | Weight | Date of experiment | Daily intake per 100 pounds live weight | | | | Daily retention per 100 pounds live weight | | | | Retention of intake | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | N | Ca | P | Mg | N | Ca | P | Mg | N | Ca | P | Mg |
| | *Months* | *Days* | *Pounds* | | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Percent* | *Percent* | *Percent* | *Percent* |
| | 6 | 21 | 310 | Mar. 22 to 31, 1930 | 22.646 | 2.897 | 3.560 | 2.387 | 8.345 | 1.339 | 1.085 | 0.072 | 36.85 | 46.21 | 30.48 | 3.01 |
| | 7 | 21 | 358 | Apr. 19 to 28, 1930 | 20.358 | 3.074 | 3.167 | 2.228 | 4.580 | 1.248 | .960 | −.197 | 22.50 | 40.61 | 30.31 | −8.87 |
| | 8 | 11 | 395 | May 10 to 19, 1930 | 18.484 | 2.778 | 2.882 | 2.019 | 5.256 | 1.160 | .978 | −.070 | 28.43 | 41.77 | 33.93 | −3.46 |
| | 9 | 3 | 415 | June 1 to 10, 1930 | 17.141 | 2.756 | 2.726 | 1.878 | 4.844 | 1.152 | .823 | −.277 | 28.26 | 41.80 | 30.19 | −14.73 |
| Average as a calf | | | | | 19.657 | 2.876 | 3.084 | 2.128 | 5.756 | 1.225 | .962 | −.118 | | | | |
| | 13 | 7 | 515 | Oct. 5 to 14, 1930 | 19.054 | 3.848 | 3.085 | 2.242 | 5.687 | .969 | .755 | .163 | 29.85 | 25.17 | 24.46 | 7.27 |
| | 14 | 8 | 580 | Nov. 6 to 15, 1930 | 16.844 | 3.394 | 2.758 | 1.996 | 4.298 | .565 | .462 | .007 | 25.52 | 16.65 | 16.75 | .35 |
| | 15 | 10 | 625 | Dec. 9 to 18, 1930 | 17.512 | 3.201 | 2.861 | 1.912 | 5.061 | .796 | .757 | .037 | 28.90 | 24.87 | 26.45 | 1.95 |
| | 16 | 26 | 705 | Jan. 24 to Feb. 2, 1931 | 15.772 | 2.994 | 2.575 | 1.763 | 5.627 | .601 | .916 | −.029 | 35.68 | 20.07 | 35.58 | −1.63 |
| | 18 | 6 | 765 | Mar. 7 to 16, 1931 | 15.132 | 3.025 | 2.467 | 1.742 | 3.829 | .838 | .793 | .201 | 25.31 | 27.69 | 32.16 | 11.53 |
| 162 | 18 | 24 | 815 | Mar. 25 to Apr. 3, 1931 | 14.354 | 2.840 | 2.338 | 1.643 | 3.041 | .662 | .705 | .142 | 21.19 | 23.33 | 30.16 | 8.66 |
| | 19 | 16 | 835 | Apr. 14 to 23, 1931 | 14.010 | 2.771 | 2.282 | 1.603 | 2.168 | .849 | .639 | .297 | 15.47 | 30.64 | 27.98 | 18.55 |
| | 20 | 3 | 845 | May 2 to 11, 1931 | 14.529 | 2.997 | 2.343 | 1.677 | 2.779 | .551 | .609 | .036 | 19.13 | 18.38 | 26.01 | 2.16 |
| | 20 | 22 | 875 | May 21 to 30, 1931 | 13.893 | 2.854 | 2.246 | 1.604 | 2.892 | .954 | .406 | .057 | 20.82 | 33.43 | 18.06 | 3.58 |
| | 21 | 10 | 900 | June 8 to 17, 1931 | 13.474 | 2.726 | 2.149 | 1.529 | 1.678 | .938 | .345 | .037 | 12.45 | 34.46 | 16.05 | 2.41 |
| Average as a yearling | | | | | 15.457 | 3.065 | 2.510 | 1.771 | 3.706 | .772 | .639 | .095 | | | | |
| | 25 | 4 | 960 | Oct. 3 to 12, 1931 | 14.303 | 3.409 | 2.766 | 1.784 | 3.763 | 1.196 | .538 | .140 | 26.31 | 35.09 | 19.45 | 7.86 |
| | 26 | 9 | 1,005 | Nov. 7 to 16, 1931 | 13.753 | 3.306 | 2.648 | 1.715 | 4.568 | 1.619 | .615 | −.102 | 33.21 | 48.96 | 23.22 | −5.95 |
| Average as a 2-year-old | | | | | 14.028 | 3.358 | 2.707 | 1.750 | 4.166 | 1.408 | .577 | .019 | | | | |
| | 9 | 10 | 495 | Oct. 20 to 29, 1930 | 17.561 | 3.587 | 2.971 | 2.149 | 4.649 | 1.372 | .520 | .028 | 26.47 | 38.25 | 17.51 | 1.32 |
| | 10 | 14 | 565 | Nov. 24 to Dec. 3, 1930 | 17.127 | 3.171 | 2.907 | 1.939 | 5.393 | 1.124 | 1.202 | .233 | 31.49 | 35.45 | 41.34 | 12.04 |
| Average as a calf | | | | | 17.344 | 3.379 | 2.939 | 2.044 | 5.021 | 1.248 | .861 | .131 | | | | |
| | 12 | 0 | 600 | Jan. 10 to 19, 1931 | 16.218 | 3.023 | 2.748 | 1.836 | 4.313 | .735 | 1.042 | .205 | 26.59 | 24.33 | 37.92 | 11.17 |
| | 12 | 29 | 650 | Feb. 8 to 17, 1931 | 15.095 | 2.773 | 1.676 | 1.295 | 3.087 | .527 | .668 | −.423 | 20.45 | 19.00 | 39.87 | −32.64 |
| | 13 | 25 | 710 | Mar. 7 to 16, 1931 | 15.621 | 2.992 | 2.560 | 1.777 | 2.931 | .683 | .645 | .102 | 18.76 | 22.84 | 25.19 | 5.71 |
| | 14 | 15 | 745 | Mar. 25 to Apr. 3, 1931 | 15.051 | 2.852 | 2.465 | 1.702 | 2.827 | .989 | .778 | .144 | 18.79 | 34.67 | 31.57 | 8.46 |
| | 15 | 4 | 765 | Apr. 14 to 23., 1931 | 14.657 | 2.777 | 2.400 | 1.658 | 2.487 | .672 | .755 | .293 | 16.97 | 24.19 | 31.47 | 17.65 |
| | 15 | 22 | 790 | May 2 to 11, 1931 | 14.917 | 2.962 | 2.417 | 1.703 | 2.691 | .355 | .511 | .013 | 18.04 | 11.98 | 21.16 | .77 |
| | 16 | 11 | 820 | May 21 to 30, 1931 | 14.232 | 2.814 | 2.312 | 1.625 | 3.206 | 1.358 | .619 | .114 | 22.53 | 48.27 | 26.75 | 7.01 |
| 175 | 16 | 29 | 840 | June 8 to 17, 1931 | 13.871 | 2.700 | 2.222 | 1.556 | 3.008 | .314 | .206 | .013 | 21.69 | 11.61 | 9.26 | .81 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 23 | 870 | Oct. 3 to 12, 1931 | 15.101 | 3.376 | 2.973 | 1.866 | 3.161 | 1.132 | .691 | .212 | 20.93 | 33.54 | 23.25 | 11.37 |
| | 21 | 28 | 925 | Nov. 7 to 16, 1931 | 14.291 | 3.223 | 2.801 | 1.765 | 3.437 | 1.424 | .293 | −.065 | 24.05 | 44.20 | 10.45 | −3.68 |
| | 23 | 16 | 1,030 | Dec. 26, 1931, to Jan. 4, 1932 | 13.921 | 3.510 | 2.670 | 1.744 | 2.971 | .819 | .221 | .015 | 21.34 | 23.34 | 8.28 | −.86 |
| Average as a yearling | | | | | 14.816 | 3.000 | 2.477 | 1.684 | 3.102 | .819 | .584 | .057 | | | | |
| | 25 | 10 | 1,120 | Feb. 20 to 29, 1932 | 12.796 | 2.724 | 2.427 | 1.837 | 2.437 | .106 | .355 | −.028 | 19.04 | 3.88 | 14.62 | −1.53 |
| | 26 | 23 | 1,190 | Apr. 2 to 11, 1932 | 12.874 | 2.996 | 2.356 | 1.908 | 2.719 | .618 | .291 | .171 | 21.12 | 20.63 | 12.34 | 8.96 |
| | 27 | 15 | 1,240 | Apr. 25 to May 4, 1932 | 12.431 | 2.900 | 2.256 | 1.831 | 2.410 | .605 | .054 | .040 | 19.39 | 20.86 | 2.38 | 2.16 |
| Average as a 2-year-old | | | | | 12.700 | 2.873 | 2.346 | 1.859 | 2.522 | .443 | .233 | .061 | | | | |
| | 6 | 8 | 340 | Oct. 20 to 29, 1931 | 25.670 | 5.241 | 4.379 | 2.844 | 7.482 | 2.036 | 1.494 | −.200 | 29.15 | 38.84 | 34.12 | −7.04 |
| | 7 | 16 | 405 | Nov. 28 to Dec. 7, 1931 | 21.494 | 4.422 | 3.677 | 2.385 | 5.531 | 2.403 | 1.032 | −.121 | 25.73 | 54.35 | 28.07 | −5.07 |
| | 9 | 11 | 490 | Jan. 23 to Feb. 1, 1932 | 20.319 | 3.614 | 3.289 | 2.451 | 4.850 | 1.193 | 1.675 | .146 | 23.87 | 33.02 | 50.93 | 5.96 |
| 190 | 11 | 7 | 568 | Mar. 19 to 28, 1932 | 18.317 | 3.490 | 2.945 | 2.255 | 3.591 | .690 | .555 | −.159 | 19.60 | 19.76 | 18.84 | −7.04 |
| Average as a calf | | | | | 21.450 | 4.192 | 3.573 | 2.484 | 5.364 | 1.581 | 1.189 | −.084 | | | | |
| | 6 | 10 | 390 | Oct. 20 to 29, 1931 | 23.503 | 5.235 | 3.977 | 2.622 | 6.858 | 1.646 | 1.038 | −.132 | 29.18 | 31.45 | 26.09 | −5.04 |
| | 7 | 18 | 456 | Nov. 28 to Dec. 7, 1931 | 20.060 | 4.503 | 3.404 | 2.240 | 6.172 | 2.094 | .772 | −.068 | 30.77 | 46.50 | 22.69 | −3.01 |
| | 8 | 16 | 495 | Dec. 26, 1931, to Jan. 4, 1932 | 21.069 | 4.725 | 3.413 | 2.250 | 6.573 | 2.029 | .882 | .051 | 31.19 | 42.94 | 25.85 | 2.25 |
| 192 | 9 | 13 | 545 | Jan. 23 to Feb. 1, 1932 | 19.120 | 3.647 | 3.071 | 2.354 | 4.726 | 1.038 | 1.359 | .091 | 24.72 | 28.45 | 44.24 | 3.87 |
| | 10 | 10 | 585 | Feb. 20 to 29, 1932 | 17.771 | 3.382 | 2.850 | 2.186 | 4.651 | .569 | .922 | −.036 | 26.17 | 16.84 | 32.36 | −1.67 |
| | 11 | 9 | 616 | Mar. 19 to 28, 1932 | 16.984 | 3.548 | 2.759 | 2.184 | 3.875 | .729 | .903 | −.141 | 22.82 | 20.54 | 32.73 | −6.47 |
| Average as a calf | | | | | 19.751 | 4.173 | 3.246 | 2.306 | 5.476 | 1.351 | .979 | −.039 | | | | |

LOW-PHOSPHORUS GROUP

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 19 | 315 | Mar. 22 to 31, 1930 | 20.605 | 3.427 | 1.643 | 1.624 | 6.407 | 0.676 | 0.522 | −.482 | 31.10 | 19.72 | 31.77 | −29.65 |
| | 7 | 19 | 365 | Apr. 19 to 28, 1930 | 18.532 | 3.515 | 1.510 | 1.566 | 4.184 | .621 | .565 | −.262 | 22.58 | 17.66 | 37.44 | −16.71 |
| | 8 | 9 | 410 | May 10 to 19, 1930 | 16.518 | 3.121 | 1.346 | 1.390 | 3.846 | .037 | .383 | −.249 | 23.28 | 1.20 | 28.42 | −17.89 |
| | 9 | 1 | 430 | June 1 to 10, 1930 | 15.300 | 3.077 | 1.266 | 1.280 | 4.967 | .971 | .498 | −.416 | 32.46 | 31.55 | 39.37 | −32.52 |
| Average as a calf | | | | | 17.739 | 3.285 | 1.441 | 1.465 | 4.851 | .576 | .492 | −.352 | | | | |
| 163 | | | | | | | | | | | | | | | | |
| | 13 | 5 | 545 | Oct. 5 to 14, 1930 | 17.719 | 3.940 | 1.862 | 1.733 | 4.588 | 1.019 | .610 | .092 | 25.89 | 25.87 | 32.75 | 5.28 |
| | 14 | 6 | 600 | Nov. 6 to 15, 1930 | 16.196 | 3.562 | 1.699 | 1.574 | 4.250 | .594 | .444 | −.067 | 26.24 | 16.67 | 26.15 | −4.23 |
| | 15 | 9 | 635 | Dec. 9 to 18, 1930 | 17.102 | 3.377 | 1.941 | 1.537 | 4.649 | .644 | .512 | −.047 | 27.18 | 19.07 | 26.40 | −3.04 |
| | 16 | 24 | 695 | Jan. 24 to Feb. 2, 1931 | 15.848 | 3.248 | 1.791 | 1.463 | .892 | .609 | .846 | −.105 | 5.63 | 18.76 | 47.25 | −7.18 |
| Average as a yearling | | | | | 16.716 | 3.532 | 1.823 | 1.577 | 3.595 | .717 | .603 | −.032 | | | | |

TABLE 5.—*Detailed balance record for each heifer in the high- and low-phosphorus metabolism experiments, 1930–33*—Continued

LOW-PHOSPHORUS GROUP—Continued

| Heifer no. | Age | | Weight | Date of experiment | Daily intake per 100 pounds live weight | | | | Daily retention per 100 pounds live weight | | | | Retention of intake | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | N | Ca | P | Mg | N | Ca | P | Mg | N | Ca | P | Mg |
| | *Months* | *Days* | *Pounds* | | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Percent* | *Percent* | *Percent* | *Percent* |
| | 10 | 4 | 430 | Oct. 20 to 29, 1930 | 18.143 | 3.621 | 1.859 | 1.664 | 4.565 | .863 | .738 | −.060 | 25.16 | 23.82 | 39.72 | −3.63 |
| | 11 | 8 | 495 | Nov. 24 to Dec. 3, 1930 | 17.484 | 3.168 | 1.921 | 1.494 | 6.146 | .994 | .965 | .201 | 35.15 | 31.38 | 50.25 | 13.45 |
| Average as a calf | | | | | 17.814 | 3.395 | 1.890 | 1.579 | 5.356 | .929 | .852 | .071 | | | | |
| 168 | | | | | | | | | | | | | | | | |
| | 12 | 25 | 520 | Jan. 10 to 19, 1931 | 16.729 | 3.052 | 1.842 | 1.433 | 4.989 | .962 | .971 | .109 | 29.82 | 31.52 | 52.72 | 7.60 |
| | 13 | 23 | 565 | Feb. 8 to 17, 1931 | 17.366 | 3.190 | 1.928 | 1.490 | 3.552 | .606 | .768 | −.486 | 20.45 | 19.00 | 39.87 | −32.64 |
| Average as a yearling | | | | | 17.048 | 3.121 | 1.885 | 1.462 | 4.271 | .784 | .870 | −.189 | | | | |
| | 6 | 8 | 390 | Oct. 20 to 29, 1931 | 23.040 | 5.170 | 2.312 | 1.796 | 8.026 | 1.874 | .796 | −.081 | 34.83 | 36.24 | 34.43 | −4.51 |
| | 7 | 16 | 455 | Nov. 28 to Dec. 7, 1931 | 19.700 | 4.457 | 1.986 | 1.539 | 6.572 | 2.227 | .748 | −.036 | 33.36 | 49.98 | 37.65 | −2.33 |
| | 8 | 14 | 490 | Dec. 26, 1931 to Jan. 4, 1932. | 20.075 | 4.702 | 2.043 | 1.580 | 6.267 | 1.993 | .847 | .029 | 31.22 | 42.38 | 41.46 | 1.83 |
| | 9 | 11 | 540 | Jan. 23 to Feb. 1, 1932 | 18.176 | 3.615 | 1.817 | 1.743 | 4.736 | 1.086 | .853 | −.094 | 26.06 | 30.08 | 46.94 | −5.38 |
| | 10 | 8 | 575 | Feb. 20 to 29, 1932 | 17.043 | 3.380 | 1.706 | 1.635 | 3.675 | .306 | .812 | −.109 | 21.56 | 9.04 | 47.59 | −6.67 |
| | 11 | 21 | 620 | Apr. 2 to 11, 1932 | 16.346 | 3.451 | 1.658 | 1.629 | 2.607 | .695 | .334 | −.064 | 15.95 | 20.13 | 20.15 | −3.92 |
| Average as a calf | | | | | 19.063 | 4.129 | 1.920 | 1.654 | 5.314 | 1.364 | .732 | −.059 | | | | |
| 191 | | | | | | | | | | | | | | | | |
| | 12 | 13 | 664 | Apr. 25 to May 4, 1930 | 15.443 | 3.267 | 1.572 | 1.539 | 3.720 | 1.005 | .441 | .065 | 24.09 | 30.77 | 28.06 | 4.25 |
| | 13 | 10 | 682 | May 22 to 31, 1932 | 15.178 | 3.166 | 1.535 | 1.503 | 3.310 | .607 | .286 | .132 | 21.81 | 19.16 | 18.63 | 8.77 |
| | 14 | 0 | 695 | June 12 to 21, 1932 | 14.823 | 3.021 | 1.495 | 1.445 | 2.765 | .723 | .529 | .036 | 18.65 | 23.92 | 35.43 | 2.46 |
| Average as a yearling | | | | | 15.148 | 3.151 | 1.534 | 1.496 | 3.265 | .778 | .419 | .078 | | | | |
| | 24 | 2 | 1,011 | Apr. 14 to 23, 1933 | 12.111 | 2.947 | 1.143 | 1.315 | 2.277 | .634 | .372 | −.096 | 18.80 | 21.52 | 32.56 | −7.28 |
| | 25 | 3 | 1,073 | May 15 to 24, 1933 | 12.736 | 3.193 | 1.209 | 1.413 | 2.221 | 1.204 | .280 | .106 | 17.44 | 37.70 | 23.20 | 7.47 |
| Average as a 2-year old | | | | | 12.424 | 3.070 | 1.176 | 1.364 | 2.249 | .919 | .326 | .005 | | | | |
| | 6 | 19 | 405 | Oct. 20 to 29, 1931 | 22.187 | 4.979 | 2.226 | 1.729 | 7.333 | 2.463 | .942 | −.209 | 33.05 | 49.48 | 42.34 | −12.11 |
| | 7 | 27 | 470 | Nov. 28 to Dec. 7, 1931 | 19.072 | 4.314 | 1.923 | 1.490 | 5.910 | 1.807 | .787 | −.175 | 30.98 | 41.89 | 40.93 | −11.74 |
| | 8 | 25 | 510 | Dec. 26, 1931 to Jan. 4, 1932. | 19.288 | 4.518 | 1.963 | 1.518 | 5.732 | 2.471 | .889 | −.205 | 29.72 | 54.69 | 45.31 | −13.49 |
| | 9 | 22 | 540 | Jan. 23 to Feb. 1, 1932 | 17.970 | 3.519 | 1.789 | 1.707 | 4.107 | 1.128 | .875 | −.160 | 22.85 | 32.05 | 48.92 | −9.35 |
| | 10 | 19 | 580 | Feb. 20 to 29, 1932 | 16.896 | 3.351 | 1.691 | 1.621 | 3.639 | .728 | .888 | −.104 | 21.54 | 21.73 | 52.50 | −6.39 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average as a calf | | | | | 19.083 | 4.136 | 1.918 | 1.613 | 5.344 | 1.719 | .876 | −.171 | | | | |
| 193 | 12 | 1 | 640 | Apr. 2 to 11, 1932 | 15.835 | 3.343 | 1.606 | 1.578 | 2.876 | .981 | .413 | −.106 | 18.16 | 29.34 | 25.74 | −6.72 |
| | 12 | 24 | 675 | Apr. 25 to May 4, 1932 | 15.191 | 3.214 | 1.547 | 1.514 | 2.825 | .952 | .303 | −.006 | 18.60 | 29.61 | 19.61 | −.37 |
| | 13 | 21 | 693 | May 22 to 31, 1932 | 14.937 | 3.116 | 1.511 | 1.479 | 3.037 | .975 | .420 | .010 | 20.33 | 31.30 | 27.77 | .67 |
| | 14 | 11 | 710 | June 12 to 21, 1932 | 14.510 | 2.957 | 1.463 | 1.415 | 2.536 | .782 | .523 | −.016 | 17.48 | 26.44 | 35.71 | −1.14 |
| Average as a yearling | | | | | 15.118 | 3.158 | 1.532 | 1.497 | 2.819 | .923 | .415 | −.030 | | | | |
| | 24 | 0 | 995 | Mar. 27 to Apr. 5, 1933 | 12.669 | 3.003 | 1.193 | 1.349 | 2.078 | .542 | .245 | −.124 | 16.40 | 18.05 | 20.56 | −9.19 |
| | 24 | 28 | 1,061 | Apr. 29 to May. 8, 1933 | 12.705 | 3.169 | 1.205 | 1.405 | 2.648 | 1.035 | .433 | −.017 | 20.84 | 32.67 | 35.91 | −1.21 |
| | 26 | 2 | 1,130 | June 3 to 12, 1933 | 12.065 | 3.024 | 1.144 | 1.338 | 1.748 | 1.024 | .292 | −.014 | 14.49 | 33.85 | 25.53 | −1.04 |
| Average as a 2-year-old | | | | | 12.480 | 3.065 | 1.181 | 1.364 | 2.158 | .867 | .323 | −.052 | | | | |

TABLE 6.—*Summary of balances by ages in the high- and low-phosphorus metabolism experiments, March 1930 to June 1933*

| Group and number of trials | Daily intake, per 100 pounds live weight | | | | Daily retention, per 100 pounds live weight | | | | Retention of intake | | | | Ratio of Ca to P | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | Ca | P | Mg | N | Ca | P | Mg | N | Ca | P | Mg | Intake | Retention |
| High-phosphorus: | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Grams* | *Percent* | *Percent* | *Percent* | *Percent* | | |
| As calves, 16 trials | 19.85 | 3.75 | 3.25 | 2.27 | 5.46 ±.22 | 1.36 ±.09 | 1.01 ±.05 | −0.05 | 27.51 ±.72 | 36.27 ±1.77 | 31.08 ±1.48 | 0 | 1.16:1 | 1.35:1 |
| As yearlings, 21 trials | 15.12 | 3.03 | 2.49 | 1.73 | 3.39 ±.16 | .80 ±.04 | .61 ±.03 | .07 | 22.42 ±.78 | 26.40 ±1.38 | 24.50 ±1.33 | 4.05 | 1.22:1 | 1.31:1 |
| As 2-year-olds, 5 trials | 13.23 | 3.07 | 2.49 | 1.82 | 3.18 ±.43 | .83 ±.26 | .37 ±.10 | .04 | 24.04 ±2.70 | 27.04 ±7.66 | 14.86 ±3.58 | 2.20 | 1.23:1 | 2.24:1 |
| Average | 16.70 | 3.31 | 2.78 | 1.94 | 4.15 ±.16 | 1.02 ±.05 | .73 ±.04 | .02 | 24.85 ±.57 | 30.82 ±1.21 | 26.26 ±1.05 | 1.03 | 1.19:1 | 1.38:1 |
| Low-phosphorus: | | | | | | | | | | | | | | |
| As calves, 17 trials | 18.61 | 3.85 | 1.80 | 1.59 | 5.22 ±.24 | 1.23 ±.12 | .73 ±.03 | −.15 | 28.05 ±.94 | 31.95 ±2.43 | 40.56 ±1.42 | 0 | 2.13:1 | 1.68:1 |
| As yearlings, 13 trials | 15.91 | 3.27 | 1.68 | 1.52 | 3.38 ±.21 | .80 ±.03 | .54 ±.04 | −.03 | 21.24 ±1.14 | 24.46 ±1.04 | 32.14 ±1.89 | 0 | 1.95:1 | 1.48:1 |
| As 2-year-olds, 5 trials | 12.46 | 3.07 | 1.18 | 1.36 | 2.19 ±.15 | .89 ±.13 | .32 ±.03 | −.03 | 17.58 ±1.08 | 28.99 ±3.82 | 27.12 ±2.90 | 0 | 2.60:1 | 2.78:1 |
| Average | 16.73 | 3.52 | 1.67 | 1.53 | 4.11 ±.19 | 1.02 ±.07 | .60 ±.03 | −.09 | 24.57 ±.77 | 28.98 ±1.29 | 35.93 ±1.14 | 0 | 2.11:1 | 1.70:1 |

### RETENTION AS RELATED TO INTAKE

Considering first the results as a whole: The nitrogen, calcium, and phosphorus balances were positive in all cases. With the average intake of nitrogen per unit of weight practically identical for both groups, the high-phosphorus group retained 1 percent more, indicating slightly, but not significantly, better utilization of nitrogen by that group.

Retention of calcium per unit of weight was the same for both groups, but since the unit intake for the high-phosphorus group was 6 percent less than for the low-phosphorus group, utilization by the former was slightly, but not significantly, superior (30.8 percent as contrasted with 29 percent).

Retention of phosphorus per unit of weight was somewhat greater in the high-phosphorus group (0.73 g as compared with 0.60 g daily), but since the intake by the low-phosphorus group was only 60 percent that of the high-phosphorus group, the utilization by the low-phosphorus group was significantly greater (35.9 percent as contrasted with 26.3 percent). This is in agreement with the earlier work on calcium requirements,[6] where it was noted that the lower intake was more efficiently utilized.

Forty-one of the magnesium balances were negative; 15 in the high-, 26 in the low-phosphorus group. Although they occurred more frequently in the low-phosphorus group, the average negative balance was not much larger for that group (−0.146 g daily per 100 pounds live weight as compared with −0.137 g daily for the high-phosphorus group). The net result for the groups as a whole was a very slight positive balance of magnesium for the high-phosphorus group and a slight negative balance of that element for the low-phosphorus group. The significance of such a large number of negative balances of an element is not readily apparent. A similar situation was noted and commented upon in the earlier paper on the subject.[7] The departure from normal environment in the conduct of metabolism experiments, while it may not interfere to any extent with storage of elements which are utilized in relatively large proportion to their intake (e. g., nitrogen, calcium, or phosphorus), may be sufficient at times to shift to the negative side the equilibrium of an element like magnesium, which at best is utilized in relatively small proportion.

### EFFECT OF AGE ON INTAKE, RETENTION, AND UTILIZATION

The average results [8] for different ages are portrayed graphically in figures 2 and 3 in addition to being summarized in table 6. The graphs show the relative decrease (or increase) in intake, retention, and percentage utilization per unit of weight with advancing age. They were constructed by assuming in each case a value of 100 for the first year, values for the second and third years being expressed in the appropriate percentage ratio. They show quite clearly—

(1) That intake per unit of weight in general decreased with advancing age, which is normal. The rate of decrease was usually more

[6] LINDSEY, J. B., ARCHIBALD, J. G., and NELSON, P. R. See footnote 3.
[7] LINDSEY, J. B., ARCHIBALD, J. G., and NELSON, P. R. See footnote 3.
[8] Because of the many negative balances, results for magnesium do not lend themselves to graphic portrayal, and hence are not included.

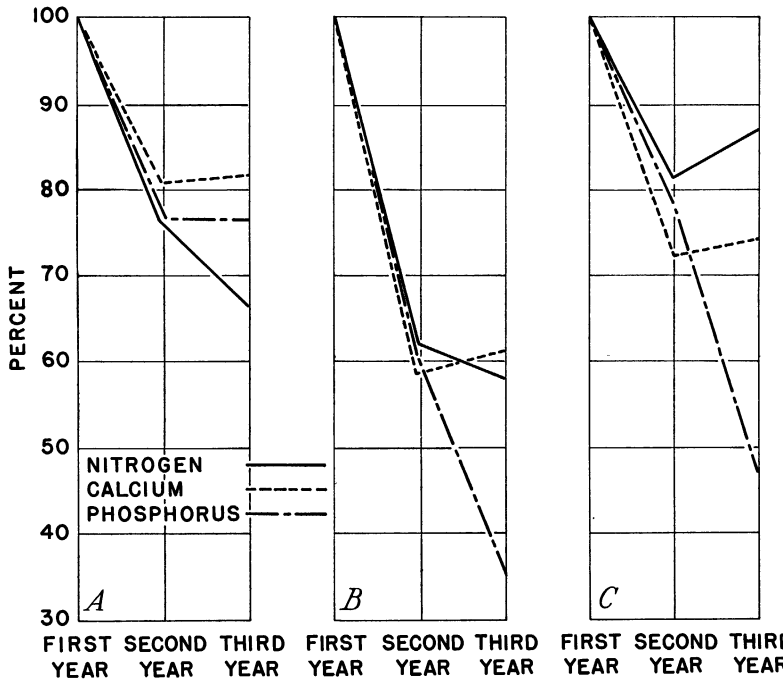


FIGURE 2.—Rate of decrease or increase in intake (*A*), retention (*B*), and percentage utilization (*C*) of nitrogen, calcium, and phosphorus by the high-phosphorus group of heifers as affected by increasing age.

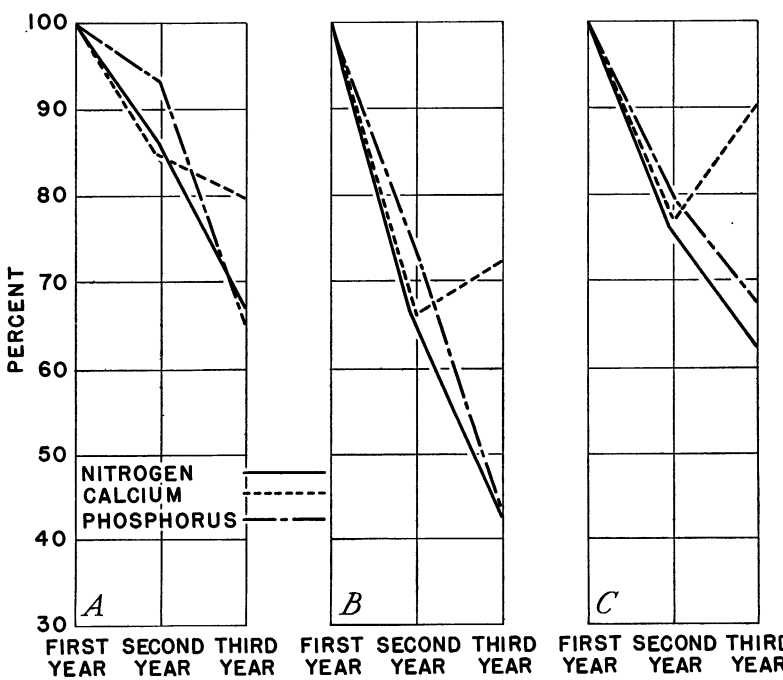


FIGURE 3.—Rate of decrease or increase in intake (*A*), retention (*B*), and percentage utilization (*C*) of nitrogen, calcium, and phosphorus by the low-phosphorus group of heifers as affected by increasing age.

rapid from the first year of life to the second than from the second to the third.

(2) That retention, per unit of weight, of all three elements decreased rapidly from the first year of life to the second, and, in the case of calcium, increased slightly from the second to the third year, the increase being more marked in the low-phosphorus group. Nitrogen and phosphorus retention continued to decrease in both groups during the third year.

(3) That in general percentage utilization (ratio of retention to intake), was roughly parallel to actual retention in its rate of decrease for both groups and the three elements.

The principal point of interest here is the upswing in retention and utilization of calcium in the third year for both groups, possibly a reflection of the demands of pregnancy.

### CALCIUM PHOSPHORUS RATIO

Respecting ratio of calcium to phosphorus fed and retained no definite conclusions can be drawn. The tendency in retention has been toward a general level at around 1.5:1. The high-phosphorus group, with a somewhat lower average intake ratio, had an average retention ratio of 1:1.4, while the low-phosphorus group, with a considerably higher average intake ratio, leveled down on retention to 1:1.7. The exceptions to this statement are the retention ratios for 2-year-olds in both groups. It is thought that possibly the marked departures in these cases are due to the relatively small amount of data for that age group.

## GROWTH AND REPRODUCTION RECORDS OF THE ANIMALS

The procedure for recording growth was the same as in the earlier work.[9] A graphic summary of the growth records appears in figure 4. Table 7 gives a record of the weight and condition at birth of each heifer's first calf.

TABLE 7.—*Weight and condition at birth of calves born to heifers in both phosphorus groups* [1]

| Calf of heifer no.— | High-phosphorus group | | Calf of heifer no. | Low-phosphorus group | |
|---|---|---|---|---|---|
| | Weight at birth | Condition at birth | | Weight at birth | Condition at birth |
| | *Pounds* | | | *Pounds* | |
| 162 | [2] 40 | Good. | [3] 163 | [4] | |
| 175 | 95 | Do. | [3] 168 | [4] | |
| 190 | 96 | Do. | [5] 191 | 85 | Good. |
| 192 | 98 | Excellent. | 193 | 100 | Excellent. |
| Average | 96.3 | | Average | 92.5 | |

[1] In all cases only one service was required for conception.
[2] Sired by a Jersey bull; not included in the average.
[3] As previously noted, these animals had to be disposed of as yearlings.
[4] No calf.
[5] Retained the placenta.

The graphs reveal a quite uniform rate of growth. The low phosphorus group averaged smaller at the start and, with respect to girth,

[9] LINDSEY, J. B., ARCHIBALD, J. G., and NELSON, P. R. See footnote 3.

they continued so throughout the experiment. Their average weights were less until within a month before the experiment ended. Their superiority in height after the nineteenth month is attributed to the fact that data were available for only two heifers in this group (191 and 193) during the latter half of the experiment. This is confirmed by plotting the height curves for these two only for the entire experi-

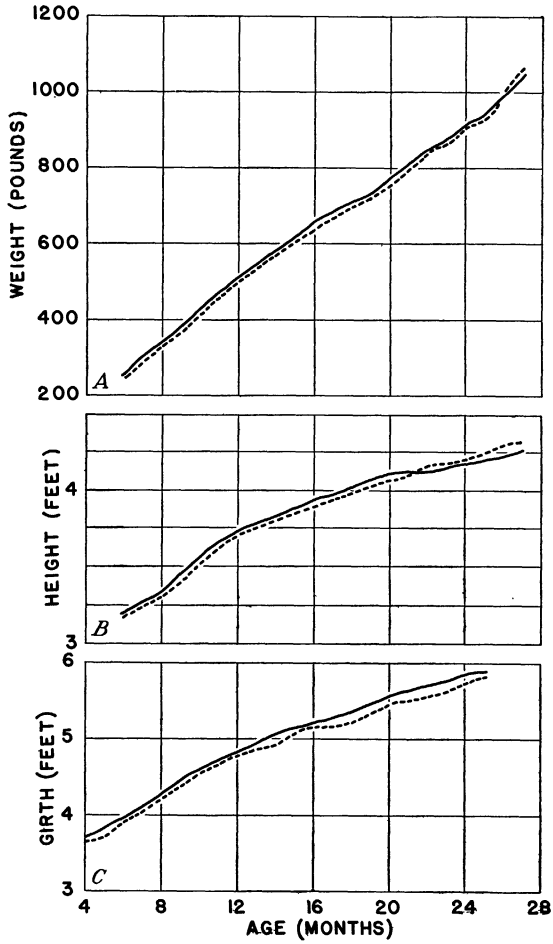


FIGURE 4.—Composite curves representing average weights (*A*), height at withers (*B*), and heart girths (*C*) of heifers in the high- and low-phosphorus groups. The solid lines represent the high-phosphorus and the broken lines the low-phosphorus groups. Commencing with the fourteenth month the curve for the low-phosphorus group is a composite for two animals only.

ment, and comparing them with the curves for their mates in the high-phosphorus group (190 and 192) also for the entire experiment. When thus segregated, the average height for the two in the low-phosphorus group is seen to have been greater throughout than that of their mates in the high-phosphorus group, indicating an obvious reason for change in the trend of the composite graph in the latter part of the period.

Differences in the evidence recorded in table 7 regarding the effect of the rations on the reproductive function are so slight that they are probably without significance.

In addition to this evidence secured while the heifers were on the experimental rations it is pertinent to include the fact that their subsequent history as cows with regard to either production or reproduction does not indicate that the high-phosphorus is superior in any way to the low-phosphorus group. If anything, the latter group has a more satisfactory record. It is possible, of course, that benefits from the larger amount of phosphorous stored by the high-phosphorus group may be apparent later on, that these individuals may have a longer productive life, or that they may be able to stand the strain of continued high production better than the low-phosphorus group.

## DISCUSSION

From the data here presented it seems reasonable to conclude that heifers can make average growth on rations supplying amounts of phosphorus similar to those supplied by the low-phosphorus ration, that is, 1.8 g of phosphorus daily per 100 pounds of live weight during the first year of life, 1.7 g during the second year, and 1.2 g during the third year. That these amounts represent the optimum is not contended; probably they are somewhere close to the minimum. Hay containing less than 0.20 percent of phosphorus and consumed in normal amounts will not supply these amounts of phosphorus. Rowen and legume hays contain sufficiently more than that amount (0.20 percent) to provide a reasonable margin of safety even if nothing else is fed, but the average of a large number of analyses of ordinary mixed hays grown in Massachusetts shows only 0.16 percent of phosphorus, while some samples have been found that run as low as 0.10 percent. Where the roughage consists entirely of ordinary mixed hay, and especially where the quality is inferior, some other source of phosphorus should be supplied. The most logical and practicable way to make up possible deficiencies in this respect is through limited grain feeding, which is nothing more than most successful feeders do regularly.

The lowest phosphorus carrier among our common grains is corn, but even this will supply the deficiency when fed at a level of 3 pounds daily, while much smaller amounts of such high phosphorus carriers as wheat bran or linseed meal will supply the necessary amount.

## SUMMARY AND CONCLUSIONS

In summarizing the results attention is called to the following points:

Retention and utilization of nitrogen and calcium were of a similar magnitude in both high- and low-phosphorus groups, such small differences as existed not being of statistical significance, except in the case of nitrogen storage by the 2-year-old subgroups. The apparently significant difference here may have been due, however, to an insufficient amount of data in these age groups.

Retention of phosphorus by the high-phosphorus group was superior at all ages, and significantly so during the first year. The low-phosphorus group made better use of the phosphorus they received, but not sufficiently so to equal the high-phosphorus group in phosphorus storage.

Differences in growth and reproductive function were very slight

U. S. GOVERNMENT PRINTING OFFICE: 1935