on both 2X and 3X milking, however, advantages attributable to management differences were minimized. The average herd in our study achieved a response in milk production within three months of beginning 3X milking and maintained the response during the three-year period.

Herds showed a range of responses to 3X milking. Among individual herds, the response ranged from −2 to +32 percent more fat-corrected milk with 3X than 2X milking, indicating the importance of a total herd management program. Better nutrition, including improved forage quality and increased feeding frequency, may be necessary to maintain response to 3X milking and minimize body weight loss during lactation. Cows should be fed according to body condition in addition to nutrient requirements of production; this will allow them to maintain lactational persistence and replace reserves before the dry period and subsequent lactation. If these reserves are not replaced during lactation, nutrition during the dry period must allow for their replacement.

First-calf heifers exhibited a greater production response to 3X milking than the entire herd or predominantly cows of second or later lactation. This complicates the management and feeding of first-calf heifers, because they have not reached mature size. On large dairies, grouping and feeding heifers together may simplify their management.

Udder health, as measured by California Mastitis Test scores, was not affected by milking frequency. Reproductive indexes were not significantly different with 3X milking; these figures were rolling herd averages, however, and will change slowly. These indexes tended to increase with 3X milking, indicating poorer reproductive status. An optimum calving interval for 3X herds has not been determined, however; it may be longer than recommended for 2X herds because of the higher milk production.

Milking dairy herds 3X will, in most cases, increase milk yield. Nutrition and reproduction management will have to be improved to maintain the production advantage. Before milking 3X, the dairy operator must weigh the increased yield against the longer milking time, increased costs of utilities, labor, feed, and milking supplies, and the demand for greater management skills.

Douglas D. Gisi is Farm Advisor, Cooperative Extension, Merced County; Edward J. DePeters is Assistant Professor, Department of Animal Science, University of California, Davis; and Clement L. Pellissier is Extension Dairy Scientist, Emeritus, Animal Science Extension, University of California, Davis. *This research was supported by a grant from the California Milk Advisory Board. The authors express their appreciation to cooperating dairymen and dairy farm advisors (N. Peterson, G. Hutton, R. Knight, and R. Eide) for their assistance.*

Residual available phosporus in soils

Parker F. Pratt □ Robert M. Lippert

Present tests fall short of needs

After decades of applications of inorganic phosphate fertilizers and animal manures, many cultivated soils have accumulated residual available phosphorus exceeding levels needed for maximum crop yields. A soil test for available phosphorus can readily identify these areas but cannot indicate how much can be removed in harvested crops before more fertilizer phosphorus is needed to maintain yields. At present, we have no quick way to estimate the amount of residual available phosphorus and must rely on cropping experiments to measure it. That is, the soil test can identify areas with excess residual available phosphorus but cannot be used to find out just how much is present.

To measure amounts of residual available phosphorus in southern California soils, we conducted two field trials and a greenhouse trial involving seven soils. The objectives of all trials were to measure the reduction in soil test values, using the sodium bicarbonate ($NaHCO_3$) test as phosphorus was removed in harvested crops and to determine the effects of soil properties on phosphorus-supplying capacity. The greenhouse experiment compared soils derived from granitic parent materials (upper Santa Ana River Basin) with soils from Colorado River sediments (Imperial and Palo Verde valleys).

Field trials

The field trials were on the University Moreno Valley farm about 10 miles south of Riverside. We established plots in March 1978 on a Hanford sandy loam and a Domino loam, both of which are derived from granitic parent materials. The trials consisted of treatments with 0, 20, 40, 80, and 120 kg of phosphorus per hectare per year except during the second year of alfalfa in the middle of the seven-year cropping sequence. The cropping sequence was corn, wheat, alfalfa, alfalfa, corn, wheat, and alfalfa.

We measured field weights of yields and took samples for laboratory measurements of dry weights and total phosphorus contents. The total forage was removed from the corn and alfalfa plots, but only the grain from the wheat plots. During the seven years, we took soil samples from each plot before treatments started and at convenient times between crops. Samples were composites of 40 cores per plot taken from the cultivated layer. Analyses of profile samples by the sodium bicarbonate soil test (HCO_3-P, bicarbonate-phosphorus) indicated very little available phosphorus below the cultivated depth.

No yield responses to phosphorus applications occurred during the first six years of these trials. In the seventh year, the alfalfa crop responded to phosphorus applications to the Hanford soil in which the bicarbonate-phosphorus had decreased from the original level of 17.6 to 7.2 mg per kg. There were no responses to phosphorus applications, however, on the Domino soil in which the bicarbonate-phosphorus had decreased from 50.4 to 12.4 mg per kg. A level of 10 mg per kg is usually considered to be the critical level for agronomic crops, so these results were expected.

In 1978, before treatments were started, the available phosphorus was relatively uniform in each field (table 1). During cropping the bicarbonate-phosphorus decreased by 10.4 and 38 mg per kg, respectively, for the Hanford and Domino soils.

The cumulative removal in the Hanford soil was 206 kg per hectare with a reduction of 10.4 mg of bicarbonate-phosphorus per kg; for the Domino soil, corresponding values were 229 kg per hectare and 38 mg per kg. The slopes of the regression lines in figure 1 suggest that considerable quantities of phosphorus were released from forms insoluble in the sodium-bicarbonate extractant during the cropping period.

Greenhouse trial

In the greenhouse, we planted crops in seven bulk samples collected from the cultivated layer of soil profiles. The purpose was to determine the relationship between bicarbonate-phosphorus and the cumulative phosphorus removal in harvested crops for coarse-textured soils derived from granitic parent materials in the Santa Ana River Basin and for more clayey soils derived from Colorado River sediments (table 2). Two of the coarse-textured soils, the Hanford and Domino, were from the same fields where the other two trials were conducted.

The greenhouse crops were sorghum, barley, wheat, and alfalfa. After each harvest, we sampled the soils and determined the bicarbonate-phosphorus. We also measured dry weights and phosphorus contents of the harvested plant materials and calculated the phosphorus removed in harvested materials, so that we could plot the bicarbonate-phosphorus against the cumulative phosphorus removed.

In all cases, there was a linear decrease in bicarbonate-phosphorus with increases in phosphorus removed in harvested plant materials. Results for the Domino soil are typical of the soils derived from granitic parent materials, and those for the Holtville soil are typical of the soils derived from Colorado River sediments (fig.2).

Phosphorus-supplying capacity

The two soil types studied differ greatly in available residual phosphorus. At any given soil test value, the coarse-textured soils derived from granitic parent materials have the greatest supplying capacity. For these soils, the ratio of phosphorus removed in harvested crops to the original bicarbonate-phosphorus averaged 2.5 for the two field trials and 2.8 for the three soils in the greenhouse trial. In contrast, the ratio for the fine-textured soils derived from Colorado River sediments averaged 1.1.

The relationship between phosphorus released from forms not soluble in the sodium bicarbonate soil test during cropping and the original bicarbonate-phosphorus for the two types of soils are presented in figure 3. We calculated the regression equations and correlation coefficients assuming that at zero bicarbonate-phosphorus there would be essentially no phosphorus released and put a data point near zero into the calculations. Also, we did not include the data from the field experiments in calculating regression equations and correlation coefficients.

The coarse-textured soils having only small amounts of calcium carbonate and no gypsum contain solid-phase phosphates that are much less stable than the phosphates in the fine-textured soils containing 11 to 15 percent calcium carbonate and gypsum. The stability of the phosphates in the soils derived from Colorado River sediments is apparently a result of the large concentration of soluble calcium that is assured because of the presence of gypsum and because of the ample calcium-dominated particle surfaces provided by calcium carbonate.

The results indicate that the bicarbonate-phosphorus must be interpreted differently for the two types of soils studied. For the soil developed on Colorado River sediments, the bicarbonate-phosphorus is nearly equal to the amount that can be removed before phosphorus deficiencies occur; in the soils derived from granite, the amounts of phosphorus that can be removed before deficiencies develop are two to three times the bicarbonate-phosphorus at the beginning of a cropping period.

In this study, we have compared soils that differ greatly in chemical properties influencing phosphorus release. As use of commercial phosphate fertilizers and manure continues and more soils accumulate residual available phosphorus, more research of the type reported here is needed to aid in interpretation of soil tests.

TABLE 1. Bicarbonate-phosphorus in 1978, before treatments were started, and in 1984 after seven years of cropping

Phosphorus added*	Hanford soil 1978	Hanford soil 1984	Domino soil 1978	Domino soil 1984
kg/ha	mg/kg			
0	17.6	7.2	50.4	12.4
120	18.3	10.0	50.0	21.0
240	18.5	15.0	54.5	29.0
480	19.3	25.2	45.8	42.5
720	18.9	36.8	50.2	56.0

*Six treatments with 0, 20, 40, 80, and 230 kg P per hectare, respectively.

TABLE 2. Data for a few properties of the surface soils used in the greenhouse trial and in the field experiments

Soil	pH	Clay	Calcium carbonate	Gypsum
Field experiments		%	%	
Hanford	7.4	8.0	0.6	absent
Domino	7.1	12.0	1.0	absent
Greenhouse trial				
Hanford	8.0	7.5	0.6	absent
Domino	7.8	12.6	0.9	absent
San Emigdio	7.6	12.2	1.3	absent
Holtville I	7.7	35.2	12.1	present
Holtville II	8.1	45.2	13.0	present
Imperial	7.6	21.6	11.1	present
Unclassified	7.7	31.0	15.4	present

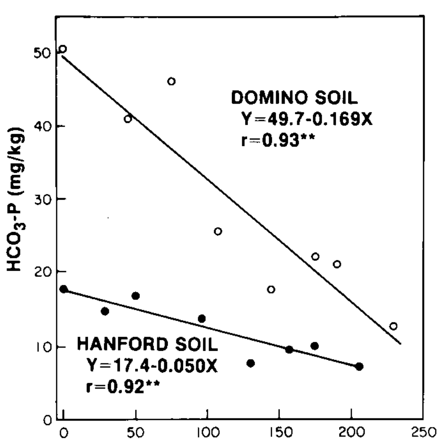


Fig. 1. Relationships between bicarbonate-phosphorus in soil test and cumulative phosphorus removed in harvested crops during field trials suggest that large amounts of phosphorus were released from forms insoluble in the sodium bicarbonate extractant during cropping.

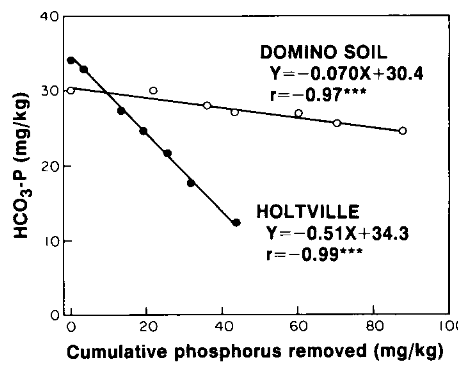
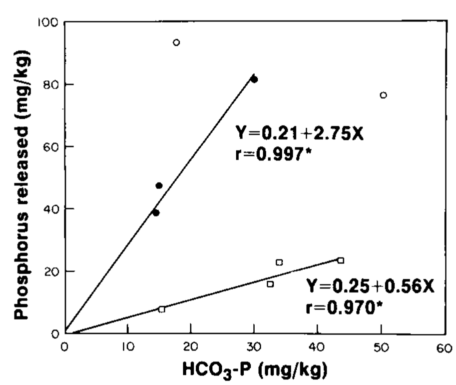


Fig. 2. In greenhouse trial, bicarbonate-phosphorus decreased as phosphorus removed in harvested crops increased.



○ Field data not included in regressions and correlations

● Soil from granitic material

□ Soil from Colorado River sediments

Fig. 3. Phosphorus released from forms insoluble in the sodium bicarbonate soil test during cropping as related to original soil test value (bicarbonate-phosphorus).

Parker F. Pratt is Professor of Soil Science, and Robert M. Lippert is former Graduate Assistant, Department of Soil and Environmental Sciences, University of California, Riverside. Dr. Lippert is presently Director, Agricultural Service Laboratory, Clemson University, Clemson, South Carolina.

The financial support of the National Fertilizer Development Center, Tennessee Valley Authority, is gratefully acknowledged.