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USE OF PHOSPHOGYPSUM FORTIFIED WITH OTHER SELECTED ESSENTIAL ELEMENTS AS A SOIL AMENDMENT ON LOW CATION EXCHANGE SOILS

FIPR

Florida Institute of Phosphate Research

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USE OF PHOSPHOGYPSUM FORTIFIED WITH OTHER SELECTED ESSENTIAL ELEMENTS AS A SOIL AMENDMENT ON LOW CATION EXCHANGE SOILS

FINAL REPORT

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PERSPECTIVE

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Phosphogypsum is a by-product of the wet-acid production of phosphoric acid. By the end of 1989, between 500 and 600 million tons will have accumulated in Florida, with about 30 million tons being added annually. A high priority research area at the Florida Institute of Phosphate Research has been to investigate potential uses for phosphogypsum in industry and agriculture. This project is one of several funded by the Institute to examine the use of phosphogypsum as an agricultural soil amendment.

In this report, Dr. Arvel Hunter of Agro Services International, Inc., describes how the application of by-product gypsum alone and in combination with other nutrients and additives affected yields and nutrient contents of various crops grown on sandy, low-cation-exchange soils in Florida. Gypsum application resulted in increased yields of several crops, including corn, potatoes, cantaloupes and watermelons. An important point of this research was that the benefits of the calcium and sulfur in gypsum might not be fully realized unless other nutrient deficiencies in the soils are also corrected. The study also found no significant effects of 0.5 to 1.5 tons of phosphogypsum per acre on radioactivity (gross alpha and gross beta emissions) or concentrations of arsenic, copper, iron, manganese, cadmium, vanadium, or zinc in several vegetable and fruit crops.

In related work (FIPR Project No. 85-Ol-048), Dr. Greg Mullins of Auburn University has examined the use of gypsum as a sulfur fertilizer for annual forages. His research has shown increases in forage quality and yield due to the sulfur in gypsum, which depend not only on the amount but also on the timing of application. The need for sulfur fertilization was greater under a reduced tillage system than with conventional tillage. Soil and plant tissue samples have been analyzed for radium and polonium radionuclide concentrations. So far the analyses have shown no effects of phosphogypsum, applied at 40 to 80 pounds sulfur per acre, on radionuclide concentrations in either plants or soils.

Dr. Malcolm Sumner at the University of Georgia (FIPR Project No. 83-Ol-024R), has shown that by-product gypsum is effective in increasing yields of several field crops grown on acid soils by ameliorating aluminum toxicity and supplying additional calcium. Gypsum has an advantage over lime in that the slightly greater solubility of gypsum makes surface application possible, whereas lime often must be tilled deeply into the soil to be as effective.

Dr. William Miller of the University of Georgia has demonstrated how surface-applied gypsum could reduce soil crusting, improve infiltration of rainwater, and reduce soil erosion (FIPR Project No. 83-01-020). Another project (FIPR No. 87-01-059) culminated in the publication of a comprehensive review article:

Shainberg, I., M.E. Sumner, W.P. Miller, M.P.W. Farina, M.A. Pavan, and M.V. Fey. 1989. Use of gypsum on soils: a review. Advances in Soil Science 9:1-111.

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EXECUTIVE SUMMARY

This research project is concerned with various aspects of the utilization of phosphogypsum in agriculture.

The first concern was to find a means of altering the physical characteristics of P-gyp as it comes from the waste piles to a form that can be readily utilized by farmers for applying the material to agricultural land. It was felt that two changes in P-gyp would greatly enhance its potential for use:

1. The material needs to be granulated or pelletized into a size, shape and hardness such that it can be mixed with other fertilizer materials or used alone to be spread with equipment normally available to the farmer. P-gyp by itself will not form a sufficiently hard particle or pellet for this purpose.

2. Some kind of material would have to be added to the P-gyp to provide hardness. It would be more economical since it would enhance the value of the finished product if the added material could be fertilizer nutrient elements normally needed. In almost every case where P-gyp could or should be used for increasing calcium levels, magnesium is also needed. Therefore, to provide proper balance of calcium and magnesium, magnesium should be added to the P-gyp in every case except where P-gyp is used only for its sulfate sulfur content.

Several additives to P-gyp were used in this study. Of those used, two reacted with the P-gyp to provide adequate hardness to the pellets. Fine ground sulfate of potash magnesia can be used either by itself with P-gyp or in combination with other materials and P-gyp such as the sulfates or chlorides of manganese, copper and zinc to form relatively hard pellets. Fine ground urea mixed with P-gyp or in combination with hydrophobic materials such as magnesium oxide, or olivine forms hard pellets. Only a pan pelletizing process was used in these studies but the same materials would no doubt work in a granulating process.

The second part of this work was concerned with a series of greenhouse pot trials using soils which by laboratory analysis indicted that crops would give positive growth response to added P-gyp. These soils came from fields which were later used in field trials for checking yield response to added P-gyp.

In the greenhouse studies, all nutrient elements were added as needed according to soil analytical data to bring the soil to a good soil fertility status except for calcium and sulfur. These elements were supplied by

adding P-gyp.

An optimum treatment was set up which had all necessary elements including P-gyp added at the rates indicated as necessary by the analytical data. An optimum treatment minus P-gyp was also set up. The minus P-gyp treatment only produced from 17 to 72 percent as much growth as the optimum treatment with P-gyp.

The greenhouse treatments were set up so as to test the status of each essential element. It was found that each soil had deficiencies not only of calcium and sulfur, but also of three to six other elements. Some of the deficiencies caused greater growth reduction than lack of P-gyp did. The greenhouse studies provided the necessary information needed for setting up proper field trials. There is no value in trying to determine the need and value of P-gyp in a soil situation where nutrient elements other than those supplied by P-gyp would be limiting to the yield.

The third part of the work was to set up field trials using various rates and placement of P-gyp in conjunction with optimum amounts of other elements as determined by the greenhouse studies to determine the yield response of various crops to P-gyp. The crops used as test crops were bell peppers, field corn, sweet corn, cowpeas, cantaloupes, oranges, potatoes, tomatoes and watermelon.

Yield increases due to P-gyp ranged from 6% for tomatoes to 107% for field corn. Cowpeas were found to give the lowest economical return on the dollar invested in P-gyp. The other crops had an economic return of $2.00 to $20.00 per dollar invested in P-gyp.

Soil and plant tissue analyses were done for the various sites and crops. The use of P-gyp increases the amount of extractable sulfur, boron, and manganese in the soil but an increase in extractable calcium is not always detectable when pelletized P-gyp is used.

In general, the leaf tissue analysis indicated an increase in magnesium, sulfur, boron and manganese content in the plants receiving P-gyp.

The harvested crop product was analyzed for radio activity and heavy metals. No apparent differences due to added P-gyp were found in any of the measurements for any of the crops.

Based on soil analysis survey, crop requirements, crop and non-crop acreages, an estimate was made of the need for phosphogypsum in agriculture in Florida. It is considered that a very conservative estimate of need for P-gyp in Florida is 929,000 tons per year. A maximum need is estimated at about 2,724,000 tons per year.

INTRODUCTION

This report should be of more than passing interest to at least three sectors of Agri-Business in Florida and other agricultural areas where soils with low cation exchange capacity are predominant.

1. The farmers who should recognize the potential for improved and increased yield through use of phosphogypsum.

2. The phosphogypsum manufacturers who should recognize the potential for the utilization of a byproduct which at present is considered as having a negative value because of the cost of disposal.

3. The fertilizer dealers who by proper promotion and marketing of phosphogypsum products could add useful and profitable items to their product lines.

Interest in the project being here reported was sparked by the analytical results from thousands of samples being analyzed in the Agro Services International laboratory which indicated that a large proportion of these samples were low in calcium, magnesium and sulfur as well as various other elements. The samples indicating these problems were mostly coming from the coastal plains of the Eastern seaboard or from highly weathered very low cation exchange capacity soils adjacent to the coastal plains and from most of Florida north of Ft. Myers and Belle Glade.

Soils which are low in calcium and magnesium which also have active acidity and low pH can have these problems corrected by using dolomitic lime. Lime is not the proper material to use on soils with no active acidity and with a pH higher than 5.8 to 6.0. Under these conditions there is generally not sufficient acidity to bring adequate amounts of calcium and magnesium into solution from dolomite to overcome deficiencies of these elements and at the same time there is danger of reducing the availability of several other essential elements in these low buffered soils by raising the pH too high through the use of lime. In either case, if sulfur is also low in these soils (as it is in a large percentage of cases) then liming does nothing to alleviate this problem.

In making fertilizer suggestions to farmers it was found that a large percentage of samples indicated the need to increase the calcium content in the soil by from 0.5 Meq Ca/100 ml of soil to 1.5 Meq Ca/100 ml of soil. Because of its little effect on the pH of the soil and because of solubility characteristics, gypsum appeared to be the ideal soil amendment to supply the much needed calcium and sulfur in those soils low in these, elements, but which should not be limed. Phosphogypsum would seem to be even more ideal because of its inherent impurities which could supply significant though not usually adequate amounts of phosphorus, boron, copper, iron, manganese and zinc.

About eight years ago a search of the fertilizer dealers in Florida indicated that gypsum was not available to the farmers. Since that time a number of Florida dealers have begun to stock gypsum, but unfortunately for the Florida phosphate industry, most if not all of the gypsum now being stocked comes from out of state sources. There are still two main problems which need to be resolved in order for farmers to utilize Florida P-gyp properly and in the significant amounts in which it is needed.

1. First there is no good way to properly or easily apply P-gyp to farmer fields in the physical condition of the material as it comes directly from the waste piles.

2. Second, an economic return on the investment in P-gyp is essentially the only thing which will create a demand for the material. Therefore, P-gyp will have to be used in situations and in ways such that better plant growth and increased yield will be recognized by the user.

The first problem can be solved by getting the P-gyp into physical conditions such that it can be effectively and easily applied to the land with available equipment. Its use would be even more enhanced if it is available in a form which can easily be blended with other fertilizer materials. This can be done by pelletizing or granulating processes which produce particles of proper size and hard enough to withstand the physical treatment to which the material would normally be subjected.

The second problem can be solved by providing general information with respect to soil and crop conditions in which the use of P-gyp would be expected to produce the desired yield increases, of growth improvement. Site specific information indicating the need for P-gyp should provide even greater incentive for use of P-gyp.

Site specific information comes primarily from proper soil analysis. It should be remembered that only rarely are calcium and sulfur deficiencies in soils so severe that they will reduce growth or yield by the same magnitude as deficiencies of nitrogen, phosphorus and potassium. This is true for each of the secondary and micronutrient elements. However, when other growth factors such as management, pest control, climate, moisture, etc. are adequate for high yields then maximum yields cannot be obtained if even incipient deficiencies of secondary or micronutrients exist.

The greenhouse and field trials conducted under this project were designed to determine and/or indicate if there was an advantage to using P-gyp when as many other growth factors as possible were maintained at optimum conditions. In other words, in all of the greenhouse and field work done in this project and reported herein, the no P-gyp treatments are based on complete soil analysis including fixation studies so that the no P-gyp treatment had all of the nutrient elements and lime added inadequate amounts as indicated by the soil analytical results with the exception of the main elements which were contained in the P-gyp mixes.

The original data and statisical analyses pertaining to the information in this report; have all been submitted to the Florida Institute of Phosphate Research in the annual and final reports and are maintained on file for inspection at that location.

ALTERING THE PHYSICAL CHARACTERISTIC OF PHOSPHOGYPSUM

At the beginning of this project there was at least one granulated gypsum product from out of state being marketed. The granules in that material are of various shapes and range in size from about 1/16 inch diameter to about 3/16 inch diameter. The binding agent appears to be a lignosulfate type material. The granules are very hard and do not readily disperse in water.

We felt that a pelletized material which was more or less round, relatively hard and of the size which could be blended well with other pelletted fertilizer materials would be very desirable from a physical standpoint.

P-gyp alone can be quite easily pelletted but the pellets are too soft to withstand blending or spreading operations.

Soil analysis experience tells us that it is extremely rare where gypsum is needed that magnesium is not also needed. Magnesium can of course be supplied to the soil in various forms but if a sufficiently available form of magnesium can be mixed with P-gyp at the ratio most often required, then this should enhance the value of both materials because the likelihood of yield response is increased. If any other fertilizer elements could be added to P-gyp to aid in achieving the physical characteristics needed then these would also enhance the value of the P-gyp.

It was with this in mind that quite a number of materials were tested for combining with P-gyp for the pelletizing process.

PREPARATION OF P-GYP MIXES FOR PELLETS

As reported in the first annual report, the following materials were mixed with P-gyp and pelletized:

1. Sulfate of Potash Magnesia
2. Magnesium oxide
3. Manganese sulfate
4. Manganese oxide
5. Potassium nitrate
6. Potassium chloride

7. Nitrate of Soda - Potash

Since the first annual report the following materials have also been used.

8. Urea

9. Olivine - This is a natural mineral composed of a solid solution of Magnesium ortho silicate and iron ortho silicate. It contains about 28% Mg and 5.5% Fe. It is normally being supplied as a powder of which 90 to 95% passes thru a 140 mesh sieve. Investigation of the availability to plants of magnesium and iron from this material is now underway by various people. Preliminary results appear promising.

10. Ammonium nitrate

All of the above materials have been mixed with P-gyp singly and in various combinations. The only two materials tested which impart sufficient hardness to the pellets are sulfate of potash magnesia and urea. These cannot be used together however because although the pellets are very hard when dry they are deliquescent or hydrophilic and rapidly become soft when standing in air.

Urea in combination with hydrophobic compounds such as magnesium oxide, manganese oxide or olivine forms a very hard pellet. The same is true of sulfate of potash magnesia. Either urea or SPM when mixed alone with P-gyp form hard pellets. The pellets formed using urea alone or in combination will readily break down and disperse in water, while those formed with SPM tend to stay aggregated for a longer time. The difference in dispersion time is no doubt due to the difference in the solubility of the two materials.

Best results with urea or SPM for hard pellet formation are achieved with the following conditions:

1. The materials should be of relatively fine grind i.e. 90% thru a 32 mesh sieve.

2. The total mix should have about 10 percent or more of urea or SPM.

3. The materials should be intimately mixed with the P-gyp and other materials prior to being placed on the pan for forming pellets.

4. After the pellets are formed they should not be subjected to extreme heat for drying but they can be dried rather rapidly.

As reported in the first annual report, other materials as follows were used for spraying on P-gyp pellets after they were formed to try to obtain hard pellets.

1. 10% KCl solution

2. 20% KCl solution

3. 0.5% formaline solution

4. 1.0% formaline solution

5. 0.5% Norleg A solution

6. 1.0% Norleg A solution

7. 2.0% Norleg A solution

8. 10.0% Norleg A solution

9. 0.5% formaline + 0.5% Norleg A solution

None of the above materials under these conditions was found to provide sufficient hardness to the pellet. It is certain that some material will nave to be mixed with P-gyp to make the pellets hard enough to be usable since P-gyp by itself forms only very soft pellets. It would seem logical to use suitable materials which increase the nutrient value of the products and/or give greater assurance that the full value of the P-gyp can be utilized. Urea and sulfate of potash magnesia serve well in all aspects as additives to P-gyp.

THE PELLETIZING PROCESS

Only a pan pelletizer was used for the work done on this project. However, the pan pelletizer works very well for the mixtures used. With a little experience and practice, pellets of proper size can be produced. The following conditions need to be met in order to obtain good results.

1. The P-gyp usually comes from the pile in lumps or chunks. These chunks are not hard but they need to be broken up so that the particle size is small like it comes from the processor. Passing the P-gyp thru a flailer system will accomplish this step.

2. The materials to be mixed with the P-gyp need to be of small size, probably 0.5 mm or less.

3. The materials need to be intimately mixed with the P-gyp prior to being fed to the pelletizer pan. We had a pin mauler which was supposed to do the mixing but by itself it was not adequate. We mixed the material by hand prior to feeding it in the mauler. We did not have a paddle mixer available but one was tested for mixing and appeared to serve very well.

4. A constant amount of mixed material needs to be fed to the pelletizer pan continuously so that the angle of the pan can be adjusted for the proper size pellets and so that the amount of water added to the material can be properly adjusted. It is impossible to obtain a uniform pellet size without constant feed to the pelletizer pan.

One way by which this may be accomplished is by use of metal chains or belts in the same was as they are used on many fertilizer spreaders to transport the fertilizer from the bin to the thrower fan.

GREENHOUSE STUDIES

The greenhouse studies were conducted during the first year of the project. The purpose of these studies was to demonstrate the effectiveness of P-gyp in giving increased growth when all other nutrient elements not contained in P-gyp in adequate amounts were supplied to the soil in optimum or adequate amounts so that they would not constitute a limiting factor in plant growth. The complete results of these studies are reported in the first annual report. An example of a typical soil used in these studies and the results obtained with two test crops is appended to this report to illustrate the greenhouse study process.

The determination of what constituted optimum fertility level was done first by a routine complete analysis of the soil to indicate the status of each element level with respect to its adequate level.

The second step was a fixation or sorption study to indicate the quantity of added element which would be tied up or taken out of available status by whatever physical or chemical reactions it would undergo in the soil. With the fixation study, a curve can be constructed which indicates the amount of element needed to be added to the soil in order to bring it to an extractable level known to provide adequate but not excessive amount of element for optimum plant growth.

The soils for the: greenhouse studies were taken from fields where the field trials would later be established. In these studies, it was found that the optimum treatment, which always included P-gyp (because these soils were typical of the soils judged to need P-gyp), gave the highest yield of all treatments. The minus P-gyp treatment, which was equal in every way to the optimum treatment except that it had no P-gyp added, yielded only from 17 to 72 percent of the optimum.

These results should stand as indisputable evidence that when P-gyp is used on soils where proper analytical evidence indicates it is needed, then a substantial growth increase can be expected.

It should be noted that these greenhouse studies also showed that in each soil studied, there were from 3 to 6 elements which were limiting to growth when they were not added in adequate quantity. Sometimes the lack of one of these elements was more limiting than lack of P-gyp and sometimes less. However, unless adequate supply of each of the other limiting elements had been added to the soil it would have been impossible to demonstrate the full value of the use of P-gyp. In some cases neglecting to add one or more of the other limiting elements would have completely obscured the need for P-gyp. While in other cases only a portion of the total response due to P-gyp could have been demonstrated.

FIELD TRIALS

FIELD TRIALS - 1986

In 1986, seven field trials were conducted as follows:

1. Field Corn - Trenton, Florida
2. Potatoes - Hastings, Florida
3. Tomatoes - Lake Helen, Florida
4. Watermelons - Lake Helen, Florida
5. Oranges - Avon Park, Florida
6. Oranges - DeSoto, Florida
7. Sweet Corn - Plant City, Florida

The data from these trials is reported in the 1986 annual report for this project.

P-gyp in the pelletted form was not available for setting up these trials so the P-gyp was used in the form that it comes from the waste pile except that it was broken up so as not to be lumpy.

Yield increases due to P-gyp were found in each of these trials with the exception of the oranges. It usually requires two or more years after treatment for yield differences to be detectable in tree fruit crops. The second year harvest of oranges in these plots was obtained in late Springs of 1988 and information concerning the orange treatments and data are given in the final part of this report.

The yield increase range was as follows: 6% for tomatoes, 19% for potatoes, 49% for watermelons, 107% for corn.

Different rates of P-gyp were used in the trials depending on the need indicated by the soil analysis. The amount generally needed to give maximum response was around 1500 to 2000 lbs/acre.

In the Fall of 1986 two field trials were established to determine the residual effect of P-gyp. Cowpeas and tomatoes were grown at Lake Helen in the plots where the P-gyp trial on tomatoes had been conducted in the Spring. The results of these trials were reported in the 1987 first quarter report. For both the cowpeas and the tomatoes the maximum yield was obtained on the plots which previously received 1000 lbs

P-gyp/acre. There was no additional benefit from the 2000 lbs/acre application. The cowpeas gave a 20% increase from the residual and tomatoes gave only a 5% increase. It is a little surprising that the yield response of tomatoes to P-gyp is not greater than found by these studies since in Florida, tomato end rot due to calcium deficiency is frequently encountered. This indicates that more calcium is required to prevent end rot in tomatoes than is required for maximum vine and fruit growth. The same phenomenon is applicable to peanuts where pod formation requires a higher calcium level than that required for maximum vine growth.

In our tomato trials, in the no P-gyp plots, from 18 to 27 percent of the tomatoes exhibited tomato end rot whereas no end rot was found where P-gyp was applied.

FIELD TRIALS - 1987

In 1987 six field trials were established as follows:

1. Potatoes - residual study - Hastings, Florida
2. Potatoes - pelletted and banded - Hastings, Florida
3. Cantaloupes - residual study - Lake Helen, Florida
4. Bell Peppers - pelletted and broadcast - Lake Helen, Florida
5. Sweet Corn - pelletted and broadcast - Lake Helen, Florida
6. Sweet Corn - pelleted, broadcast and banded - Plant City, Florida

In addition, the orange trials were maintained and were harvested in the late Spring of 1988.

Potato Residual Trial

The yield data for the potato residual study is shown on Table 1. There was a 22% increase in yield in 1987 for the 2000 lbs/acre P-gyp applied as a powder in 1986.

Potato Pelletted-Banded Trial

The yield data for the pelletted-banded P-gyp trial on potatoes is shown in Table 2. There was no significant difference at the 5% level but the mean yield at the 1000 lbs P-gyp/acre rate was 8% greater. During harvest of these plots, the banded pellets were visible and appeared to be mostly intact even though very soft. Apparently, some of the material in the pellets had dissolved but certainly not all. It may well be that a higher rate of P-gyp in pelletted form would have supplied sufficient calcium and sulfate sulfur to give significant increased yield.

Cantaloupe Residual Trial

The yield data for the residual study on cantaloupes is shown in Table 3.

TABLE 1

PHOSPHOGYPSUM PROJECT

1987 P-GYP RESIDUAL STUDY - POTATOES - HASTINGS, FLORIDA

YIELD IN 100 WT/ACRE

P-GYP TREATMENTS APPLIED ONLY IN 1986	REPLICATIONS					
	A	B	C	D	TOTAL	MEAN
No P-Gyp	125	123	120	130	498	124.5
1000 lbs/acre	117	112	162	131	552	130.5
2000 lbs/acre	146	162	154	149	611	152.7

LSD at .10 = 18.4

TABLE 2

PHOSPHOGYPSUM PROJECT

PELLETTED - BANDED P-GYP STUDY - POTATOES - HASTINGS, FLORIDA

YIELD IN 100 CWT/ACRE

P-GYP APPLIED IN BANDS 1987	REPLICATIONS					
	A	B	C	D	TOTAL	MEAN
No P-Gyp	141	102	128	102	473	118.2
500 lbs/acre	112	110	105	113	460	115.0
1000 lbs/acre	123	133	129	128	513	128.2

N.S.D.

TABLE 3

PHOSPHOGYPSUM PROJECT

1987 YIELD OF CANTALOUPE

RESIDUAL STUDY - LAKE HELEN, FLORIDA

TREATMENT	TOTAL NO. MELONS/PLOT <2.5 LBS	TOTAL NO. MELONS/PLOT >2.5 LBS	YIELD CWT/ACRE
No P-gyp applied			
A	34	5	10.14
B	25	5	6.47
REPS C	23	10	7.36
D	48	6	10.98
TOTAL YIELD	130	26	34.95
AVERAGE YIELD	32.5	6.5	8.74
1500 Lbs/Acre			
A	16	13	7.14
B	30	6	8.30
REPS C	34	7	8.71
D	44	28	16.83
TOTAL YIELD	124	54	40.98
AVERAGE YIELD	31.0	13.5	10.25
3000 Lbs/Acre			
A	31	13	10.06
B	33	12	10.07
REPS C	57	7	13.41
D	36	30	16.11
TOTAL YIELD	157	62	49.65
AVERAGE YIELD	39.2	15.5	12.41

LSD at .10 = 3.57

There was a 17% yield increase in weight for the 1500 lbs/acre P-gyp added in 1986 and a 42% increase for the 2000 lbs/acre rate. Not only was the total weight greater where P-gyp was added but the number of cantaloupes weighing more than 2.5 lbs. each was greatly increased. Both of these differences are important from a marketing standpoint.

Bell Pepper Trial

The yield data for the pelletted P-gyp broadcast with bell peppers is shown in Table 4. The variability was so great that no significant difference at the 55 level was indicated. However, the trend for increased yields due to added P-gyp is certainly indicated and if real, would amount to about 40% increase in weight.

Sweet Corn - Lake Helen Trial

The yield of sweet corn from the Lake Helen trial are shown in Table 5. The P-gyp used for this trial was pelleted and applied broadcast then mixed with the soil by roto-tilling.

The maximum increase occurred at the 2000 lbs/acre rate which is the amount predicted from the soil analysis as being necessary to supply adequate calcium. In this soil, an adequate amount of sulfur would have been supplied by adding only about 300 lbs P-gyp per acre.

The maximum yield increase for sweet corn was 55%.

Sweet Corn - Plant City Trial

There were some difficulties encountered with the 1987 sweet corn trial at Plant City. Just before the tasseling stage, heavy rains and strong winds caused the corn in the P-gyp treated plots to lodge because of its height so that it was lying almost to the ground. The no P-gyp plots were not seriously affected because the height of the plant was much less as can be seen in Table 6. The average height of the no P-gyp corn was 3.5 feet while that from the 5000 lbs/acre P-gyp banded was 5.9 feet.

After this first storm the corn was erected as best could be done and there appeared to be no serious affects. However, about two weeks after tasseling, another severe storm occurred which flattened the corn in the P-gyp plots even worse than before. It was felt that the only way to salvage any data was to harvest the plots as silage.

The fresh weight of the total corn plants from these plots is shown in Table 7. The 5000 lbs/acre P-gyp banded gave 72% increase over the no P-gyp treatments.

Both the 1986 and 1987 field trial data indicate that tomatoes give only small yield increases to added P-gyp when the soil analysis indicates a need for additional calcium and sulfur whereas sweet corn gives very large yield response to added P-gyp where soil analysis indicated a need.

The statistical analysis for the yield data of 1987 appear in Appendix A of the final report.

TABLE 4

PHOSPHOGYPSUM PROJECT

1987 BELL PEPPER YIELD BY DATE

LBS/ACRE

TREATMENT	25 MAY	5 JUNE	16 JUNE	23 JUNE	6 JULY	TOTAL	
No P-Gyp Added							
REPS A	1363	2017	4086	409	1394	9270	
B	492	1851	653	1063	653	4713	
C	1115	928	980	436	1132	4591	
D	923	1908	436	627	828	4722	
TOTAL	3894	6704	6155	2535	4008	23295	
AVERAGE	976	1673	1538	636	1002		5824
500 Lbs. P-Gyp/Acre							
REPS A	2017	2696	3049	2260	2004	12027	
B	980	2126	1089	1037	1307	6538	
C	1908	1254	4138	1333	1089	9723	
D	462	1525	1198	1063	1263	5510	
TOTAL	5367	7601	9474	5262	5663	33798	
AVERAGE	1342	1899	2370	1316	1416		8382
1000 Lbs. P-Gyp/Acre							
REPS A	1877	2587	3184	1607	1089	10346	
B	436	1172	601	845	1045	4099	
C	301	1960	462	1115	653	4491	
D	980	1690	3350	2317	1481	9818	
TOTAL	3594	7409	7597	5885	4269	28754	
AVERAGE	897	1851	1899	1472	1067		7187
2000 Lbs. P-Gyp Acre							
REPS A	897	2261	871	1115	828	5972	
B	1333	2126	4029	1442	1568	10497	
C	1254	2640	736	1254	1307	7192	
D	1551	2452	1877	1551	1176	8607	
TOTAL	5036	9478	7514	5362	4879	32269	
AVERAGE	1259	2370	1877	1342	1220		8059
							NSD

TABLE 5

PHOSPHOGYPSUM PROJECT

1987 YIELD OF SWEET CORN - LAKE HELEN, FLORIDA

LBS/ACRE

LSD .05 = 2804
LSD .01 = 3837

TREATMENT	3 JULY 1987	10 JULY 1987	TOTAL
No P-Gyp			
A	8,277	3,267	11,544
B	7,405	436	7,841
REPS C	9,366	1,525	10,890
D	5,881	740	6,621
TOTAL	30,929	5,968	36,896
AVERAGE	7,710	1,481	9,224
500 Lbs P-Gyp/Acre			
A	9,148	1,742	10,890
B	10,019	1,829	11,848
REPS C	10,673	436	11,108
D	9,583	653	10,237
TOTAL	39,423	4,661	44,084
AVERAGE	9,845	1,176	11,021
1000 Lbs P-Gyp/Acre			
A	11,326	740	12,066
B	8,930	3,354	12,284
REPS C	11,761	740	12,502
D	11,544	3,484	15,029
TOTAL	43,561	8,320	51,881
AVERAGE	10,890	2,091	12,970
2000 Lbs P-Gyp/Acre			
A	11,108	1,742	12,851
B	10,455	1,829	12,284
REPS C	13,722	1,394	15,116
D	12,851	4,138	16,989
TOTAL	48,135	9,104	57,240
AVERAGE	12,023	2,265	14,310
3000 Lbs P-Gyp/Acre			
A	8,494	1,960	10,455
B	9,583	1,612	11,195
REPS C	8,712	5,663	14,375
D	12,850	2,614	15,464
TOTAL	39,641	11,849	51,489
AVERAGE	9,932	2,962	12,872

TABLE 6

PHOSPHOGYPSUM PROJECT

1987 YIELD OF SILVER QUEEN SWEET CORN - PLANT CITY, FLORIDA

TREATMENT	REPLICATIONS AVE. HEIGHT IN FEET A	B	C	D	TOTAL	AVE.
No P-Gyp	4.1	3.1	3.5	3.2	13.9	3.48
500 Lbs P-Gyp/Acre Broadcast	5.2	5.0	3.6	5.4	19.2	4.80
500 Lbs P-Gyp/Acre Banded	6.2	5.6	5.9	5.9	23.6	5.90
1000 Lbs P-Gyp/Acre Broadcast	4.4	3.3	5.8	4.7	18.2	4.55

TABLE 7

PHOSPHOGYPSUM PROJECT

SILVER QUEEN SWEET CORN - PLANT CITY, FLORIDA

TREATMENT	REPLICATIONS FRESH WEIGHT - TONS/ACRE A	B	C	D	TOTAL	AVE.
No P-Gyp	5.7	3.2	2.9	2.4	14.2	3.6
500 Lbs P-Gyp/Acre Broadcast	5.8	5.0	2.7	3.9	17.4	4.4
500 Lbs P-Gyp/Acre Banded	7.3	6.5	5.6	5.3	24.7	6.2
1000 Lbs P-Gyp/Acre Broadcast	6.1	3.4	5.0	3.1	17.6	4.4

LSD .01 = 1.16

TISSUE AND SOIL ANALYSIS

FIELD TRIALS - 1987

Leaf tissue samples from all of the field trials were collected for analysis. First, to determine if leaf tissue analysis might be a useful tool for indicating situations where P-gyp could or should be utilized. Second, to determine the effect of P-gyp on the uptake of the various essential elements by the plant.

A few summary statements concerning these results are made here.

Potato Residual Trial

Eight composite leaf tissue samples were taken from treatment 2 replication C of the residual trial potato plots at Hastings. One sample was taken on 14 March and another 14 April.

These samples were taken to determine the coefficient of variation occurring within a plot and to determine the change of concentration in the leaf tissue in a month period.

The following results were obtained as shown in Table 8.

It can be seen that the calcium concentration increased by almost 3 times within the month period. Manganese and zinc also increased. Sodium, nitrogen, phosphorus, sulfur and copper all decreased in concentration and magnesium, potassium, boron and iron remained about the same. The coefficient of variation was higher at the April sampling except for sodium and zinc.

Sweet Corn - Lake Helen

Leaf tissue samples were taken from the sweet corn plots at lake Helen on 19 May, 29 May, and 12 June 1987. From 19 May to 12 June the potassium, nitrogen, boron, copper, iron, manganese and zinc concentration all decreased in the newest fully mature leaf,

The calcium concentration increased slightly and the magnesium, sodium, phosphorus and sulfur concentrations remained about the same.

On 12 June leaf samples were taken from three positions on the corn plants at Lake Helen as follows: 1 - the youngest fully mature leaf, 2 - the leaf immediately below the ear, 3 - the oldest living leaf at the bottom of the stalk.

There was an increase in concentration from top to bottom of calcium, magnesium, potassium, sodium, copper, iron and manganese. There was a decrease of nitrogen concentration from top to bottom and the sulfur, boron, and zinc concentration remained essentially the same.

The changes or lack of change in concentration of elements from top leaf to bottom do not appear to be in any way related to P-gyp levels. Table 9 shows the mean concentration at two different dates for elements having significant differences due to treatment with P-gyp.

TABLE 8

PHOSPHOGYPSUM PROJECT

POTATO LEAF ANALYSIS - HASTINGS, FLORIDA PLOT

ELEMENT	14 MARCH 1987 AVERAGE CONCENTRATION PPM	14 MARCH 1987 COEFFICIENT OF VARIABILITY	14 APRIL 1987 AVERAGE CONCENTRATION	14 APRIL 1987 COEFFICIENT OF VARIABILITY
Ca	.25	21.94	.72	25.44
Mg	.32	14.40	.28	34.63
K	4.92	8.62	4.80	12.05
Na	.032	21.76	.026	19.72
N	5.21	8.49	4.69	9.88
P	.59	3.17	.33	4.72
S	.30	7.69	.15	16.51
B	25.9	3.83	27.9	8.45
Cu	24.0	4.40	14.6	9.55
Fe	104.0	7.55	102.3	12.01
Mn	282.0	12.0	387.7	23.44
Zn	68.9	23.35	73.1	19.52

TABLE 9

PHOSPHOGYPSUM PROJECT
TOP MATURE LEAF TISSUE ANALYSIS FROM SWEET CORN - LAKE HELEN, FLORIDA
ELEMENTS SHOWING SIGNIFICANT DIFFERENCES

19 MAY 1987 - MEAN CONCENTRATION - 4 REPLICATIONS

TREATMENT NO.	Mg	F VALUE	P	F VALUE	S	F VALUE	B	F VALUE	Mn	F VALUE
No P-Gyp Added	.272		.412		.133		4.7		71.5	
500 Lbs P-Gyp/Acre	.290		.393		.177		9.2		104.7	
1000 Lbs P-Gyp/Acre	.320		.410		.190		13.7		156.0	
2000 Lbs P-Gyp/Acre	.330		.373		.270		24.5		180.0	
3000 Lbs P-Gyp/Acre	.327	12.6**	.325	6.6**	.210	13.7**	35.0	30.2**	208.5	10.6**
	LSD .01 = .020		LSD .01 = .039		LSD .01 = .039		LSD .01 = 6.43		LSD .01 = 19.6	

29 MAY 1987

TREATMENT NO.	B	F VALUE	Mn	F VALUE
No P-Gyp Added	6.5		72.0	
500 Lbs P-Gyp/Acre	12.0		88.2	
1000 Lbs P-Gyp/Acre	14.0		88.0	
2000 Lbs P-Gyp/Acre	27.0		134.2	
3000 Lbs P-Gyp/Acre	37.5	21.3**	144.0	13.5**
	LSD .01 = 7.8		LSD .01 = 25.2	

The increase in concentration of magnesium, sulfur, boron, and manganese were all significant at the .01 level while a decrease in phosphorus was significant at the .05 level.

On 29 May only boron and manganese were increased due to treatment. Table 10 shows the mean concentration of elements giving significant differences to P-gyp rates in the sweet corn leaves of various positions on the stalk samples on 12 June 1987.

It can be seen that P-gyp caused an increase in calcium. manganese, nitrogen, sulfur, and boron in the top mature leaf. There was an increase of sulfur and manganese in the mid leaf but a decrease in phosphorus. In the bottom leaf there was an increase in magnesium, sulfur, boron and manganese due to P-gyp.

Soil analyses were done on samples taken from the sweet corn plots at Lake Helen on 19 May, 29 May, and 12 June 1987. These analyses were made to determine the effect of the P-gyp treatments on the various soil parameters measured, and to determine if the parameters changed with time after application.

Table 11 shows the soil elements which gave significant differences at three different dates due to P-gyp treatments. The P-gyp treatments on the corn plots were applied on 13 April. By 19 May, the magnesium, phosphorus, sulfur, boron, and manganese levels in the soil were all measurably higher where P-gyp was applied.

On 29 May the magnesium, sulfur, boron and manganese were still higher in the treated plots but the extractable amounts were somewhat smaller. On 12 June only the magnesium and sulfur were measurably higher on the treated plots.

At no time did the calcium measure higher on the treated plots. However, in 1986 when the treatments were made using powdered P-gyp there was significantly higher calcium on the treated plots.

The fact that the sulfur levels in these plots increased with increasing levels of P-gyp indicates that the pelleted P-gyp was actually dissolving to some degree.

Bell Peppers - Lake Helen

Table 12 shows the elements which had significantly different concentrations in the leaf tissue due to the P-gyp treatments and at different dates. The concentration of elements in the leaf tissue of bell pepper is different from that of sweet corn but the same effects due to P-gyp are present in both plants. At the last sampling date the iron concentration effect did not occur with sweet corn.

Table 13 indicates the elements extracted from the soil which show a significant difference due to P-gyp treatment. The results are similar to those for the sweet corn plots except that calcium extraction shows a slight increase and ammonium nitrogen a slight decrease.

Cantaloupe Residual - Lake Helen

Soil samples were taken form the residual plots on 18 February 1987. The only element showing a difference was manganese which was higher in the plots where P-gyp was added in 1986.

Cantaloupe leaf samples were taken during 1987 growing season. There was no significant difference at the .05 level in any of the element concentrations due to P-gyp treatment but nitrogen, phosphorus and manganese had a trend in the same way as for sweet corn and bell peppers.

The general trend of levels of elements in leaf tissue and in the soil, and the greater yield indicate that there is some carry over of benefit of added P-gyp from one year to the next.

It may not be possible to have a long range build up in low cation exchange capacity soils from the addition of P-gyp but there may be sufficient carry over so that good results could be achieved by somewhat lower yearly application.

Sweet Corn - Plant City

Leaf tissue samples were taken on 21 July 1987, soil samples on 16 August 1987. The variability was so large within plots for both leaf and soil analysis that no significant differences could be demonstrated. However, small differences in tissue levels can apparently have considerable affect on the growth and yield of crops.

The results from these trials indicate that tissue analysis is not as good an indicator for plant nutrient requirements as is soil analysis. Significant yield increases may be achieved even when the tissue analysis levels are all in the low average concentrations or greater. When tissue analysis levels fall below a somewhat poorly defined "critical level" for a particular element then yield increases can be expected due to the addition of that element. Apparently, tissue analysis would not be a very sensitive indicator for the situation in which P-gyp would be beneficial unless either calcium and sulfur were below a critical level. The critical level would need to be defined for each type of crop because crops do have greatly different concentrations of calcium and sulfur in the leaf tissue.

TABLE 10

PHOSPHOGYPSUM PROJECT
LEAF TISSUE ANALYSIS FROM SWEET CORN - LAKE HELEN, FLORIDA
ELEMENTS SHOWING SIGNIFICANT DIFFERENCES

12 JUNE 1987 - MEAN CONCENTRATION - 4 REPLICATIONS

TOP MATURE LEAF

TREATMENT NO.	Ca	F VALUE	Mn	F VALUE	N	F VALUE	S	F VALUE	B	F VALUE
No P-Gyp Added	.475		59.2		2.77		.10		8.2	
500 Lbs P-Gyp/Acre	.535		76.7		3.17		.15		10.2	
1000 Lbs P-Gyp/Acre	.573		108.2		3.37		.18		18.0	
2000 Lbs P-Gyp/Acre	.568		105.5		3.19		.17		20.7	
3000 Lbs P-Gyp/Acre	.527	5.7*	134.5	7.1*	3.14	10.6**	.20	23.9**	22.7	4.8*
LSD .05 =	.05	LSD .05 =	28.1	LSD .01 =	.31	LSD .01 =	.04	LSD .05 =	7.0	

MID OR EAR LEAF

TREATMENT NO.	P	F VALUE	S	F VALUE	Mn	F VALUE
No P-Gyp Added	.32		.13		60.2	
500 Lbs P-Gyp/Acre	.29		.15		75.7	
1000 Lbs P-Gyp/Acre	.28		.16		106.2	
2000 Lbs P-Gyp/Acre	.26		.21		133.7	
3000 Lbs P-Gyp/Acre	.29	7.0*	.24	35.5**	167.0	5.1**
LSD .05 =	.028	LSD .01 =	.02	LSD .01 =	59.8	

BOTTOM LEAF

TREATMENT NO.	Mg	F VALUE	S	F VALUE	B	F VALUE	Mn	F VALUE
No P-Gyp Added	.51		.13		4.7		125.7	
500 Lbs P-Gyp/Acre	.56		.19		5.7		219.2	
1000 Lbs P-Gyp/Acre	.60		.19		8.8		250.0	
2000 Lbs P-Gyp/Acre	.61		.26		13.7		335.0	
3000 Lbs P-Gyp/Acre	.60	6.7*	.27	23.4**	15.7	9.6**	405.0	9.8**
LSD .05 =	.06	LSD .01 =	.04	LSD .01 =	4.5	LSD .01 =	125.6	

TABLE 11

PHOSPHOGYPSUM PROJECT
SOIL ANALYSIS FROM SWEET CORN PLOTS - LAKE HELEN, FLORIDA
ELEMENTS SHOWING SIGNIFICANT DIFFERENCES DUE TO TREATMENT
MEAN AMOUNT EXTRACTED - 4 REPLICATIONS

19 MAY 1987

TREATMENT NO.	Mg	F VALUE	P	F VALUE	S	F VALUE	B	F VALUE	Mn	F VALUE
No P-Gyp Added	.51		60		10.0		.20		1.9	
500 Lb P-Gyp/Acre	.57		62		23.2		.29		5.2	
1000 Lb P-Gyp/Acre	.60		65		33.5		.12		7.6	
2000 Lb P-Gyp/Acre	.66		69		43.5		.39		13.9	
3000 Lb P-Gyp/Acre	.71	10.5**	65	4.7*	81.3	17.9**	.48	9.6**	14.6	16.7**
	LSD .01 = .09		LSD .05 = 3.7		LSD .01 = 18.6.		LSD .01 = .09		LSD .01 = 4.6	

29 MAY 1987

TREATMENT NO.	Mg	F VALUE	S	F VALUE	B	F VALUE	Mn	F VALUE
No P-Gyp Added	.48		6.0		.04		2.1	
500 Lb P-Gyp/Acre	.57		41.2		.16		7.6	
1000 Lb P-Gyp/Acre	.61		38.5		.13		8.6	
2000 Lb P-Gyp/Acre	.58		39.0		.20		8.8	
3000 Lb P-Gyp/Acre	.77	7.7*	85.7	5.7*	.44	10.8**	18.1	11.0**
	LSD .05 = .09		LSD .05 = 29.9.		LSD .01 = .13		LSD .01 = 5.9	

12 JUNE 1987

TREATMENT NO.	Mg	F VALUE	S	F VALUE
No P-Gyp Added	.34		9.5	
500 Lb P-Gyp/Acre	.39		22.2	
1000 Lb P-Gyp/Acre	.42		37.2	
2000 Lb P-Gyp/Acre	.43		44.5	
3000 Lb P-Gyp/Acre	.52	5.4*	65.2	14.1**
	LSD .05 = .07		LSD .01 = 19.5	

Soil analysis appears to be a much more sensitive indicator not only for the need of calcium and sulfur but also for other elements and for the balance between elements. In other words, soil analysis properly executed and interpreted can provide a sensitive indicator of the need for gypsum as well as the rate of gypsum needed under site specific conditions.

TABLE 12

PHOSPHOGYPSUM PROJECT
LEAF TISSUE ANALYSIS FROM BELL PEPPER - LAKE HELEN, FLORIDA
ELEMENTS SHOWING SIGNIFICANT DIFFERENCES
YOUNGEST FULLY MATURE LEAF - MEAN CONCENTRATION - 4 REPLICATIONS

19 MAY 1987

TREATMENT NO.	Mg	F VALUE	S	F VALUE	B	F VALUE	Mn	F VALUE
No P-Gyp Added	.74		.07		23.7		250	
500 Lb P-Gyp/Acre	.97		.27		42.2		291	
1000 Lb P-Gyp/Acre	1.06		.30		62.5		319	
2000 Lb P-Gyp/Acre	1.16	32.5**	.32	174.9**	96.5	63.3**	387	7.9*
	LSD .01 = .15		LSD .01 = .05		LSD .01 = 14.5		LSD .01 = 54.0	

29 MAY 1987

TREATMENT NO.	Mg	F VALUE	P	F VALUE	S	F VALUE	B	F VALUE	Cu	F VALUE	Mn	F VALUE
No P-Gyp Added	.87		.50		.07		38.2		5.9		372	
500 Lb P-Gyp/Acre	1.10		.30		.22		56.7		4.5		447	
1000 Lb P-Gyp/Acre	1.11		.30		.22		73.0		4.5		471	
2000 Lb P-Gyp/Acre	1.38	10.5**	.25	98.3**	.25	109.1**	132.0	32.7**	4.7	7.8*	568	5.3**
	LSD .01 = .27		LSD .01 = .06		LSD .01 = .04		LSD .01 = 22.8		LSD .05 = .9		LSD .05 = 98.8	

12 JUNE 1987

TREATMENT NO.	Mg	F VALUE	P	F VALUE	S	F VALUE	B	F VALUE	Cu	F VALUE	Fe	F VALUE
No P-Gyp Added	.53		.46		.12		35.2		7.6		177	
500 Lb P-Gyp/Acre	.77		.33		.28		53.0		5.9		335	
1000 Lb P-Gyp/Acre	.78		.33		.26		58.5		5.7		345	
2000 Lb P-Gyp/Acre	.87	82.0**	.31	45.9**	.29	84.9**	100.5	21.7**	6.1	20.8**	440	16.9**
	LSD .01 = .08		LSD .01 = .05		LSD .01 = .05		LSD .01 = 20.2		LSD .01 = 1.0		LSD .01 = 126.8	

TREATMENT NO.	Mn	F VALUE
No P-Gyp Added	295	
500 Lb P-Gyp/Acre	335	
1000 Lb P-Gyp/Acre	345	
2000 Lb P-Gyp/Acre	440	5.6*
	LSD .05 = 96.3	

TABLE 13

PHOSPHOGYPSUM PROJECT
SOIL ANALYSIS FROM BELL PEPPER PLOTS - LAKE HELEN, FLORIDA
ELEMENTS SHOWING SIGNIFICANT DIFFERENCES DUE TO TREATMENT
MEAN AMOUNT EXTRACTED - 4 REPLICATIONS

19 MAY 1987

TREATMENT NO.	Ca	F VALUE	Mg	F VALUE	NH_4-N	F VALUE	S	F VALUE	Mn	F VALUE
No P-Gyp Added	2.1		.46		19.7		5.7		4.8	
500 Lb P-Gyp/Acre	2.4		.53		15.7		18.0		7.6	
1000 Lb P-Gyp/Acre	2.4		.55		15.5		27.2		8.9	
2000 Lb P-Gyp/Acre	2.4	5.2*	.66	34.7**	15.2	6.7*	49.2	17.5**	12.5	113.6**
	LSD .05 = .3		LSD .01 = .06		LSD .05 = 3.0		LSD .01 = 16.3		LSD .01 = 1.2	

ECONOMIC RETURNS DUE TO USE OF P-GYP

The magnitude of the economic returns due to the use of P-gyp on the various crops tested in these studies can only be a speculative estimate. This estimate can only be achieved: 1. by assigning a cost to pelleted P-gyp material and its application in the field, 2. by assigning a selling price to the crop produced, and 3. by using the percentage yield increases found in the field studies as being equal to those which could be expected by farmers under normal crop management practices.

COST OF P-GYP

Mined P-gyp in powder form sold for about $70.00 per ton in 1987. Mined gypsum in pelleted form using ligno sulfates as the binder sold for about $115.00 per ton.

If other additives such as urea or sulfate of potash magnesia were used as the binder for pelletizing, then the price of the resulting mix would depend on the additional cost of the nitrogen, potash, magnesium, etc. used but the actual cost of the pelleted P-gyp should not be more than about $90.00 per ton including cost of application.

SELLING PRICE OF PRODUCE

Based on what some in produce marketing consider to be a moderate price to the farmer for produce, the following prices will be used for calculating economic return:

	Price Per Pound
Cowpea	$ 0.06
Cantaloupe	0.10
Sweet Corn	0.12
Bell Peppers	0.25
Potatoes	0.08
Tomatoes	0.14
Watermelon	0.05

AVERAGE YIELD OF CROPS

The following yields are considered to be average good per acre yields of the field crops tested with P-gyp:

	Cwt/acre
Cantaloupes	180
Sweet Corn	120
Bell Peppers	60
Potatoes	300
Tomatoes	180

Listed below is the percent yield increase needed to break even using 1000 lbs P-gyp and 2000 lbs P-gyp per acre:

Percentage increases needed to break even

	Using 1000 lbs/acre	Using 2000 lbs/acre	% increases found
Cantaloupe	2.5	5.0	37
Sweet Corn	3.1	6.2	55
Cowpeas	12.5	25.0	20
Bell Peppers	1.0	2.0	40
Potaotes	1.9	3.8	22
Tomatoes	1.8	3.6	6
Watermelon	4.5	9.0	49

According to the above calculations, cowpeas and tomatoes would give the least return on the investment in P-gyp application.

Probably, of the above crops, only cowpeas presents a real risk in obtaining an economic return on investment in P-gyp. As mentioned earlier, tomatoes which have an insipient calcium deficiency will produce about the same weight of fruit as those without deficiency but with deficiency a large percentage of the fruit will have blossom and rot which makes them unmarketable either for the fresh or processing market.

The other crops tested would return from about $2.00 to $20.00 for each dollar invested in P-gyp. The risk factor is very low on all the crops tested except cowpeas.

FIELD TRIALS WITH ORANGES - PROCEDURES

Field tests were established in the Swann (near Wachula) and Rawle (Desoto City) groves of the Coca-Cola Company in November 1985. Initial activities included site selection and collection of soil samples for fixation and greenhouse nutrient studies as well as for standard analyses. Sampling was limited to a depth of six inches in both areas.

Mature orange trees of both groves were spaced by 28' between rows and 15' within rows. Trees of the Swann Grove were pineapple variety on Cleopatra rootstock. Trees of the Rawle Grove were valencias on rough lemon. Both tests were periodically monitored for nutritional status by standard leaf tissue and soil analyses.

Following completion of initial soil analyses, phosphogypsum treatments were applied in February 1986 in both groves. Treatments were as follows:

1. Normal Grove Management. Fertilizers or lime supplied during the course of normal day to day management of the total grove.

2. Monitoring/Supplemental Fertilizer. Trees of this treatment received fertilizer or lime as described for Normal Grove Management plus additional nutrients as indicated by leaf or soil monitoring. However, calcium and sulfur were excluded where possible. from this treatment. Small amounts of calcium and sulfur were introduced into this treatment through use of trace element sulfates and phosphate fertilizer.

3. Supplemental Fertilizer plus 500 lbs/acre of Gypsum Mix. Trees received fertilizer or lime equal to that described for the Normal Grove Management and Monitoring/Supplemental Fertilizer treatments plus 500 lbs/acre of the gypsum mix.

4. Supplemental Fertilizer plus 1000 lbs/acre of Gypsum Mix. Trees received fertilizer or lime equal to that described for the Normal Grove Treatment and Monitoring/Supplemental Fertilizer treatments plus 1000 lbs/acre of the gypsum mix.

Gypsum treatments were re-applied approximately one year after the initial applications in both groves. A third annual application of gypsum treatments together with supplemental fertilizers was made in the Rawle Grove due to a later harvest date. Gypsum treatments and supplemental fertilizers were lightly incorporated when applied.

Plan nutrient composition of the gypsum mix utilized was as follows:

Calcium	16%
Sulfur	17%
Potassium (K_2O)	4%
Magnesium	2%
Manganese	1.4%

Amounts of potash, magnesium and manganese were proportionately adjusted to be equal between treatments when contained in supplemental fertilizers spread on or near the dates of gypsum application.

Soil samples were collected from each plot at about one year after the gypsum treatments were applied to determine plant nutrient status for monitoring purposes and at the end of each test. Leaf samples for monitoring purposes were collected in late April and late July of 1987 and in August of 1988.

Plots of the Swann Grove were harvested in January of 1987 and 1988. Harvests of the Rawle Grove were accomplished in May and June of 1987 and 1988, respectively. Care was taken to select, as uniform as possible, trees for conducting the tests in both locations. However, some variation in tree size was noted in both groves. Canopy volume of each tree within the experimental plots was measured with a sighting devise from constantdistance and tree size indices developed. Linear regression was used to relate yield and tree size index for each treatment. Yields were proportionally adjusted to average tree size for the whole experiment. Regression curves were used to adjust yield data.

Equal amounts of fruit were removed from each plot during the 1987 harvests for analysis of radioactivity and heavy metal content. (For results of analyses for radioactivity, see tables 36 and 37). Fruit was also taken from the 1988 harvests for measurement of sugar and acid content and calculation of the sugar/acid ratio by the Coca-Cola Quality Concentrate Laboratory in Auburndale.

Each plot of both groves consisted of four trees. Treatments were applied according to randomized complete block design. There were four replications.

Yield data statistically analyzed individually each year and as combined experiments for two harvests from both groves.

Results of sorption tests for initial determination of plant nutrient re-commendation levels showed an absence of nutrient fixation.

RESULTS

Results of the initial analyses of soils taken from the test areas of the Swann and Rawle Groves are presented in Table 14. Both soils were found somewhat typical of the Central Florida ridge, characterized by a low cation exchange capacity and organic matter content. Nutrient status of the two locations was similar, indicating less than adequate amounts of all major and secondary elements as well as boron, iron and mangnese for citrus production. The calcium/magnesium ratio was considered borderline high for both locations.

LEAF SAMPLE MONITORING - SWANN

Following gypsum mix applications in February 1986, leaf samples collected in late April generally reflected results of the initial soil analysis regardless of treatment (Tables 15, 16). Analyses for late July 1986 suggest an improvement in leaf content of Mg, B, Fe, Mn and Zn from that of April (Tables 17, 18). However, levels of nitrogen and sulfur appeared slightly lower. Calcium content was low for both sampling dates.

The analyses for leaf samples taken in August 1987 indicate optimum to high levels of all nutrients except sulfur, manganese and zinc (Tables 19, 20). Differences in leaf content of P, B and Fe as a result of supplemental fertilizer treatments had become obvious by the August 1987 sampling date although these three elements were considered adequate in all treatments. No differences between treatments were found for any elements of the gypsum mix.

LEAF SAMPLE MONITORING - RAWLE

Analyses of the samples collected in April 1986 indicated a high potassium leaf content with nitrogen and phosphorus borderline between low and optimum (Tables 21, 22). Only sulfur and copper were measured at optimum levels on that sampling date. Ca, Mg, B, Fe and Zn were all considered low. There were no apparent differences between treatments. Leaf nutrient levels remained somewhat constant from April through the July 1986 sampling date although Mg, N, Fe and Zn were found slightly increased (Tables 23, 24). Phosphorus and sulfur had both decreased between April and July.

Analyses of samples collected in August 1987 reflected sufficient levels of all elements except zinc (Tables 25, 26). Leaf content of P, B and Fe appear higher in plots that received supplemental fertilizer.

SOIL SAMPLE MONITORING - SWANN

Monitoring of soil nutrient status in the Swann Grove was first

TABLE 14

RESULTS OF INITIAL SOIL ANALYSES AND INTERPRETATION OF NUTRIENT STATUS FOR THE SWANN AND RAWLE GROVES NOVEMBER 1985

Measure	SWANN Observation	SWANN Interpretation	RAWLE Observation	RAWLE Interpretation
CEC (meq/100)	4.0	-	2.6	-
% Organic Matter	1.6	-	0.9	-
pH	6.5	-	6.2	-
% Base Saturation	100	-	100	-
Ca/Mg ratio	5.6	O-H*	5.5	O-H
Calcium (meq/100)	3.4	L-O	2.2	L-O
Magnesium (meq/100)	0.61	L	0.40	L
Potassium (meq/100)	0.01	L	.03	L
Nitrogen (ppm)	3	L	3	L
Phosphorus (ppm)	6	L	13	L
Sulfur (ppm)	9	L	4	L
Boron (ppm)	0.62	L-O	0.69	L-O
Copper (ppm)	23.9	H	30.9	H
Iron (ppm)	29	L-O	24	L-O
Manganese (ppm)	1.6	L	2.9	L
Zinc (ppm)	24.6	O	25.5	O

*L = LOW O = OPTIMUM H = HIGH

TABLE 15

MEAN NUTRIENT STATUS. RESULTS OF APRIL 1986 LEAF TISSUE ANALYSES ON PINEAPPLE ORANGE ACCORDING TO GYPSUM TREATMENTS SWANN GROVE

	TREATMENTS*		
Plant Nutrient	Monitoring/ Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium, %	1.91	1.89	2.00
Magnesium, %	0.24	0.24	0.24
Potassium, %	1.27	1.35	1.38
Nitrogen, %	2.15	2.20	2.19
Phosphorus, %	0.12	0.13	0.13
Sulfur, %	0.18	0.19	0.17
Boron, ppm	20	19	22
Copper, ppm	11.0	11.1	10.6
Iron, ppm	37	39	40
Manganese, ppm	19	19	20
Zinc, ppm	25	25	23

*No supplemental fertilizers had been applied at the April 1986 sampling date. Thus, the Monitoring/ Supplemental Fertilizer treatment and normal grove management were considered equal.

TABLE 16

INTERPRETATION OF RESULTS OF APRIL 1986 LEAF TISSUE ANALYSES ON PINEAPPLE ORANGE ACCORDING TO GYPSUM TREATMENTS SWANN GROVE

Plant Nutrient	TREATMENTS** Monitoring/ Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium	L*	L	L
Magnesium	L	L	L
Potassium	L-0	0	0
Nitrogen	D-L	D-L	D-L
Phosphorus	L-0	L-0	L-0
Sulfur	L-0	L-0	L-0
Boron	D-L	D-L	D-L
Copper	0	0	0
Iron	L	L	L
Manganese	L	L	L
Zinc	L-0	L-0	L-0

*D = DEFICIENT L = LOW O = OPTIMUM H = HIGH E = EXCESS

**NO supplemental fertilizers had been applied at the late April 1986 sampling date. Thus, the Monitoring/ Supplemental Fertilizer treatment and normal grove management were considered equal.

TABLE 17

MEAN NUTRIENT STATUS. RESULTS OF JULY 1986 LEAF TISSUE ANALYSIS ON PINEAPPLE ORANGE ACCORDING TO GYPSUM TREATMENTS
SWANN GROVE

	TREATMENTS		
Plant Nutrient	Monitoring/* Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium, %	2.76	2.84	2.76
Magnesium, %	0.34	0.35	0.35
Potassium, %	1.26	1.38	1.36
Nitrogen, %	2.20	2.13	2.00
Phosphorus, %	0.12	0.12	0.12
Sulfur, %	0.13	0.14	0.15
Boron, ppm	26	26	28
Copper, ppm	57	69	59
Iron, ppm	48	59	60
Manganese, ppm	31	34	29
Zinc, ppm	40	43	36

*No supplemental fertilizer had been applied at the July 1986 sampling date. Thus, the Monitoring/ Supplemental Fertilizer treatment was equal to normal grove management.

TABLE 18

INTERPRETATION OF RESULTS OF JULY 1986 LEAF TISSUE ANALYSES ON PINEAPPLE ORANGE ACCORDING TO GYPSUM TREATMENTS SWANN GROVE

	TREATMENTS**		
Plant Nutrient	Monitoring/ Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium	L*	L	L
Magnesium	0	0	0
Potassium	L-0	0	0
Nitrogen	D-L	D	D
Phosphorus	L-0	L-0	L-0
Sulfur	L	L	L
Boron	L	L	L
Copper	E	E	E
Iron	L	L-0	L-0
Manganese	0	0	0
Zinc	0	0	0

*D = DEFICIENT L = LOW 0 = OPTIMUM. H= HIGH E = EXCESS

**NO supplemental fertilizers had been applied at the late July 1986 sampling date. Thus, the Monitoring/ Supplemental Fertilizer treatment and normal grove management were considered equal.

TABLE 19

MEAN NUTRIENT STATUS. RESULTS OF AUGUST 1987 LEAF TISSUE ANALYSIS ON PINEAPPLE ORANGE ACCORDING TO GYPSUM TREATMENT
SWANN GROVE

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium, %	3.51	3.49	3.41	3.38
Magnesium, %	0.37	0.37	0.36	0.36
Potassium, %	1.88	1.78	1.97	1.88
Nitrogen, %	3.97	4.01	4.08	4.12
Phosphorus, %	0.13	0.14	0.14	0.16
Sulfur, %	0.19	0.18	0.19	0.20
Boron, ppm	53	98	97	96
Copper, ppm	11.4	10.3	9.2	9.4
Iron, ppm	76	86	87	92
Manganese, ppm	15	15	13	15
Zinc, ppm	23	21	22	22

TABLE 20

INTERPRETATION OF RESULTS OF AUGUST 1987 LEAF TISSUE ANALYSES ON PINEAPPLE ORANGE ACCORDING TO GYPSUM TREATMENTS
SWANN GROVE

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium	O*	O	O	O
Magnesium	O	O	O	O
Potassium	O-H	O-H	O-H	O-H
Nitrogen	E	E	E	E
Phosphorus	O	O	O	O-H
Sulfur	L	L	L	L
Boron	L-O	O	O	O
Copper	O	O	O	O
Iron	O	O	O	O
Manganese	D	D	D	D
Zinc	L	L	L	L

*D = DEFICIENT L = LOW O = OPTIMUM H = HIGH E = EXCESSIVE

TABLE 21

MEAN NUTRIENT STATUS. RESULTS OF APRIL 1986 LEAF TISSUE ANALYSES ON VALENCIA ORANGE ACCORDING TO GYPSUM TREATMENTS
RAWLE GROVE

Plant Nutrients	TREATMENTS		
	Monitoring/ Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium, %	2.00	1.99	2.14
Magnesium, %	0.25	0.27	0.26
Potassium, %	1.92	1.90	1.99
Nitrogen, %	2.51	2.36	2.59
Phosphorus, %	0.12	0.11	0.12
Sulfur, %	0.30	0.32	0.31
Boron, ppm	23	23	24
Copper, ppm	13.8	13.6	13.9
Iron, ppm	51	50	58
Manganese, ppm	14	15	14
Zinc, ppm	19	19	20

*No supplemental fertilizers had been applied at the April 1986 sampling date, Thus, the Monitoring/ Supplemental Fertilizer treatment and normal grove management were considered equal.

TABLE 22

INTERPRETATION OF RESULTS OF APRIL 1986 LEAF TISSUE ANALYSES ON VALENCIA ORANGE ACCORDING TO GYPSUM TREATMENTS RAWLE GROVE

	TREATMENTS**		
Plant Nutrients	Monitoring/ Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium	L*	L	L
Magnesium	L	L	L
Potassium	H	H	H
Nitrogen	L-O	L-O	L-O
Phosphorus	L-O	L-O	L-O
Sulfur	O	O	O
Boron	L	L	L
Copper	O	O	O
Iron	L	L	L
Manganese	D	D	D
Zinc	L	L	L

*D = DEFICIENT L = LOW O = OPTIMUM H = HIGH E = EXCESS

**NO supplemental fertilizers had been applied at the late April 1986 sampling date. Thus, the Monitoring/ Supplemental Fertilizer treatment and normal grove management were considered equal.

TABLE 23

MEAN NUTRIENT STATUS. RESULTS OF JULY 1986 LEAF TISSUE ANALYSES ON VALENCIA ORANGE ACCORDING TO GYPSUM TREATMENTS RAWLE GROVE

Plant Nutrients	TREATMENTS* Monitoring/ Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium, %	2.79	2.78	2.95
Magnesium, %	0.29	0.30	0.30
Potassium, %	1.70	1.72	1.62
Nitrogen, %	2.70	2.53	2.70
Phosphorus, %	0.09	0.09	0.09
Sulfur, %	0.16	0.17	0.19
Boron, ppm	26	27	29
Copper, ppm	320	315	314
Iron, ppm	55	59	72
Manganese, ppm	16	17	18
Zinc, ppm	33	36	33

*No supplemental fertilizers had been applied at the July 1986 sampling date. Thus, the Monitoring/ Supplemental Fertilizer treatment was equal to normal grove management.

TABLE 24

INTERPRETATION OF RESULTS OF JULY 1986 LEAF TISSUE ANALYSES ON VALENCIA ORANGE ACCORDING TO GYPSUM TREATMENTS RAWLE GROVE

Plant Nutrients	TREATMENTS** Monitoring/ Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/acre Gypsum Mix	Supplemental Fertilizer + 1000 lbs/acre Gypsum Mix
Calcium	L*	L	L-O
Magnesium	L-O	L-O	L-O
Potassium	O-H	O-H	O
Nitrogen	O-H	L-O	O-H
Phosphorus	D-L	D-L	D-L
Sulfur	L	L	L
Boron	L	L	L
Copper	E	E	E
Iron	L	L-O	O
Manganese	D-L	D-L	D-L
Zinc	O	O	O

*D = DEFICIENT L = LOW O = OPTIMUM H = HIGH E = EXCESS

**No supplemental fertilizers had been applied at the late July 1986 sampling date. Thus, the Monitoring/ Supplemental Fertilizer treatment and normal grove management were considered equal.

TABLE 25

MEAN NUTRIENT STATUS. RESULTS OF AUGUST 1987 LEAF TISSUE ANALYSES ON VALENCIA ORANGE ACCORDING TO GYPSUM TREATMENTS
RAWLE GROVE

Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium, %	3.22	2.98	3.06	3.12
Magnesium, %	0.31	0.29	0.30	0.29
Potassium, %	1.86	1.96	1.89	1.86
Nitrogen, %	4.33	4.54	4.35	4.39
Phosphorus, %	0.11	0.14	0.12	0.14
Sulfur, %	0.24	0.23	0.28	0.23
Boron, ppm	58	72	74	70
Copper, ppm	81.8	89.4	82.2	77.8
Iron, ppm	71	93	99	92
Manganese, ppm	32	32	32	31
Zinc, ppm	19	23	20	19

TABLE 26

INTERPRETATION OF RESULTS OF AUGUST 1987 LEAF TISSUE ANALYSES ON VALENCIA ORANGE ACCORDING TO GYPSUM TREATMENTS
RAWLE GROVE

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium	0*	L-0	L-0	0
Magnesium	0	L-0	L-0	L-0
Potassium	H	H	H	H
Nitrogen	E	E	E	E
Phosphorus	L-0	0	0	0
Sulfur	0	0	0	0
Boron	0	0	0	0
Copper	E	E	E	E
Iron	0	0	0	0
Manganese	0	0	0	0
Zinc	L	L	L	L

*D = DEFICIENT L= LOW O = OPTIMUM H = HIGH E = EXCESS conducted in January 1987, approximately eleven months after the first gypsum mix treatments had been applied and two months after supplemental fertilizers were utilized. With the exception of boron, no differences were seen between treatments (Table 27). In fact, plots were interpreted as being essentially unchanged from the initial sampling information (Table 14) obtained in November 1985. Almost all plant soil nutrients were considered low when the final sampling occured in January 1988 (Table 28). However, greater amounts of Mg, P and S were found present in soil of plots receiving supplemental fertilizer as compared to soil of the normal grove management plots.

SOIL SAMPLE MONITORING - RAWLE

Analyses of soils collected from the Rawle plots in February 1987 indicated less than desirable levels for all nutrients except copper, iron and zinc (Table 29). Phosphorus was measured at 18 ug/ml in soil from treatments which had received supplemental fertilizer as compared to 13 ug/ml for soils of normal grove management.

Soil phosphorus content of plots treated with supplemental fertilizer was significantly elevated over P content of plots not receiving treatments but was still interpreted as low for citrus production in January 1988 (Table 30). Magnesium and zinc also appeared increased as a result of supplemental fertilizer applications. However, only zinc was considered optimum.

Soil samples were collected the last day of May in 1988, about 10 weeks after the final gypsum mix and supplemental fertilizer treatments were applied. Sulfur was analyzed at 17 and 30 ppm, respectively, for plots which had received 500 and 1000 lbs/acre of gypsum mix as compared to about 3 ppm for the other treatments (Table 31). Calcium appeared slightly increased only where 1000 lbs/acres of the mix was applied. Magnesium, P, B, Fe, Mn and Zn appeared considerably increased as a result of supplemental fertilizer use over normal grove management plots. With exception of phosphorus, copper and zinc, soil nutrient levels for the surface six inches of soil were considered low.

YIELD

Fresh fruit yields as an average of all plots for both groves are presented in Table 32 Production of the Swann Grove in 1987 was only about a third of that recorded for 1988. Less fruit was harvested in 1988 than 1987 in the Rawle Grove. Yield differences between years in each grove were found statistically significant. Interactions of treatments and years were not apparent from the data for either location.

Yield averages of the normal grove management plots were lower both years in both locations when compared to plot averages for treatments involving the gypsum mixes and/or supplemental fertilizer (Table 33). However, statistical differences between treatments were indicated only by data of the 1988 harvest of the Rawle Grove. An increase equivalent to five tons/acre was measured for the 1000 lbs/acre gypsum treatment over normal grove management. Production for the monitoring supplemental

TABLE 27

MEAN NUTRIENT STATUS. RESULTS OF JANUARY 1987 SOIL ANALYSES ACCORDING TO GYPSUM TREATMENTS
SWANN GROVE

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium, meq/100	2.7	3.1	3.1	2.9
Magnesium, meq/100	0.63	0.64	0.70	0.66
Potassium, meq/100	0.24	0.20	0.23	0.17
Nitrogen, ppm	9	10	9	10
Phosphorus, ppm	7	8	6	7
Sulfur, ppm	14	13	13	13
Boron, ppm	0.28	0.44	0.40	0.40
Copper, ppm	34.2	33.2	31.7	35.3
Iron, ppm	58	49	40	49
Manganese, ppm	2.0	1.9	1.7	2.3
Zinc, ppm	33.8	38.1	33.2	35.0

TABLE 28

MEAN NUTRIENT STATUS. RESULTS OF JANUARY 1988 SOIL
ANALYSES ACCORDING TO GYPSUM TREATMENTS
FINAL SAMPLING - SWANN GROVE

Plant Nutrient	TREATMENTS: Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium, meq/100	2.3	2.0	2.0	2.0
Magnesium, meq/100	0.51	0.63	0.69	0.63
Potassium, meq/100	0.31	0.23	0.32	0.26
Nitrogen, ppm	3	4	4	4
Phosphorus, ppm	9	15	22	16
Sulfur, ppm	4.3	6.0	6.0	5.5
Boron, ppm	0.06	0.02	0.02	0.02
Copper, ppm	21.2	20.4	19.7	20.9
Iron, ppm	58.3	58.8	52.5	52.5
Manganese, ppm	6.1	6.5	4.3	2.4
Zinc, ppm	17.4	19.0	18.1	16.2

TABLE 29

MEAN NUTRIENT STATUS. RESULTS OF FEBRUARY 1987 SOIL ANALYSES
ACCORDING TO GYPSUM TREATMENTS
RAWLE GROVE

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium, meq/100	1.2	1.2	1.3	1.3
Magnesium, meq/100	0.36	0.34	0.39	0.37
Potassium, meq/100	0.08	0.08	0.07	0.07
Nitrogen, ppm	9	9	9	9
Phosphorus, ppm	13	18	18	18
Sulfur, ppm	12	12	13	12
Boron, ppm	0.31	0.41	0.30	0.31
Copper, ppm	31.1	34.0	34.2	34.1
Iron, ppm	34	38	36	37
Manganese, ppm	2.2	3.4	2.7	3.2
Zinc, ppm	12.9	14.0	13.9	13.9

TABLE 30

MEAN NUTRIENT STATUS. RESULTS OF JANUARY 1988 SOIL ANALYSES
ACCORDING TO GYPSUM TREATMENTS
RAWLE GROVE

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium, meq/100	1.43	1.25	1.28	1.50
Magnesium, meq/100	0.35	0.52	0.52	0.54
Potassium, meq/100	0.15	0.14	0.16	0.15
Nitrogen, ppm	3	3	3	3
Phosphorus, ppm	16	29	35	41
Sulfur, ppm	6	6	7	7
Boron, ppm	0.02	0.04	0.05	0.03
Copper, ppm	22.1	18.9	19.5	19.4
Iron, ppm	31	35	34	40
Manganese, ppm	1.3	2.1	1.8	1.8
Zinc, ppm	8.7	9.4	10.7	10.9

TABLE 31

MEAN NUTRIENT STATUS. RESULTS OF MAY 1988 SOIL ANALYSES
ACCORDING TO GYPSUM TREATMENTS
FINAL SAMPLING - RAWLE GROVE

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium, meq/100	1.4	1.3	1.4	1.8
Magnesium, meq/100	0.32	0.69	0.63	0.65
Potassium, meq/100	0.03	0.04	0.04	0.03
Nitrogen, ppm	4	4	4	4
Phosphorus, ppm	10	53	51	64
Sulfur, ppm	2.8	2.0	17.3	30.0
Boron, ppm	0.25	0.46	0.40	0.39
Copper, ppm	18.3	17.6	16.3	17.6
Iron, ppm	28.0	33.5	29.5	37.8
Manganese, ppm	1.1	6.2	7.3	7.7
Zinc, ppm	6.0	8.4	7.0	8.3

TABLE 32

ORANGE YIELD ACCORDING TO YEAR AND LOCATION

YEAR	YIELD (LBS/PLOT)*	
	SWANN	RAWLE
1987	1109b	2079a
1988	3281a	1787b

YEAR	YIELD (TONS/ACRE)*	
	SWANN	RAWLE
1987	14.5b	27.0a
1988	42.7a	23.2b

*Means followed by different letters are significantly different at the 5% level of probability, or less. Compare in columns only.

TABLE 33

YIELD OF ORANGE ACCORDING TO GYPSUM TREATMENTS FOR YEAR AND LOCATION

	YIELD (TONS/ACRE)			
	SWANN		RAWLE	
Treatment	1987	1988	1987	1988*
Normal Growth Management	12.5	41.6	25.9	21.2c
Monitoring - Supplemental Fertilizer	13.6	43.7	27.5	22.4b
Supplemental Fertilizer + 500 lbs/acre Gypsum*	16.3	43.3	26.5	23.0b
Supplemental Fertilizer + 1000 lbs/acre Gypsum	15.4	42.0	28.2	26.3a

*Means followed by different letters are significantly different at the 5% level of probability, or less.

fertilizer treatment and the fertilizer supplement plus 500 lbs/acre gypsum treatment was recorded at 22.4 and 23.0 tons/acre, respectively, more than three tons/acre less than the fertilizer supplement plus 1000 lbs/acre gypsum mix treatment.

QUALITY

No significant differences in brix, acid or the brix acid ratio according to treatments were found in 1988 for either grove.

SUPPLEMENTAL PLANT NUTRIENTS

Total supplemental plant nutrients applied in addition to fertilizer and lime normally utilized to maintain the Swann and Rawle Groves over 23 and 28 month periods, respectively, are listed in Tables 34 and 35 according to treatments. Nutrients were carried at fixed rates with the gypsum mix or-applied as indicated by results of monitoring with leaf and soil analyses. Plant nutrients in supplemental fertilizer were spread in the Spring and Fall; gypsum mix treatments in February or March.

The greatest range in amounts applied between treatments were with calcium, sulfur and manganese. Differences between the smallest and largest amounts of Mg and K would be considered inconsequential over the 23 month period the Swann test was in progress. Supplemental potassium may have contributed to production differences between treatments in the Rawle test. Adjustments in nutrient balance made possible through monitoring is equal in importance to annual determination of fertilizer and lime requirements in establishing increased production trends.

TABLE 34

TOTAL SUPPLEMENTAL PLANT NUTRIENTS APPLIED OVER A 23 MONTH PERIOD FOR THE SWANN GROVE ACCORDING TO TREATMENT

Plant Nutrient	TREATMENTS			
	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium	-	61	221	381
Magnesium	-	125	135	145
Potassium (K_2O)	-	124	144	164
Nitrogen	-	175	175	175
Phosphorus (P_2O_5)	-	185	185	185
Sulfur	-	24	190	356
Boron	-	1.5	1.5	1.5
Iron	-	10	10	10
Manganese	-	27	34	41
Zinc	-	3	3	3

TABLE 35

TOTAL SUPPLEMENTAL PLANT NUTRIENTS APPLIED OVER A 28 MONTH PERIOD FOR THE RAWLE GROVE ACCORDING TO TREATMENT

	TREATMENTS			
Plant Nutrient	Normal Grove Management	Monitoring Supplemental Fertilizer	Supplemental Fertilizer + 500 lbs/ac Gypsum Mix	Supplemental Fertilizer + 1000 lbs/ac Gypsum Mix
Calcium	-	110	350	590
Magnesium	-	275	286	297
Potassium (K_2O)	-	124	167	209
Nitrogen	-	188	188	188
Phosphorus (P_2O_5)	-	335	335	335
Sulfur	-	35	284	532
Boron	-	1.5	1.5	1.5
Iron	-	20	20	20
Manganese	-	37	45	54
Zinc	-	3	3	3

DISCUSSION/CONCLUSIONS

Lag time between the application of fertilizers and the response of many mature perennial fruit crops is common. Soils to a depth of several inches in mature groves of Central Florida are often characterized by high copper levels. Copper toxicity inhibits the proliferation of young roots and efficiency of nutrient uptake. Although almost all fertilizer elements are known to leach rapidly through the ridge soils, copper toxicity may contribute to the lag time realized between nutrient application and citrus response in mature groves.

Dr. Carl Anderson of the IFAS experiment station at Lake Alfred has presented data indicating that root weight of immature citrus in Central Florida were greater at a depth of 30" than other portions of the profile. (Paper presented at the 1984 Florida Citrus Growers Institute and Trade Show. Lakeland Civic Center, Lakeland, Florida.) Movement of plant nutrients to this depth may be necessary before a response to some nutrients is fully measurable. Anderson suggested that deep sampling may provide a better basis for determining citrus fertilizer needs than to a soil depth of 6 to 12".

Results presented in this report indicated a trend of increasing production in plots treated with gypsum mix and/or supplemental fertilizers over normal grove management in both the Swann and Rawle Groves. However, statistically significant mean differences were measured only by the 1988 Rawle harvest. The Rawle test was in progress 28 months as compared to 23 months for the Swann test and required an additional application of the gypsum mix and supplemental fertilizer. The delay in response by citrus to applications of gypsum mix and/or supplemental fertilizer could represent a lag time as discussed above. Gypsum is relatively insoluble when compared to most other fertilizer salts and may move rather slowly through the soil profile.

The 1988 Rawle Grove yields of the supplemental fertilizer and 500 lbs/acre gypsum mix treatments were statistically equal but both were greater than yield of the normal grove management treatment. Any or all of the nutrients supplied by these treatments could have been responsible for this increase. The yield difference between the 500 and 1000 lbs/acre gypsum mix treatments would have to be attributed to variation in the amounts of Ca, Mg, K, S and Mn carried by each treatment. As previously stated, the difference in magnesium supplied by the two treatments is considered small. The difference in potassium might also be considered small in terms of a 28 month time span. The 1000 lbs/acre gypsum mix treatment supplied approximately 250 lbs/acre more of both calcium and sulfur than the 500 lbs/acre treatment. Large disparity in these two elements between the treatments suggests that significantly greater fruit production of the 1000 lbs/acre gypsum mix plots was directly attributable to larger amounts of calcium and sulfur for the Rawle test. Manganese, required in much smaller amounts, may have been equally important for the yield increase of the 1000 lbs/acre gypsum mix treatment. A total of 9 lbs/acre more of Mn was applied in the 1000 lbs/acre gypsum plots over the 28 month period.

Leaching of nutrients from the upper 6" of the ridge soil profile occurred rapidly in both groves according to soil analysis. Final analyses showed almost no improvement in soil nutrient status from that reflected by the initial soil test results. Determination of rates for supplemental fertilizers and subsequent improvement in citrus plant nutritional status was possible through leaf tissue sampling and analysis in combination with the soils data. Totals of supplemental elements applied in addition to those received through normal grove managment during the course of the study may appear high. However, experience indicates that amounts of supplemental nutrients required would have decreased with time because of the build up of the nutrients in the soil if the trials had continued. Field studies of this nature should be conducted over a minimum period of five years to better insure the validity of treatment differences.

The value of agricultural gypsum for fertilizer and as a soil amendment in crop production has been demonstrated. The phosphate fertilizer manufacturing bi-product of phosphogypsum has been shown to be a good source of calcium and sulfur for citrus and other crops. Pelletted phosphogypsum used in the grove tests was ideal in its handling properties and would be appropriate for common agricultural equipment such as spinner-spreaders for distribution on a commercial basis. Utilization of pelletted phosphogypsum as a carrier of selected plant nutrients adds to the potential value of the material. Analysis of soil and leaf tissue provides a foundation for efficient use of P-gyp in citrus groves and on other agricultural sites.

CROP ANALYSIS FOR RADIO ACTIVITY AND HEAVY METALS

Since phosphogypsum in waste piles has been found to have a certain amount of natural radio activity it was considered advisable to measure the Alpha and Beta radioactivity in the various crops from field trials where P-gyp was used.

Samples of the yield from each replication of the crop treatment were combined to form a composite sample for each treatment. Only the composite sample of the No P-gyp treatment and the highest level of P-gyp treatment were analyzed. The TMA Eberline laboratory in Albuquerque NM did the radio activity analysis. Table 36 shows the results of these analyses. There was no gross Alpha radiation found in any of the samples except oranges. In this case, a very slight amount was found in the fruit from the No P-gyp treatment. The gross Beta radiation was very low in all samples with no apparent difference due to treatment.

In three crops i.e. sweet corn - Lake Helen, watermelon and cowpeas there was somewhat higher Beta radiation in the No P-gyp treatment than in the highest P-gyp treatment. In the other three crops the situation was reversed. Thus, one could conclude that there was no significant effect of P-gyp on the radiation levels found in the crops.

These same samples were analyzed for Arsenic by A & L Laboratory in Memphis, TN, and for copper, iron, manganese, zinc, cadmium and vanadium here in our own laboratory at Orange City. Table 37 gives the results of these analyses. There are no apparent differences in any of these elements between the No P-gyp treatment and the addition of the highest rate of P-gyp.

TABLE 36

EFFECT OF P-GYP ON RADIO ACTIVITY IN CROPS

ANALYSIS OF COMPOSITE SAMPLE FROM 4 REPLICATIONS

TREATMENT NO.	CROP	PC I/GM DRY WT. GROSS ALPHA	PC I/GM DRY WT. GROSS BETA
0 P-gyp	Sweet Corn - Lake Helen	0 ± 5	13 ± 2
3000 lbs P-Gyp/acre	" " " "	0 ± 5	10 ± 2
0 P-gyp	Citrus	9 ± 6	8 ± 1
1000 lbs P-Gyp/acre	"	0 ± 5	14 ± 2
0 P-gyp	Watermelon	0 ± 5	22 ± 2
1000 lbs P-Gyp/acre	"	0 ± 5	8 ± 2
0 P-gyp	Cowpeas	0 ± 5	17 ± 2
2000 lbs P-Gyp/acre	"	0 ± 5	8 ± 2
0 P-gyp	Sweet Corn - Plant City	0 ± 5	3 ± 1
1000 lbs P-Gyp/acre	" " " "	0 ± 5	4 ± 1
0 P-gyp	Tomato	0 ± 5	15 ± 2
1000 lbs P-Gyp/acre	"	0 ± 5	25 ± 2

TABLE 37

EFFECT OF P-GYP ON ARSENIC AND HEAVY METAL CONTENT OF CROPS

ANALYSIS OF COMPOSITE SAMPLE FROM 4 REPLICATIONS

TREATMENT NO.	CROP	PPM As	PPM Cu	PPM Fe	PPM Mn	PPM Cd	PPM V	PPM Zn
0 P-gyp	Sweet Corn - Lake Helen	.04	4	33	4	.22	.00	33
3000 lbs P-Gyp/acre	" " " "	.06	2	37	5	.12	.00	22
0 P-gyp	Citrus	.05	6	20	3	.28	.00	7
1000 lbs P-Gyp/acre	"	.03	6	14	2	.25	.00	6
0 P-gyp	Watermelon	.01	7	44	12	.28	.00	26
1000 lbs P-Gyp/acre	"	.04	6	31	45	.31	.00	33
0 P-gyp	Cowpeas	.01	3	45	15	.22	.00	33
2000 lbs P-Gyp/acre	"	.02	3	44	17	.25	.00	33
0 P-gyp	Sweet Corn - Plant City	.06	2	28	6	.17	.00	20
1000 lbs P-Gyp/acre	" " " "	.01	2	20	4	.09	.00	21
0 P-gyp	Tomato	.04	13	76	19	.53	.00	35
1000 lbs P-Gyp/acre	"	.06	15	79	22	.51	.00	44

AN ESTIMATE OF PHOSPHOGYPSUM NEED IN FLORIDA AGRICULTURE

INTRODUCTION

Large amounts of gypsum (phosphogypsum) are generated as a biproduct of the phosphate fertilizer manufacturing process. Accumulated masses of this material in mining areas of West Central Florida are often unsightly and environmentally controversial.

Gypsum is a neutral salt that has long been utilized as an amendment on agricultural soils as well as a source for calcium and sulfur as plant nutrients. Gypsum is relatively insoluble as a fertilizer material, and because of this, tends to leach less readily from sandy soils than other products providing available calcium. It is commonly applied alone or is mixed with other fertilizer materials. Almost all gypsum currently used in Florida agriculture is imported from other states.

Phosphogypsum resulting from the phosphate industry is for the most part unused in agriculture. However, some farmers in Florida and other phosphate producing states occasionally apply phosphogypsum on fields for nutritional purposes or as a soil amendment. Continued use of the biproduct sometimes results in a slight increase in soil acidity due to the presence of components other than gypsum. Phosphogypsum taken directly from the mounds at the processing sites is difficult to apply with existing farm equipment and uniform applications to an area are practically impossible.

In addition to nitrogen, potassium and phosphorus, low cation exchange soils such as the sandy soils common to Central Florida require periodic application of a number of other elements for support of crop growth. Both calcium and sulfur are frequently deficient in soils of this nature. Studies conducted by Agro Services International, Inc. (ASI) for the Florida Institute of Phosphate Research (FIPR) were designed to consider phosphogypsum fortified with other selected essential plant elements as a soil amendment on low cation exchange soils. The response of several crop plants to various phosphogypsum mixes was examined through greenhouse and field tests. Neutralization of acidic materials present in phosphogypsum, the addition of other commonly deficient elements particularly magnesium, and the development of a pelletizing process have been emphasized.

The purpose of this report is to estimate the need of phosphogypsum in Florida agriculture.

PH, CALCIUM AND SULFUR CONSIDERATIONS

Soils of Florida and other southeastern states with neutral or near neutral soil reaction following the application of lime tend to gradually become acid over time. Rainfall, the breakdown of organic matter and the use of fertilizer, particularly nitrogen, contribute to this process. Both exchangeable and nonexchangeable acidity may be present in acid soils. By definition, exchangeable acidity is that displaced from the soil exchange sites with a neutral salt solution, including potassium chloride, calcium chloride or sodium chloride. The acidity removed in the exchange reaction is titratible. In mineral soils, the exchangeable acidity is largely associated with aluminum. Nonexchangeable acidity usually is associated with hydrated iron and aluminum oxides. The nonexchangeable acidity is titratible but is not exchangeable. The presence of active or exchangeable acidity generally indicates the need for liming.

Using finely ground dolomitic limestone to neutralize exchangeable acidity releases considerable amounts of available calcium and magnesium and will continue to do so as long as enough lime and exchangeable acidity is present to react with the lime to dissolve it. In low pH, low cation exchange soils, the application of relatively small amounts of lime will neutralize the active soil acidity and raise the pH to around 6.0 or 6.5. The addition of dolomitic lime on low cation exchange soils having a pH of 5.8 or higher provides very little, if any, readily available calcium or magnesium because there is not enough acidity present to dissolve much lime but it does raise the pH so that other essential elements such as manganese, copper, iron and zinc become less available.

Low cation exchange soils of Florida as well as other areas are often deficient in available calcium. It is sometimes assumed that a pH range considered favorable for a particular crop also indicates sufficient calcium for yield and quality. This simply is not true for many low cation exchange soils. pH does not necessarily reflect adequate or inadequate amounts of calcium for plant growth.

CROP CONSIDERATIONS

As would be expected, different crops have different requirements for calcium and sulfur, the two main elements found in phosphogypsum. These elements are essential for plant growth, and they are taken up in rather significant quantities by the plant, thus it is reasonable to expect that when the level of these elements falls below a certain critical level in the soil then the plant will benefit by the addition of these elements to the soil in an available form. This fact has been established by an abundance of research.

Various types of plants vary considerably in the content of calcium and sulfur found in their tissues. For instance, adequate levels for calcium in corn leaves is about 0.5% whereas citrus requires about 4.2% in the leaves. The same is true for sulfur. Sugar cane requires a concentration of about 0.18% in the leaves to be adequate while cabbage and celery require a concentration of about 1.2% in their leaves.

A lack of adequate calcium in some crops causes very pronounced and visible effects in the quality of the product such as blossom end rot in watermelons and tomatoes. In peanuts a slight deficiency of calcium will prevent pod formation and thus result in an almost total loss of yield. In most crops, calcium and sulfur deficiency is more subtle. There may be no obviously visible deficiency symptoms but the crop just doesn't grow as well as it could and the yield is reduced because of this.

Where visible quality defects in produce occur because of calcium deficiency the loss of revenue may be greater than if the affect had been just a reduction in yield.

The type of crops and acres harvested in Florida according to the 1982 Agricultural Census are listed in Table 38.

The need for calcium from sources other than lime has been suggested for every type of crop grown in Florida. The need for non-lime calcium is based on the soil pH level as well as the level of available calcium in the soil and the use characteristics of the particular crop to assure that calcium deficiency does not occur under good crop production practices.

TABLE 38

Crops harvested and acreages for Florida according to the 1982 U.S. Census of Agriculture (Table 39).

Crop	Harvested Acres
Corn, Grain, Seed	190,254
Corn, Silage, Green chop, etc.	26,317
Sorghum, Grain, Seed	20,045
Sorghum, Silage, Green chop, etc.	11,700
Wheat	94,639
Other Small Grains	47,140
Soybean Grain	334,401
Peanuts (Nuts)	46,081
Cotton	10,838
Tobacco	8,208
Irish Potatoes	31,003
Sweet Potatoes	2,190
Pineapples	-
Sugar Cane	343,680
Hay (Alfalfa, other tame, small grain, wild, grass silage and Green Chop	281,747
Vegetables	283,780
Land in Orchard	938,527
Berries	4,265
Nursery, Greenhouse, Mushrooms, Sod	60,064
Other Crops	48,648
Harvested Cropland Florida	2,793,527

SOIL CONSIDERATIONS

Calcium Requirements

In the southeastern states a soil pH range of from 5.8 to 6.5 is generally considered best for the majority of crops grown. For most crops, when the pH of the soil drops below 5.8 then lime is suggested to bring the pH up to a level of between 6.5 and 7.0. Under these conditions, if the available calcium already in the soil is not too low, then the added lime can be expected to provide sufficient calcium through the soil acidity neutralization process which makes the calcium available to the plant.

In low cation exchange capacity soils which have a very low exchangeable calcium level (i.e. less than about 1.2 meq/100 ml soil) and a low pH, the addition of lime cannot be expected to supply the needed calcium because normally not more than about 2000 lbs. of lime would be added to sandy or low cation exchange capacity soils. If 60 percent of the lime (i.e. the portion which is smaller than 100 mesh) reacted rapidly it would only supply about 0.7 meq Ca/100 ml soil. This would leave about 0.5 meq Ca to be supplied from a non-lime source such as P-gyp, or Calcium nitrate etc.

To supply 0.5 meq Ca from P-gyp as the source would require about 1000 lbs. P-gyp/acre. If the soil has a pH above 5.8 and therefore does not require lime or has a lower pH but no active acidity so that there is not enough acidity to react with a significant amount of lime to supply calcium then all of the needed additional calcium should be supplied from a non-lime source. In Florida, the additional calcium needed under the above-described conditions ranges from about 0.5 to 1.5 meq/100 ml of soil or on the average about 1 meq Ca/100 ml soil. Thus on the average these low CEC soils with no active acidity would require about 2000 lbs. P-gyp per acre to supply the needed additional calcium.

A summarization of 3500 low cation exchange capacity soils from Florida was made. In Table 39 is shown the number of samples which had no measureable active acidity but low in available calcium. These ranged in pH from 4.9 to above 7.1. The average amount of calcium needed for each pH category is also shown. It is not unusual for low CEC soils to have no measureable active acidity down to a pH of about 5.0. On higher CEC soils, a measureable active acidity almost always is present in soils. with pH 5.8 or less.

TABLE 39

Summary of 3500 soil samples showing number of calcium deficient samples without active acidity and average pounds per acre of calcium recommended according to pH.

pH Range	No. of Samples		Ave. Calcium Recommended (Lbs/acre)
4.9			400
5.0-5.2	54		420
5.3-5.5	107		350
5.6-5.8	123		365
5.9-6.1	133		370
6.2-6.4	80		350
6.5-6.7	50		340
6.8-7.0	42		355
7.1 or greater	24		350
TOTAL	664	AVERAGE	367

The significance of these observations is that in low CEC soils even when the pH is quite low, there frequently is not enough acidity to react with lime to raise the available calcium level significantly. Under these circumstances a more soluble calcium source is needed. P-gyp is a logical choice as that source.

It can be seen in Table 39 that of the 3500 samples there were 664 samples or 20% which needed an average of about 370 lbs. of calcium from a non-lime source. In addition to this, of the same 3500 samples there were 596 samples or 18% with pH below 5.6 which had some measureable active acidity but had available calcium levels below 1.2 meq Ca/100 ml soil. If on these soils we calculate that the added lime would supply from 0.3 to 0.7 meq Ca/100 ml soil then that would leave an additional 0.3 to 0.7 meq Ca or on the average about 0.5 meq Ca to be supplied by a non-lime source. It requires 1000 lbs. per acre of phosphogypsum to supply 0.5 meq Ca. The field studies conducted under this project offer verification of the needs indicated above.

Sulfate Sulfur Requirements

Sulfate sulfur is the form in which sulfur is taken up by the plant for use in the growth process. When plants become deficient in sulfur it is because there is not an adequate supply of sulfate sulfur in the soil. Sulfate sulfur is about as readily leached from soil as is nitrate nitrogen.

Many products and processes have been developed in the fertilizer industry to prevent nitrogen from leaching from the soil. The so called "slow release nitrogen" products have gained much popularity for use in soils which are subject to leaching.

Although farmers generally have not been so concerned about the loss of sulfate sulfur by leaching as they have been about nitrogen, the same considerations should apply for both elements. The amount of sulfur required for plant growth is not so large as for nitrogen but it is just as essential an element.

There are several sources for supplying sulfate sulfur to plants. One source which has been quite significant in the past is from smoke and fumes released into the air from industrial processes or by burning of coal. Because of antipollution regulations, this source has largely disappeared.

Most fertilizer materials containing sulfate sulfur are readily water soluble and some such as magnesium sulfate are quite expensive. The lower solubility of phosphogypsum and its potentially lower price qualify it as a strong competitor as a source material for supplying sulfate sulphur.

Of the 3500 samples summarized for calcium status as mentioned earlier, it was found that 2675 of these samples or 81% also had a low sulfate sulfur content. The sulfate sulfur recommended for these soils ranged from 10 to 50 lbs. per acre with 30 lbs. per acre being the average amount required. This 30 lbs. is a minimum requirement. Numerous field trials, greenhouse trials, and solution culture trials done over the past 100 years or so have established that sulfate sulfur can be present in the soil in quantities five to ten times greater than that required as the minimum needed for high yield without having adverse effects on growth. It requires about 200 lbs. of phosphogypsum to supply 36 lbs. of sulfate sulfur.

PROJECTED PHOSPHOGYPSUM NEEDS FOR FLORIDA AGRICULTURE

A very conservative estimate for the need for phosphogypsum in Florida agriculture can be made by calculating the need based on the 1982 acreage of cropland harvested and the need for non-lime calcium as well as the sulfate sulfur needs.

In 1982 there was a total of 2,793,527 acres of cropland harvested according to the U.S. Census of Agriculture 1982 Volume 1, Part 9. According to the previously mentioned summary of the soil analysis data, 20% of this land needs on the average of 370 lbs. of calcium from non-lime source. The use of phosphogypsum to fill this need would require about 558,000 tons of P-gyp per year.

In addition, about 18% of the soils i.e. those which require lime but are very low in calcium, need on the average of 180 lbs. non-lime calcium. It would require 251,000 tons of P-gyp to fill this need.

Eighty-one percent of the soil was also found to require an average of 30 lbs. sulfate sulfur per acre. Where P-gyp is used to supply needed calcium, these soils would receive adequate sulfate sulfur. However, that would leave at least 43% of the soils still needing sulfur which could be supplied by P-gyp. To supply this amount of sulfur would require another 120,000 tons per year.

Therefore, a very conservative estimate of the need for P-gyp would be 929,000 tons per year.

The 1982 U.S. Census of Agriculture lists the total crop land in Florida as 4,095,030 acres. If all of this land was planted and we assume the same percentage as needing P-gyp at the same rate, then the P-gyp need on this basis would be 1,362,000 tons per year. Actually, land which does not get cropped every year would likely have a larger requirement than that which does because it is not as likely to have received recent lime applications to help maintain good calcium levels.

The above estimates are based solely on the agriculturally cropped land. Apparently, no statistical data is available as to the land area being used in Florida for pastureland, home lawns, golf courses, parks and landscaped area.

Soil analytical data indicate calcium and sulfur needs on lands used for these-other purposes are at least as great as for regular crop land. If we estimate that there is an equal amount of land being used for the above-mentioned purposes as for crop land then our estimated need for P-gyp would be between 1,858,000 and 2,724,000 tons per year.

NEED OF PHOSPHOGYPSUM VERSUS POTENTIAL USE

Considering the state of the art of agricultural production practices at the present time along with the fact that at this moment almost no phosphogypsum is being used in the state of Florida, it is certainly valid to raise the question as to what proportion of the need for phosphogypsum will ever turn into actual use.

It seems a shame for so much phosphogypsum to be lying in unused mountains when it could be so effectively utilized to increase soil productivity capabilities.

From a marketing standpoint, it should be remembered that the use of soil fertility improvement materials probably never equates to the need. This is true even when the needs are well documented and commonly known by the potential users. For instance, even with the three major plant nutrients., i.e. nitrogen, phosphorus and potash whose needs have been well documentedand whose benefits from proper use have been well demonstrated for many years, their use still falls short of the need.

There is no doubt in anyone's mind about the essentiality of calcium and sulfur for plant growth, but there is much to be done to promote the use of these elements such that they will give an economical return on investment.

An essential first step in promoting P-gyp use is to provide P-gyp in a form or forms that can be easily used either as P-gyp or by blending with other fertilizer materials. If the fertilizer blending industry had P-gyp available in pelleted form and at a reasonable price, they would no doubt use it as a fill material in their blends where fillers are needed.

An important second step in promoting the use of P-gyp is the use of soil analysis to provide information as to where P-gyp can be expected to provide economic returns.

Beyond the above two steps, it is a matter of demonstration and education in order to get agricultural use of P-gyp to begin to approach the need.

CONCLUSIONS AND RECOMMENDATIONS

The results obtained through this research project indicate at least the following conclusions:

1. P-gyp can be pelletized using urea or sulfate of potash magnesia as a binder to form hard pellets. Both of these materials increase the value of the final product for crop production.

2. A pan pelletizer provides at least one effective means of pelletizing P-gyp.

3. A one year residual effect of P-gyp has been demonstrated. The residual appears to be relatively small but could be important where P-gyp is applied annually.

4. Soil analysis provides an efficient means of determining soil conditions under which P-gyp can be effective and economically advantageous for increased yields.

5. The crops tested varied in their response to P-gyp added as a soil amendment but all crops tested gave economic response considering present produce prices and the price of other gypsum being marketed to the farmers at this time.

6. Additional. pelletizing or granulating processes should be investigated to provide alternatives in binding agents as well as in types of equipment which can be used.

7. Additional field trials or demonstrations should be established to acquaint farmers with the proper use and value of P-gyp as a soil amendment. These should never be set up without first properly evaluating the soil fertility status of the site so as to be sure that P-gyp is actually needed at the site for increased production.

The effect of a demonstration failure is worse than no demonstration at all.

8. There already exists a need for significant quantities of phosphogypsum in Florida agriculture at the present time. The challenge is to develop a demand commensurate with the need.

AGRO SERVICES INTERNATIONAL, INC. 215 E. Michigan Ave. P.O. Box 667 Orange City, Florida 32763 PH. 904-775-6601

Dr. A.H. Hunter
Lake Helen, Florida

Crop to Fert. ______ Field & Sample No. Lake Helen
Yield Goal ______ Farm Location Phosphogypsum area- WEGROW
Last Crop ______
Approx. Yield ______ Date Sample Rec'd. ______
Lime Applied ______ Date Processed 09-28-89

Act. C.E.C. 3.1 meq/100 ml; Base Satn. 100 %; Acid. Satn. 0 %; pH 5.5 ; O.M. 1.3 %; Sol. Salts ______ ppm Texture Code G1

ELEMENTS		SOIL ANALYSIS Lab No. W7 139 -9 meq/100 ml	Lbs/Acre	INTERPRETATION GUIDE (Below / Optimum / Above; Critical Level)	FERTILIZER SUGGESTIONS	Lbs./1000 sq.ft. kg/205 m²	Lbs./acre kg/ha
Act. Acidity	A.A	0.0					
Calcium	Ca	2.4	864	*************	Calcium	0.0	0
Magnesium	Mg	0.51	111	**********	Magnesium	0.0	0
Potassium	K	0.18	151 K2O	******	Potash (K_2O)		
Sodium	Na						
Ca/Mg Ratio	Ca/Mg	4.7		*****************************	Dolomitic Lime	34	1500
Mg/K Ratio	Mg/K	2.8		**************	Calcitic Lime	0	0
		ug/ml					
Nitrogen	N	4	7	*	Nitrogen		
Phosphorus	P	15	61 P2O5	***********	Phosphate (P_2O_5)		
Sulphur	S	2	3	*	Sulfate-S		
Boron	B	0.21	.4	*******	Boron		
Copper	Cu	0.5	.9	***	Copper		
Iron	Fe	48	86	******************	Iron		
Manganese	Mn	0.9	1.6	*	Manganese		
Zinc	Zn	2.8	5	**********	Zinc		
Other							

Comments:

Crop nitrogen rates are general and can be adjusted according to local information.
Recently applied organic material is not indicated by the analysis. Adjustments can be made in this case.

"FIXATION" OR "SORPTION" STUDY

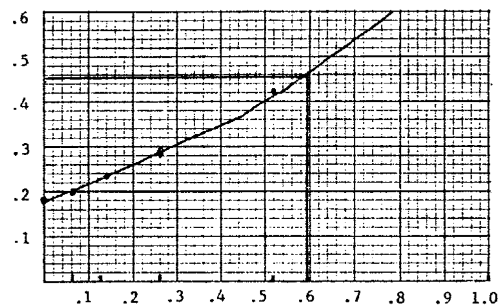
AGRO SERVICES INTERNATIONAL INC.
Research, Analysis, Consultation, Planning
POST OFFICE BOX 667
ORANGE CITY, FLORIDA 32763

Sample No. R5 195-5

Location LAKE HELEN

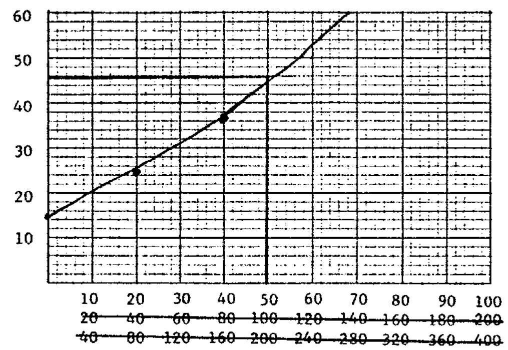
POTASSIUM
meq/100 ml Soil

Added	Extracted
0	.18
.065	.20
.13	.23
.26	.29
.52	.42
1.04	1.05



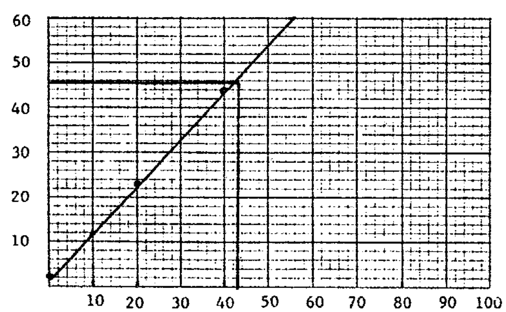
PHOSPHORUS
ug/ml Soil

Added	Extracted
0	15
20	25
40	37
80	82
160	150
320	301



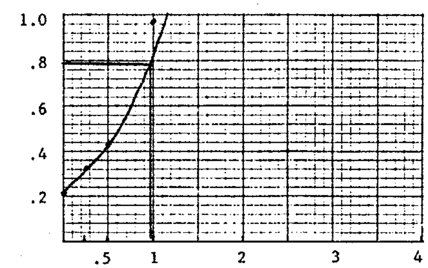
SULFUR
ug/ml Soil

Added	Extracted
0	2
10	12
20	23
40	44
80	78
160	154



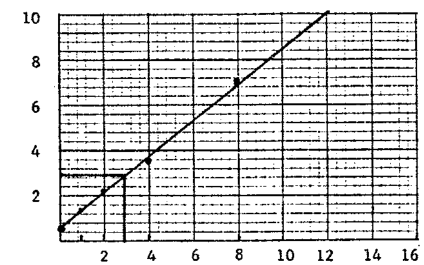
BORON
ug/ml Soil

Added	Extracted
0	.21
.25	.35
.5	.44
1	.98
2	1.93
4	4.05



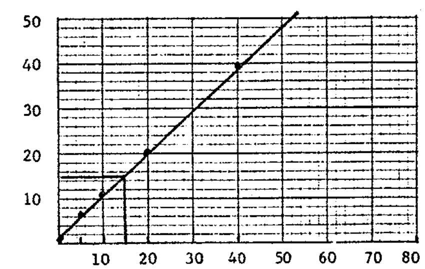
COPPER
ug/ml Soil

Added	Extracted
0	.5
1	1.3
2	2.2
4	3.7
8	7.2
16	14.2



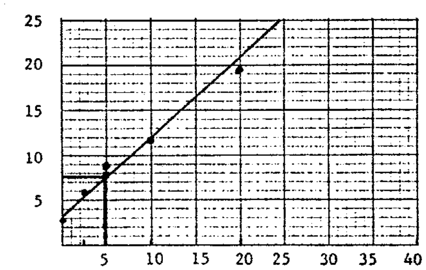
MANGANESE
ug/ml Soil

Added	Extracted
0	.9
5	6.1
10	11.5
20	20.0
40	39.4
80	71.2



ZINC
ug/ml Soil

Added	Extracted
0	2.8
2.5	5.6
5	7.8
10	11.2
20	19.6
40	27.5



AGRO SERVICES INTERNATIONAL, INC.
Research, Analysis, Consultation, Planning
POST OFFICE BOX 667
ORANGE CITY, FLORIDA 32763

SOIL NUTRIENT SURVEY STUDY

Laboratory No. R5 195-5 Sample Identification LAKE HELEN WEGROW

TEST PLANT USED	VARIETY	NO. OF PLANTS PER POT	AMOUNT OF SOIL PER POT	DATE PLANTED	DATE HARVESTED
SUN FLOWER		3	200 ml	8 Nov 85	9 DEC 85

Yield - Dry Weight of Plants - Grams

TREATMENT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	OPT.	-PGyp	-DoL.	-N	-P	-K	-B	-Cu	+Fe	-Mn	+Mo	-PGyp +S	-Zn	½ DoL.	2 PGyp	½ PGyp	PGyp PELLET
1	3.64	.52	2.24	1.44	2.31	1.25	1.84	3.69	3.44	3.60	2.60	3.32	4.40	2.64	3.30	3.95	2.78
2	3.83	.74	2.60	1.32	2.48	1.32	1.79	3.74	3.85	3.49	2.85	3.18	3.79	2.78	3.86	4.10	2.76
Ave.	3.73	.63**	2.42**	1.38**	2.39**	1.28**	1.81**	3.71	3.64	3.54	2.72**	3.25*	4.09	2.71**	3.58	4.02	2.77**
TREATMENT																	

** SIGNIFICANT AT .01 * SIGNIFICANT AT .05 COMPARED TO OPTIMUM

Predicted Amount of Elements Needed According to Fixation Study and Other Criteria to Bring Soil to Optimum Fertility Level

lbs/acre or kg/ha											
Dolomite	P_2O_5	K_2O	~~Ca~~ PGYP	Mg	S	B	Cu	Fe	Mn	Zn	Mo
1800	200	420	4000	250	90	1.8	4.0	0	30	9	0

Note: These amounts may be higher than the most economical level.

Amount of element added to the + element treatment when the element was not added in order to bring soil to optimum.

+ P_2O_5 ______ + S ______ + Fe 36 + Mo 1.8
+ K_2O ______ + B ______ + Mn ______ + Mg ______
+ Ca ______ + Cu ______ + Zn ______

Comments or Observations:

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SOIL NUTRIENT SURVEY STUDY

Laboratory No. R5 195-5 Sample Identification LAKE HELEN WEGROW

TEST PLANT USED	VARIETY	NO. OF PLANTS PER POT	AMOUNT OF SOIL PER POT	DATE PLANTED	DATE HARVESTED
SORGHUM	BEEFEATER	5	200 ml	8 Nov. 85	9 DEC 85

Yield - Dry Weight of Plants - Grams

TREATMENT NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	2.36	.41	1.41	.50	1.12	1.32	2.90	1.82	2.68	1.88	1.61	1.78	1.82	2.04	1.85	1.71	1.76
2	2.00	.34	2.05	.55	1.53	1.34	1.80	1.91	2.56	2.25	1.37	1.62	2.45	1.71	2.00	1.82	2.38
3																	
Ave.	2.18	.37**	1.73*	.52**	1.32**	1.33**	2.35	1.86	2.66	2.06	1.49**	1.70*	2.13	1.87	1.92	1.76*	2.07
TREATMENT	OPT.	-Pgyp	-Dol.	-N	-P	-K	-B	-Cu	+Fe	-Mn	+Mo	-Pgyp +S	-Zn	½ Dol.	2 Pgyp	½ Pgyp	Pgyp Pellet

** SIGNIFICANT AT .01   * SIGNIFICANT AT .05   COMPARED TO OPTIMUM

Predicted Amount of Elements Needed According to Fixation Study and Other Criteria to Bring Soil to Optimum Fertility Level

lbs/acre or kg/ha											
Dolomite	P_2O_5	K_2O	~~Ca~~ PGYP	Mg	S	B	Cu	Fe	Mn	Zn	Mo
1800	200	420	4000	250	90	1.8	4.0	0	30	9	0

Note: These amounts may be higher than the most economical level.

Amount of element added to the + element treatment when the element was not added in order to bring soil to optimum.

+ P_2O_5 ______	+ S ______	+ Fe 36	+ Mo 1.8
+ K_2O ______	+ B ______	+ Mn ______	+ Mg ______
+ Ca ______	+ Cu ______	+ Zn ______	

Comments or Observations:

SOIL NUTRIENT SURVEY STUDY

Soil Sample No. R5 195-5 Location LAKE HELEN WEGROW Texture SAND

Analysis of Original Soil Sample

Method	Acid	Acid Base	pH	O.M.	Ca	Mg	K	Ca/Mg	Mg/K	N	P	S	B	Cu	Fe	Mn	Zn		
1	0	0	5.5	1.3	2.4	.51	.18	4.7	2.8	4	15	2	.21	.5	48	.9	2.8		
2																			
3																			

SORPTION STUDY ANALYSIS

	Acid	Acid Base	pH	O.M.	Ca	Mg	K	Ca/Mg	Mg/K	N	P	S	B	Cu	Fe	Mn	Zn		
Rate 1							.20				25	12	.35	1.3		6.1	5.6		
2							.23				37	23	.44	2.2		11.5	7.8		
3							.29				82	44	.98	3.7		20.0	11.2		
4							.42				150	78	1.93	7.2		39.4	19.6		
5							1.05				301	154	4.05	14.2		71.2	27.5		

AMOUNT OF ELEMENT NEEDED ACCORDING TO SORPTION STUDY OR OTHER CRITERIA USED

Acid	Acid Base	pH	O.M.	Ca	Mg	K	Ca/Mg	Mg/K	N	P	S	B	Cu	Fe	Mn	Zn		
				.5	1.2	.6				50	45	1	2.7	0	15	5		

WEIGHT OF COMPOUNDS OR ml OF STOCK SOLUTIONS TO BE ADDED TO 600 ml SOIL FOR GREENHOUSE STUDY

Treatment No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Trtmnt Description		OPT.	-PGYP	-DOL.	-N	-P	-K	-B	-CU	+FE	-MN	+MO	-PGYP +S	-ZN	½ DOL.	2 PGYP	½ PGYP	PGYP PELLET
Grams DOLOMITE		.6	.6	0	.6								.6		.3	.6	.6	
Grams PGYP		1.5	0	1.5	1.5								0			3.0	.75	1.5
ml OF STOCK SOLUTION	N	6			0													
	P	3				0			NOTE: ALL TREATMENTS ARE IDENTICAL TO									
	K	18					0		OPT. EXCEPT FOR INDICATED CHANGES									
	B	3						0										
	Cu	6							0									
	Fe	0								6								
	Mn	3									0							
	Mo	0										3						
	S	0											9					
	Zn	3												0				
Gms NH_4NO_3/5 liters IRRIGATION SOLUTION																		