GYPSUM AS A CALCIUM AND SULFUR SOURCE FOR CROPS AND SOILS IN THE SOUTHEASTERN UNITED STATES

Reconciliation of Literature Review with EPA=s Final Rule on Phosphogypsum

EXECUTIVE SUMMARY

Malcolm E. Sumner, D.Phil. (Oxford), D.Sc. (Natal), CPSSc, CPAg
Agricultural and Environmental Consultant

Preamble

In 1992, the Environmental Protection Agency (EPA) banned the use of phosphogypsum containing more than 10 pCi ^{226}Ra g^{-1} for application to soils. This ban was based on calculations of risk assessment on the assumption that phosphogypsum would be applied to a given soil at a rate of 2700 lb ac^{-1} biennially for 100 years. As will be shown in this report, this assumption is incorrect. The Fertilizer Institute unsuccessfully challenged the Final Rule made by the EPA who contended that this application rate truly reflected the likely usage of phosphogypsum in agriculture.

Introduction

Gypsum is used in agriculture for the following purposes:

- as an ameliorant for sodium-affected (sodic) soils which occur mainly in arid areas and is therefore of minor interest in this report,
- as a source of the nutrients calcium (Ca) and sulfur (S) required by all crops,
- as an ameliorant for the subsoil acidity syndrome which commonly afflicts soils in the Southeast, and
- as an ameliorant for crust and seal formation at the soil surface, a condition commonly encountered in the sandy textured soils of the Southeast.

This is a summary of a report prepared for the Florida Institute of Phosphate Research (FIPR) with the following objectives:

- to independently assess the published experimental evidence on gypsum use in agriculture in the Southeastern United States and in Florida in particular, and
- to compare the gypsum application rate assumed by the EPA in their calculations to actual field practice by computing both on a lb ac^{-1} yr^{-1} basis.

To achieve these objectives, a thorough literature review was undertaken in an attempt to survey all citations so that the final outcome cannot be contested on the basis of a limited data set.

Calcium (Ca) Requirements of Crops

The following are the essential roles Ca plays in the nutrition of all plants:

- serves vital functions in the development of cells,
- is essential for membrane integrity and functioning of hormones,
- aids in the signaling of environmental changes, and
- partially offsets the toxic effects of aluminum (Al).

The amounts of Ca required to be present in soil by various crops can differ widely and in circumstances where soil Ca levels are low, gypsum is often used to remedy this deficiency.

Peanuts

The major crop in the Southeast for which Ca is most critical, is the peanut which has received most of the attention in the literature. The responses obtained in the field have served as the basis for the development of State Recommendations by the Cooperative Extension Service for the application of gypsum to peanuts. As the literature review undertaken in this treatise indicates that these application rates are based on sound scientific data, they should be used as the basis for calculating an annual gypsum application rate. Research has clearly demonstrated substantial benefits to be derived from rotating peanuts with other crops which are not susceptible to peanut pests. This is by far the cheapest and most effective way of controlling peanut pests in the field. Consequently, the Cooperative Extension Service advises farmers to rotate peanuts with other crops on a routine basis. Rotation of peanuts in a 2- or 3-year rotation is practiced by over 75% of the farmers in the Southeast. This aspect of peanut production was not apparently considered by the EPA in arriving at the Final Rule on Phosphogypsum. Therefore, the gypsum application rates recommended by the various states in Table S1 must be divided by 2 or 3 depending in whether peanuts appear every other year or every third year in the rotation. Very few peanut farmers would ever be foolish enough to plant peanuts continuously on the same piece of land.

On a whole field basis (broadcast application), the highest gypsum rate recommended for peanuts in the Southeast is 1720 lb gypsum ac^{-1}. Taking the most conservative approach assuming that peanuts are grown in a two-year rotation, the maximum recommended rate on an annual long-term basis would be 860 lb ac^{-1} yr^{-1}. Because there is substantial financial gain to be achieved by growing peanuts in a three- over a two-year rotation, many farmers follow a three-year rotation system which would reduce this figure to 573 lb gypsum ac^{-1} yr^{-1}. Thus by comparison with the maximum rate at which gypsum would ever be applied in practice on a long-term basis to a given field (860-573 lb gypsum ac^{-1} yr^{-1}), the figure of 1350 lb gypsum ac^{-1} yr^{-1} used by the EPA in their risk assessment calculations is too high by a factor of between 1.56 and 2.35.

However in many cases, farmers usually band place gypsum because this is much more economical as only between 1/3 and 1/2 of the amount is required. As a result the most

likely rates at which gypsum would be applied to most production fields in any one year would be between 250 and 860 lb gypsum ac^{-1} yr^{-1} (Table S1). Consequently, the actual long-term rates would lie between 125 and 430 for a two- and 83 and 267 lb gypsum ac^{-1} yr^{-1} for a three-year rotation system. Thus in the most likely case, the EPA figure overestimates actual field practice by a factor between 3.1 and 16.3.

Table S1 Recommended gypsum rates for peanuts in the Southeast (Hodges et al., 1994)

State	Type	Soil Ca	Gypsum recommendation			
			lb ac^{-1}		kg ha^{-1}	
			Band[H]	Broadcast	Band	Broadcast
Alabama	Runner	Low	250[%]		280	
		Low	500		560	
		Med	250		280	
Florida	Virginia	All	800	1600	898	1795
	Runner, Spanish-seed	All	400	800	449	896
	Runner, Spanish	Low	400	800	449	896
Georgia[1]	Virginia	All	688-860	1376-1720	772-956	1544-1913
	Runner, Spanish-seed	All	344-430	688-860	386-483	772-965
North Carolina	Virginia	All	600-800	1200-1600	673-897	1346-1795
South Carolina	Virginia	All	600-800	1200-1600	673-897	1346-1795
	Runner, Spanish	All	400-500	800-1000	449-561	898-1122
Virginia	Virginia, Seed	All	600	900-1500	673	1010-1683

[H] Band widths vary by State: Alabama = 30 cm (12 in); Florida, Georgia, North Carolina, South Carolina = 45 cm (18 in); Virginia = 50 cm (20 in)

[1] Values for Georgia have been converted from Ca to equivalent pure $CaSO_4.2H_2O$

[%] When lime is applied

Assuming that half the farmers would broadcast phosphogypsum in a 2-year rotation and half would band place phosphogypsum in a 3-year rotation, the maximum average rate would be (860+267)/2 = 563 lb gypsum ac^{-1} yr^{-1}.

- ***Maximum Rate***: 600 lb phosphogypsum ac^{-1} yr^{-1}
- ***Most Likely Rate***: 125-430 lb phosphogypsum ac^{-1} yr^{-1}
- ***Minimum Rate***: 0-83 lb phosphogypsum ac^{-1} yr^{-1}

Tomatoes and Other Crops

Tomatoes and peppers also have a definite requirement for Ca which reduces the incidence of blossom-end rot that can take a heavy toll on the quality of the crop. However in most cases, leaf sprays of Ca salts in minute amounts are highly effective and seldom if ever would gypsum applications be made to the soil. Only two States (Georgia and Tennessee) have gypsum recommendations for soil application ranging from 430 to 860 lb ac^{-1}. Again these crops are highly susceptible to a wide range of diseases and for phytopathological control, rotations of these crops with others more resistant would always be practiced by farmers. Consequently, the most likely long-term annual rates would range between 215 and 430 for a two- and 143 and 287 lb ac^{-1} yr^{-1} for a three-year rotation. These values are between 3.1 and 9.4 times lower than the assumed EPA figure of 1350 lb ac^{-1} yr^{-1}.

- ***Maximum Rate***: 430 lb phosphogypsum ac^{-1} yr^{-1}
- ***Most Likely Rate***: 200-300 lb phosphogypsum ac^{-1} yr^{-1}
- ***Minimum Rate***: 0-143 lb phosphogypsum ac^{-1} yr^{-1}

Sulfur Requirements of Crops

Sulfur (S) which is an essential element for plant growth is a constituent of a number of amino acids and is therefore required for protein synthesis. Crops take up between 10 and 20 lb S ac^{-1} for normal growth. Extensive experimentation has been carried out in all States in the Southeast to determine the rate of S required to be applied to soil for optimal crop production and forms the basis of the State Recommendations complied by the Cooperative Extension Service. These recommendations which have been converted to an equivalent gypsum basis, are summarized in Table S2.

Table S2 Recommended rates of gypsum application to crops in the Southeast to supply the essential element sulfur (S)

State	Crop	Gypsum Rate (lb ac^{-1})
Alabama	All	54
Florida	Agronomic, grass	80-108
Georgia	All	54
North Carolina	Corn, small grains, cotton, tomato, bermudagrass	108-161

South Carolina	All	54

Thus the maximum recommended gypsum rate is 161 lb ac^{-1} yr^{-1} which is more than eightfold lower than the rate (1350 lb ac^{-1} yr^{-1}) assumed by the EPA in their risk assessment calculations.

- ***Maximum Rate***: 161 lb phosphogypsum ac^{-1} yr^{-1}
- ***Most Likely Rate***: 50-80 lb phosphogypsum ac^{-1} yr^{-1}
- ***Minimum Rate:*** 0 lb phosphogypsum ac^{-1} yr^{-1}

Gypsum for Subsoil Acidity Amelioration

Only a limited amount of research has been conducted in the Southeast to study the beneficial effects of gypsum on soils with acid subsoils where root penetration is limited. Most of the research has been confined to Georgia where a single 2.2-4.4 t gypsum ac^{-1} application has resulted in substantial yield responses which have been sustained over a long period of time. Because the longevity of this effect is in excess of 10 years, the recommended rate on an annual basis would be 400-800 lb gypsum ac^{-1} yr^{-1} which is at least 1.7-fold less than the assumed EPA value. At present very few farmers have attempted this amelioration strategy and because of the high initial cost in excess of $175 ac^{-1}, only very limited acreage devoted to highly remunerative crops is likely to be used in this cropping system.

- ***Maximum Rate***: 800 lb gypsum ac^{-1} yr^{-1}
- ***Most Likely Rate***: 400 lb gypsum ac^{-1} yr^{-1}
- ***Minimum Rate***: 0 lb gypsum ac^{-1} yr^{-1}

Gypsum as an Ameliorant for Soil Physical Properties

Reclamation of Sodic Soils

Although sodic soils do not occur to any appreciable extent in the Southeast, a brief overview of the gypsum requirements of these soils was made for the sake of completeness. Applications of between 7 and 35 t gypsum ac^{-1} are required to reclaim the top 20 in of a highly sodic soil (ESP =30). On an annual basis, this would correspond to applications between 140 and 700 lb gypsum ac^{-1} yr^{-1} over a 100 year period which is between 2- and 10-fold less than the EPA assumed value. However in certain cases, applications in excess of these amounts have been made to certain soils but these cases represent the exception rather than the rule.

- ***Maximum Rate***: 700 lb gypsum ac^{-1} yr^{-1}
- ***Most Likely Rate***: 200-500 lb gypsum ac^{-1} yr^{-1}
- ***Minimum Rate***: 0-200 lb gypsum ac^{-1} yr^{-1}

Crusting and Seedling Emergence

Most of the research on this aspect of gypsum use has been conducted in Georgia where, as a result of reduced crusting, substantial improvements in water entry into soils have been obtained thereby reducing runoff and erosion. Typically applications ranging between 0.5 and 2 t gypsum ac^{-1} have proven to be highly successful and currently the Cooperative Extension Service recommends 0.5-1 t gypsum ac^{-1} for this purpose. Such applications are only recommended as an interim measure in the establishment of a permanent vegetative cover of highly erosible soils. Thus, this should be considered as an application which would be made once only or at the most, once in five years in a no-till system. Thus the maximum amount of gypsum which would be applied over a 100 year period would not exceed 20 t ac^{-1}.

- ***Maximum Rate***: 400 lb gypsum ac^{-1} yr^{-1}
- ***Most Likely Rate:*** 100-200 lb gypsum ac^{-1} yr^{-1}
- ***Minimum Rate***: 10 lb gypsum ac^{-1} yr^{-1}

Mechanical Impedence

Gypsum applications to the soil surface have been shown to reduce the mechanical impedence (resistance to root penetration) of subsoil horizons as a result of improved flocculation of the clay. A single 4.4 t ac^{-1} application of gypsum was sufficient for this purpose and the effect has lasted in excess of 10 years giving a long-term application rate of about 800 lb gypsum ac^{-1} yr^{-1}. Because of the high cost involved in the initial gypsum application, very few farmers have attempted to use this strategy.

- ***Maximum Rate***: 800 lb gypsum^{-}ac^{-1} yr^{-1}
- ***Most Likely Rate***: 400^{-}lb gypsum ac^{-1} yr^{-1}
- ***Minimum Rate***: ?

Environmental Impacts Associated with the Agricultural Use of Phosphogypsum

Application of a phosphogypsum with a high ^{226}Ra content (35 pCi g^{-1}) at the maximum rates for the different uses described above for a 100 year period would result in a maximum cumulative ^{226}Ra concentration of 1.57 nCi ^{226}Ra kg^{-1} of soil (58.0 Bq kg^{-1}) which is much lower than the 5 nCi ^{226}Ra kg^{-1} (185 Bq kg^{-1}) considered to be the upper limit of a safe range. Where phosphogypsum has been used as a source of Ca or S for crops, radiation added to the soil has, in all cases, not significantly increased native background levels. Even where a single rate of 4.45 t phosphogypsum (17.6 pCi ^{226}Ra g^{-1}) ac^{-1} was applied, no significant increases in ^{214}Pb, ^{214}Bi or ^{226}Ra could be detected anywhere in the profile of two different soils to a depth of 3 ft, 5 years after application. No significant differences in plant uptake of these radionuclides could be detected due to phosphogypsum treatment. However in a leaching experiment on a very sandy soil, elevated ^{226}Ra concentrations were found in the leachate but these concentrations were well below the maximum allowed in drinking water. Based on the scientific data, the conclusion can be drawn that there should be little concern associated with the use of phosphogypsum

containing more than 10 pCi ^{226}Ra g^{-1} provided that Cooperative Extension Service application rates are used.

Conclusions

All the soundly based experimental data strongly suggest that the phosphogypsum rate of 1350 lb ac^{-1} yr^{-1} for 100 years used by the EPA as the basis for formulating the Final Rule on phosphogypsum use, is too high. A more appropriate maximum figure would be in the range 600-800 lb gypsum ac^{-1} yr^{-1} with the most likely application rate lying in the range 100-400 lb gypsum ac^{-1} yr^{-1}.

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