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PRODUCTION AND CONSUMPTION OF SULFUR-BEARING FERTILIZERS IN THE UNITED STATES

For Presentation at the
American Chemical Society
186th National Meeting
August 31, 1983
Washington, D.C.

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Introduction

In 1966 and in 1971 TVA and The Sulphur Institute jointly sponsored symposia on the use of sulfur in agriculture. The 1966 symposium emphasized the importance of sulfur as a plant nutrient. The 1971 symposium emphasized methods by which fertilizer sulfur could be marketed (1). Also in 1971 a fertilizer technology publication thoroughly addressed the subjects of production, marketing, and use of sulfur products (2). Now 12 years later it seems appropriate to once again review the use of sulfur in fertilizers. This paper will review the agronomic need for sulfur, sulfur-bearing fertilizers in widespread use, and consumption of these fertilizers. Since this paper is part of a symposium on sulfur in fertilizers, emphasis will be given to fertilizer production schemes not covered in later papers.

Areas of Sulfur Deficiency

In 1971 The Sulphur Institute identified parts or all of 17 states where sulfur deficiencies were apparent (3). In 1982 TVA sent a questionnaire to the directors of all of the state soil testing laboratories. Responses from all 50 states showed that 28 states are now reporting sulfur deficiencies. The 8 states not shown in figure 1 are Illinois, Iowa, Maryland, Missouri, North Dakota, Oklahoma, Virginia and Wyoming. Thirty-eight of the state soil testing laboratories reported that sulfur fertilizer was being sold in their states.

Results of this survey show that sulfur deficiencies are associated mainly with well drained sandy soils low in organic matter. General regions of sulfur deficiency include the Atlantic coastal plain, Nebraska sand hills, northern Minnesota and central Wisconsin, central California, and the Pacific Northwest. Sulfur deficiencies also occur in scattered areas of other states such as North and South Dakota, Iowa, Illinois, and Indiana.

Identifying sulfur-deficient soils and recommending agronomic sulfur requirements for crops are complicated by a number of factors. Sulfur is present in many applied fertilizers, in soil organic matter, in irrigation water, and in the subsoil.

Also, there is atmospheric deposition of sulfur--probably a minimum of 200,000 tons per year. But less is being deposited. The Environmental Protection Agency's (EPA) 9th report on national air quality states that levels of sulfur dioxide in the atmosphere dropped by 27 percent in the U.S. between 1975 and 1981 (4). While some of this decrease in sulfur dioxide levels may be the result of reduced industrial activity, much is due to implementation of air pollution controls.

Another factor complicating the definition of sulfur deficiencies in soil and agronomic sulfur recommendations for crops is the difference of opinion in the intrepretation of sulfur soil tests. Less than 4 percent of all soil samples tested by the state soil testing laboratories is tested for available sulfur. Many laboratories do not analyze soil samples for available S because they say that the results of these tests do not correlate well with crop response to sulfur. Some states now use plant tissue analyses to aid in their sulfur recommendations, and several others are considering the use of plant analyses. A third factor complicating scientific studies regarding sulfur needs of crops is the fact that many fertilizers contain significant quantities of sulfur that are applied incidental to any specific soil test recommendation. In addition to the approximately 12 percent sulfur present in normal superphosphate (NSP), the ammonium phosphates also contain 1.5 to 4.0 percent sulfur.

Opinions differ regarding agronomic needs for sulfur, but the intentional use of sulfur on crops is increasing. The decrease in atmospheric deposition, the use of plant tissue analyses to give more reliable sulfur recommendations, and more complete documentation of the sulfur contents of the fertilizers should provide agronomically improved use of sulfur on crops in sulfur-deficient soils.

Production of Granular Sulfur-Bearing Fertilizers

By 1981 the annual production of NSP, 0-20-0-12S, had dropped to about 1.1 million tons (5). Basic phosphate producers have relied on NSP and concentrated superphosphate to carry the phosphoric acid sludge which is produced when higher grades of phosphoric acid are processed to be used in diammonium phosphate (DAP) and liquid fertilizers. These low-analysis superphosphate materials are becoming increasingly difficult to produce from the higher-impurity sludge acids. Also rapidly escalating freight rates favor the higher total nutrient content of ammonium phosphates. Basic phosphate producers are looking more and more to variable-analysis granular monoammonium phosphate (MAP) to carry the sludge phosphoric acid. Table 1 shows typical data for the production of such MAP's using the TVA pipe-cross reactor (PCR) (6). A sketch of a TVA PCR for granulation plants is shown in figure 2 (6). Although much of the commercially available MAP is 11-53-0-2S, in the future lower analysis MAP's such as 11-51-0-3S will become more prevalent. Although these MAP's do not contain nearly as much sulfur as NSP, the increasing annual tonnages will make their 2 to 4 percent sulfur content a factor in the total amount of sulfur applied to crops.

Granular DAP also contains a significant amount of sulfur. Analyses of samples of available DAP show a sulfur content of about 1.5 percent. The MAP and the DAP can be applied to crops as a constituent in NPKS mixtures of either suspensions or dry bulk blends. Indications are that the basic phosphate producers will use these two products to market most of the phosphate. MAP will carry the sludge phosphoric acid impurities that are put in normal and concentrated superphosphates.

Another major source of sulfur in granular fertilizers is homogeneous NPKS granular grades. These homogeneous fertilizers are produced at about 60 regional NPKS granulation plants. About half of these plants have installed PCR's which enable them to use large quantities of phosphoric and sulfuric acids. At least two of the basic phosphate producers are using or developing stabilized higher concentration wet-process acids. These acids contain 58 to 61 percent P_2O_5 and should be economically attractive to these regional granulation plants. As greater percentages of the sulfuric acid production are available from secondary sources throughout the United States, these regional plants should be logical users of this material in their granular fertilizers (7). In 1982 production of recovered sulfur exceeded Frasch sulfur production (8). Table 2 shows data for PCR production of 16-20-0-13S monoammonium phosphate sulfate (6). This particular data is from a regional granulation plant located near the facility of a basic phosphate producer. Thus the phosphoric acid concentration used is lower than merchant-grade phosphoric acid.

In addition to PCR production of MAP, DAP and homogeneous NPKS grades, granular ammonium sulfate can also be produced. Although much of the development work to produce granular ammonium sulfate with the PCR has been conducted in Australia, some tests have been made in this country. A teflon-lined reactor is used to produce granular ammonium sulfate from sulfuric acid and aqua ammonia. A temperature of about 260°F is obtained in the ammonium sulfate melt, which is sprayed onto a bed of smaller granules recycling at a rate of 5 tons of recycle per 1 ton of product. Another Australian fertilizer company has a patent which discusses the greatly improved ammonium sulfate crystal strength obtained when iron and/or aluminum sulfate salts are included in the process. The logical way to include such salts is to add a small amount of wet-process phosphoric acid. Although such technology is not routinely used in the U.S., if greater quantities of byproduct sulfuric acid become available, this production scheme for stronger granules of ammonium sulfate may become attractive. Such ammonium sulfate granules would normally be used in dry bulk blend application.

Another granulation scheme for sulfur-bearing granules involves combining elemental sulfur and about 10 percent by weight of sodium bentonite clays. The clay content contributes to the dispersion and wettability of the elemental sulfur. This sulfur is then more readily oxidized to the sulfate form and used by the growing crop.

Production of Fluid Sulfur-Bearing Fertilizers

Ammonium thiosulfate, $(NH_4)_2S_2O_3$, continues to be one of the most widely used sources of sulfur in fluid fertilizers. A typical situation for manufacturing this sulfur-bearing fertilizer occurred several years ago in southwestern Wyoming. A gas production company was operating a Claus recovery plant in its gas production field. This Claus process was producing about 90 tons per day of elemental sulfur which was readily marketable. A byproduct stream was also produced at a rate of 10 gpm. This stream consisted of 40 weight percent ammonium bisulfite-sulfite. TVA recommended that this company produce ammonium thiosulfate solution which had a ready market. Ammonium thiosulfate is produced when a slight excess of sulfur is added to a solution of ammonium sulfite in the presence of excess ammonia at a temperature of 80 to 110^{o}C. This company has since expanded its ammonium thiosulfate production as larger quantities of sour gas have needed to be desulfurized. More than a half dozen companies in the midwest produce ammonium thiosulfate solution for sale in the fertilizer industry. This solution, which has an analysis of 12-0-0-26S, is readily usable in both solution and suspension fertilizers. Almost a third of a million tons of this solution is produced, amounting to almost 90,000 tons of sulfur which is intentionally used in fluid fertilizers.

For many years TVA and The Sulphur Institute have reported on the use of elemental sulfur in suspensions. Recently TVA investigated the use of byproduct sulfur in attapulgite clay suspensions. The results of this laboratory evaluation are shown in table 3. The variable speed stirrer used in the first test is a small air driven propellor agitator. The blender is a typical laboratory blender similar to the type for domestic use. The Shar 5-gallon capacity laboratory mixer consists of a high shear disk which simulates the action of an actual batch mix fertilizer suspension plant. Tetrasodium pyrophosphate (TSPP), a wetting agent, is commonly used to improve the gelling characteristics of the attapulgite clay. The other raw materials used included the recovered sulfur (95% S), industrial MAP (11-54-0), aqua ammonia, urea-ammonium nitrate solution, and potash. These tests show that a suspension containing about 50 weight percent sulfur can be made and successfully handled, while a 9-27-0-5S base suspension of good quality can also be made.

Researchers have found that finely divided elemental sulfur can supply sulfur to crops (9). This sulfur is oxidized to sulfate form in the soil under favorable conditions of temperature and moisture. However, since the oxidation of this elemental sulfur may take several months, this form of sulfur should not be used in starter fertilizers. This controlled release aspect of elemental sulfur can be an advantage in some cases.

Ammonium sulfate is another widely used sulfur source for suspension fertilizers. The amount of ammonium sulfate available depends upon steel and nylon production, since it is a byproduct of both manufacturing processes. TVA researchers have reported laboratory and small plant data for including ammonium sulfate in ammonium phosphate systems. Some of these early ammonium phosphate suspensions were derived from electric furnace acid and later ones were wet-process ammonium phosphates containing large amounts of polyphosphate. Recent efforts have been directed toward the study of ammonium sulfate in wet-process ammonium orthophosphate suspensions. With increasing numbers of fertilizer dealers using microcomputers to calculate not only inventories and financial accounts but also actual fluid fertilizer formulations, TVA has developed mathematical equations for NPK clay suspensions. The following mathematical equations can be used to successfully predict the total nutrient and clay concentrations of varying ratios of NPK ammonium orthophosphate suspensions.

$$Y = 43.67 - 6.67C + 15Rp$$

where: $Y = N + P_2O_5 + K_2O$
C = Percent clay
$Rp = P_2O_5/Y$

These equations, developed on the basis of laboratory data and later verified in actual field use, enable fertilizer dealers to formulate consistent quality clay suspensions on the basis of soil test recommendations. Fertilizer dealers also wanted to know how to formulate when ammonium sulfate is added as the sulfur source. Table 4 shows a calculation scheme which has been successful for predicting NPKS suspensions containing ammonium sulfate. The above predictive mathematical equations indicate that a 1:1:1 ratio grade should contain 42 total units of NPK with a clay content of 1 percent. If we assume that we want two units of sulfur in this 1:1:1 ratio grade and use a weight factor of two for this ammonium sulfate, we get a total of 46 units. We can then ratio back to the NPKS grade by multiplying the numbers 14 and 2 by 42 divided by 46. The final grade then becomes a 12.8-12.8-12.8-1.8S-1 percent clay. The ammonium sulfate contains 1.6 units of nitrogen, so 1.6 units of supplemental nitrogen already in the 14-14-14, probably as UAN solution, can be taken out of the formulation. Laboratory tests of this weight factor-predictive calculation for ammonium sulfate showed it to be successful. The two grades 14-14-14-1 clay and 12.8-12.8-12.8-1.8S-1 clay were made using water, attapulgite clay, 11-53-0-2S MAP, aqua ammonia, UAN solution (32% N), and soluble potash, 0-0-62. In this particular laboratory test the sulfur content of the MAP would add 0.2 percent S to the final grade giving a 12.8-12.8-12.8-2.0S. Both samples had initial viscosities of 400 to 500 cP and 2 percent settling with 95 percent pourability after 4 days. The use of micro-computers by fluid fertilizer dealers will enable mathematical predictions of NPKS formulations such as this one to be field tested and refined as necessary.

Another sulfur-bearing fertilizer has recently been developed by TVA. This 29-0-0-5S urea-ammonium sulfate suspension is produced from economical raw materials. It is readily usable in suspension grades. The production equipment consists essentially of a boiling type-tank reactor and two coolers. Urea-water solution, sulfuric acid, ammonia, and water are feed materials. The reactor effluent is cooled to slightly above saturation temperature and suspending clay is added. Finally the product is rapidly cooled further in a second-stage spray tower evaporative cooler to obtain an abundance of small crystals. Product concentration and cooling temperature are primary factors affecting product quality and the process. TVA plans to be producing this material in a demonstration-scale plant by about mid-1984.

Table 5 summarizes a number of other forms of both solid and liquid sulfur sources that are used in fluid fertilizers (10). Sulfuric acid has been used to a limited extent on high pH and sodic soils in Arizona and south central Colorado. The danger to humans and the highly corrosive nature of sulfuric acid have, however, greatly limited its use. Many dealers who are able to obtain sulfuric acid for use in their fertilizer programs ammoniate it to form ammonium sulfate. Ammonium bisulfite and ammonium polysulfide solutions are also sometimes used as sulfur sources. Both of these solutions, like the previously discussed ammonium thiosulfate solution, cannot normally be used in acidic solutions. However, when combined with ammonium phosphate solutions slightly acidic grades of pH 6 to 7 have been prepared. In some cases sulfur dioxide gas is added to irrigation water as a sulfur source. Another sulfur-bearing fluid fertilizer gaining in popularity in the far west and midwest is mixtures of urea and sulfuric acid. Manufacturers claim less danger to humans in handling the material and less ammonia loss when applied to calcareous soils.

Also, other sulfate materials are used in fluid fertilizers. Potassium sulfate is used when chloride-free NPKS fertilizer solutions or suspensions are desired. Such fertilizers are used in foliar fertilization and on tobacco. Potassium magnesium sulfate has also been successfully used in suspension fertilizers. Because of the extreme hardness of this crystalline material, only moderate amounts should be used in suspension fertilizers. Large amounts of this material will cause excessive erosion of piping and pumps in batch mix suspension fertilizer plants. Also potassium magnesium sulfate should only be added to final NPKS suspension grades that are to be taken directly to the field. The presence of magnesium and phosphate in the same suspension will often cause solidification of the mixture. Other sources of sulfur in fluid fertilizers are the micronutrient sulfates of zinc, copper, iron, cobalt, and manganese. As indicated in table 5 these micronutrient materials contain 10 to 18 percent sulfur.

Consumption of Sulfur-Bearing Fertilizers

Tables 6, 7, and 8 and figures 3, 4, and 5 summarize available USDA data for selected sulfur-bearing fertilizers. The data is summarized by year back to 1962 and in table 8 the data is reported by regions of the United States. These data shown in these tables are the available USDA consumption data for ammonium sulfate, NSP, gypsum, 16-20-0, and sulfur and sulfuric acid. These data do not take into account materials that have been applied as a soil amendment rather than as a sulfur-bearing fertilizer. Also these data do not by themselves represent the total sulfur applied to U.S. farmland, since such sulfur-bearing fertilizers as MAP, DAP, and ammonium thiosulfate solution are not included in this tabulation.

Summary

Assessing sulfur in fertilizer is complex when compared to the other macro and secondary nutrients. In addition to sulfur applied in fertilizers, which may or may not be labeled for their sulfur content, environmentally occurring sulfur is also deposited on cropland. About one million tons of sulfur are applied annually in the fertilizers tabulated in table 6. Also, about 90,000 tons of sulfur are applied in ammonium thiosulfate, about 200,000 tons of sulfur are applied in DAP and MAP, and about 200,000 tons of sulfur are deposited atmospherically. A rough estimate of the total sulfur deposited on cropland in the United States is 1-1/2 million tons per year. As previously discussed it is expected that the atmospheric deposition of sulfur will slowly decrease. Also there is a trend toward intentional use of sulfur materials in fertilizer rather than the incidental inclusion of sulfur in fertilizer materials applied to the cropland. Increased use of plant tissue analyses to supplement soil testing should provide more reliable sulfur recommendations for crops. This expanded data on the use and agronomic response of sulfur should lead to increased usage of sulfur.

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Table 1

Production of Monoammonium Phosphate
Using the TVA-Type Pipe-Cross Reactor (PCR)
and Merchant-Grade Phosphoric Acid (52-57% P_2O_5)

Test Number	1[a]	2[b]	3[c]
Grade	11-53-0-2S	11-53-0-2S	12-48-0-5S
PCR diameter, in	6	8	6
PCR length, ft	10	18	10
Production rate, ton/hr	25	25	27.6
Formulation, lb/ton			
PCR			
Anhydrous ammonia	146[d]	200[d]	276[e]
Phosphoric acid[f]			
52.5% P_2O_5	1,530	-	1,889
57.0% P_2O_5	-	1,674	-
Sulfuric acid			
93% H_2SO_4	84	70	-
96% H_2SO_4	-	-	129
Water (to PCR ammonia sparger)	50	60	88
Scrubber liquor to PCR	NM[g]	NM[g]	90
Total water to PCR (calculated)	-	-	474
Granulator			
Anhydrous ammonia	129	75	-
Phosphoric acid			
52.5% P_2O_5	505	-	-
PCR Operating Conditions			
Temperature, °F	265	260	270
Heat flux, Btu/in^2-hr	300,000	252,000	1,540,130[h]
Ammonia loading, lb NH_3/in^3-hr	1.08	0.46	2.2
N:P mole ratio	0.6	0.77	1.0
Granulator Operating Conditions			
Recycle rate, ton/hr	95	80	80
Recycle ratio, tons recycle/ton product	3.8	3.2	2.9
N:P mole ratio	1.0	1.0	1.0
Airflow, estimated across bed, cfm	7,000	7,000	-
Air velocity ft/sec	3.3	2.6	-
pH fertilizer	4.0	3.9	4.0
Moisture	-	-	2.9
Dryer Fuel Requirement, Btu/ton product	98,000	0	0[j]
Scrubber, pH	4.0-5.0	4.0-5.0	3.5-4.0
Product Chemical Analysis (%)			
N	11.2	11.4	10.2[k]
P_2O_5	53.4	52.8	45.8
Al_2O_3	1.6	-	-
Fe_2O_3	1.6	-	-
F	0.3	-	-
S	2.5	-	-
H_2O	1.0	1.6	1.14
Screen Analysis (%)			
+6	0.3	0	-
-6 +14	96.7	93.1	-
-14 +16	98.7	98.7	-
-16	100.0	100.0	-
Average Crushing Strength, lbs	9.9[l]	-	9.8[l]

a. 8' x 16' granulator Ohio U.S.A.
b. 9' x 20' granulator Missouri U.S.A.
c. 9' x 36' granulator Sweden
d. Ammonia at room temperature
e. Ammonia at -27°F Sp Gr 0.62
f. Produced from Florida phosphate rock
g. Not measured
h. 4-inch insert in discharge end of PCR
i. Assume only 70% granulator cross-section available for airflow
j. Pilot burner on low fire
k. Grade low because recycle contained superphosphate
l. Average crushing strength DAP 18-46-0 from conventional process = 8.5

Table 2

Production of Monoammonium Phosphate Sulfate Using TVA Pipe-Cross Reactor and Medium Strength Phosphoric Acid (40-50% P_2O_5)

Test Number	4
Production rate, ton/hr	25
Grade	16-20-0-13S
Granulator size, D x L, ft	10 x 20
PCR diameter, in	6
PCR length, ft	20
Formulation, lb/ton product	
PCR	
Phosphoric acid[a] (43.5% P_2O_5, 30% H_2O)	789
Byproduct ammonium sulfate liquor (7% N, 8% S, 67% H_2O)	430
Sulfuric acid (93% H_2SO_4)	924
Ammonia	364
Water[b]	175
Scrubber seal tank slurry (60% H_2O)	140
Total water PCR (calculated)	849
Granulator	
Weak acid slurry (23% P_2O_5, 25% $CaSO_4$, 43% H_2O)	265
Ammonia	31
PCR Operating Conditions	
Temperature, ^oF (skin temperature)	260
Total, Btu/ton	963,814
Ammonia loading, lb NH_3/in^3-hr	0.73
Mole ratio slurry to PCR, N:P	0.4
Mole ratio melt from PCR, N:P	1.0
Granulator Operating Conditions	
Temperature material, ^oF	200
Recycle rate, tons/hr	95
Recycle ratio	3.8
Granulator	
N:P mole ratio	1.0
Airflow, cfm (estimated across bed)	15,000
Air velocity, ft/sec	4.6
pH	4.8
Electricity, Btu/ton equivalent	317,000
Dryer fuel, Btu/ton	200,000
Dust loss from granulator (recovered in scrubber), lb/hr	230
% of total product ton/hr	0.46
Ammonia loss from granulator (recovered in scrubber) (lb/hr)	930
% of total NH_3 in process[c]	9.4

a. Via scrubber
b. Premixed with ammonia in ammonia sparger
c. Recovered by phosphoric acid in scrubber

Table 3

Laboratory Evaluation of Recovered Sulfur in Suspensions

Mixer used	35%S Var. speed stir.	35%S blen.	35%S Shar	45%S Shar	55%S Shar	60%S Shar	35%S 1% TSPP Shar	45%S 1% TSPP Shar	55%S 1% TSPP Shar	60%S 1% TSPP Shar	9-27-0 2% S Shar	9-27-0 3% S Shar	9-27-0 4% S Shar	9-27-0 5% S Shar
Formulation, lb/ton product														
Water	1230	1230	1140	930	720	615	1120	910	700	595	666	666	666	666
Dry clay	30	30	-	-	-	-	-	-	-	-	30	30	30	30
Fluid clay (25%)[1]	-	-	120	120	120	120	120	120	120	120	-	-	-	-
TSPP	-	-	-	-	-	-	20	20	20	20	-	-	-	-
Sulfur (95%S)	740	740	740	950	1160	1265	740	950	1160	1265	40	60	80	100
MAP, 11-54-0[2]	-	-	-	-	-	-	-	-	-	-	1000	1000	1000	1000
Aqua, 23-0-0	-	-	-	-	-	-	-	-	-	-	304	304	304	304
Total clay (%)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Initial viscosity (cP)	40	80	270	480	650	840	60	200	500	880	200	200	195	190
1 week viscosity (cP) (75°F)	30	70	250	470	710	845	35	165	440	970	510	450	430	525
1 week pourability (%) (75°F)	90	90	95	95	93	90	90	95	95	80	98	98	98	98
1 week liquor layer (%) (75°F	33	33	20	20	15	15	20	20	10	5	5	5	5	5
pH (75°F)	2.6	2.7	2.8	2.6	2.3	2.1	7.2	6.7	6.3	5.3	7.1	7.2	7.0	7.0
Specific gravity (75°F)	1.27	1.23	1.24	1.26	1.40	1.44	1.24	1.37	1.42	1.48	1.36	1.34	1.36	1.36

1. 25% attapulgite clay. Actual clay added = 1.5%.
2. Monoammonium phosphate.

It was decided to use fluid clay in the sulfur suspensions since the two samples containing dry clay had very rapid settling. Large 35% sulfur suspension batches were made and the 45%, 55%, and 60% were made from these batches by adding the extra sulfur and hand shaken in a jar. Large batches of the 9-27-0 were made. Sulfur was added to this grade and hand shaken in a jar.

Table 4

<u>Estimation of Maximum Suspension Grades Containing Ammonium Sulfate (A/S)</u>

Assume a 14-14-14 (1:1:1 Ratio) is wanted to contain 2 units of Sulfur.

$$14 + 14 + 14 = 42$$

Use a weight factor of 2 for A/S.

$$14 + 14 + 14 + 2\ (2) = 46$$

Ratio NPKS grade back to 42 total units.

$$\frac{42}{46}\ (14) = 12.8$$

$$\frac{42}{46}\ (2) = 1.8$$

Maximum NPKS suspension grade becomes

12.8-12.8-12.8-1.8S

Table 5

Forms of Sulfur Used in Fluid Fertilizers

The various materials which can be used to provide sulfur in fluid fertilizers are listed below, together with selected properties of these materials in their usual commercial form.

Usual Commercial Form

	%S	%N	pH	Density lbs/gal	Minimum Storage Temp. °F	VP PSIG 60°F
I. LIQUID						
(a) Aqueous						
(1) Sulfuric Acid (93.2% H_2SO_4)	30.4	-	<1	15.3	30	neg.
(2) Ammonium Bisulfite (55-60% $NaHSO_3$)	17.0	8.5	5.2	10.8	32	neg.
(3) Ammonium Thiosulfate $(NH_4)_2S_2O_3$	26.0	12.0	7.5	11.1	0	neg.
(b) Non-aqueous						
(1) Sulfur Dioxide (SO_2)	50.0	-	-	12.0	<0	25
(2) Ammonium Polysulfide $(NH_4)_2S_x$	40-45	20	>10	9.5	30	10

	%S	%N	%K_2O	%Other	Solubility in water. Pts. salt/100 pts. H_2O @32°F	@100°F
II. SOLID						
(1) Sulfur (S)	100	-	-	-	0	
(2) Ammonium Sulfate ($\{NH_4\}_2SO_4$)	24.2	21.1	-	-	70.5	80.2
(3) Potassium Sulfate (K_2SO_4)	18.4	-	54.0	-	7.4	14.4
(4) Potassium Magnesium Sulfate ($K_2SO_4 . 2MgSO_4$)	22.0	-	22.0	18.0 MgO	20	44
(5) Micronutrients						
Zn ($ZnSO_4 . H_2O$)	18	0	0	36 (Zn)		
Cu ($CuSO_4 . 5H_2O$)	13	0	0	25 (Cu)		
Fe ($FeSO_4 . 7H_2O$)	10	0	0	20 (Fe)		
Co ($CoSO_4 . 7H_2O$)	11	0	0	21 (Co)		
Mn ($MnSO_4 . 4H_2O$)	16	0	0	27 (Mn)		

Table 6

U.S. Consumption of Sulfur in Selected Sulfur-Bearing Fertilizers

(Thousand Tons of Sulfur)

Year	Ammonium Sulfate[1]	Normal Super-Phosphate[1]	Gypsum[2]	16-20-0	Potassium Sulfate[1]	Other[3]	Total
1962	352	710	208	72	56	24	1422
1963	383	731	231	75	63	26	1509
1964	428	722	234	77	61	25	1547
1965	421	670	240	74	60	26	1491
1966	421	674	226	78	58	32	1489
1967	377	698	217	75	62	21	1450
1968	402	626	250	74	64	20	1436
1969	392	505	203	77	64	30	1271
1970	480	455	196	64	72	31	1298
1971	606	373	183	58	69	35	1324
1972	509	405	202	61	71	30	1278
1973	534	367	220	71	78	41	1311
1974	602	401	322	86	98	67	1576
1975	510	365	267	73	88	56	1359
1976	576	246	307	66	85	103	1383
1977	631	225	336	67	109	48	1416
1978	502	180	253	72	52	136	1195
1979	388	188	273	55	55	183	1142
1980	458	227	316	65	101	161	1328
1981	511	211	299	62	95	147	1325
1982	431	89	233	44	80	82	959

1. Based on available supply to reflect the large usage in mixtures.
2. Not necessarily applied for sulfur content.
3. Sulfur materials for direct application and sulfuric acid.

Table 7

U.S. Consumption of Sulfur in Selected Sulfur-Bearing Fertilizers

(Percent of Total)

Year	Ammonium Sulfate[1]	Normal Super-Phosphate[1]	Gypsum[2]	16-20-0	Potassium Sulfate[1]	Other[3]
1962	25	50	15	5	4	2
1963	25	48	15	5	4	2
1964	28	47	15	5	4	2
1965	28	45	16	5	4	2
1966	28	45	15	5	4	2
1967	26	48	15	5	4	1
1968	28	44	17	5	4	1
1969	31	40	16	6	5	2
1970	37	35	15	5	6	2
1971	46	28	14	4	5	3
1972	40	32	16	5	6	2
1973	41	28	17	5	6	3
1974	38	25	20	5	6	4
1975	38	27	20	5	6	4
1976	42	18	22	5	6	7
1977	45	16	24	5	8	3
1978	42	15	21	6	4	11
1979	34	16	24	5	5	16
1980	34	17	24	5	8	12
1981	39	16	23	5	7	11
1982	45	9	24	5	8	9

1. Based on available supply to reflect the large usage in mixtures.
2. Not necessarily applied for sulfur content.
3. Sulfur materials for direct application and sulfuric acid.

Table 8

Consumption of Sulfur in Selected Sulfur-Bearing Fertilizers[1]
By Region

Region and Product	1965	1970	1975	1976	1977	1978	1979	1980	1981	1982
	(Short Tons of Sulfur)									
NEW ENGLAND										
Ammonium Sulfate		99	203	50	270	16	51	158	1047	319
NSP	2209	759	123	88	75	42	39	43	29	43
16-20-0		28								
Gypsum	3	2	37	5	6	28	21	27	104	21
Potassium Sulfate	6	3		6	9				5	5
Other		9	17						20	5
Total	2218	900	380	149	360	86	111	228	1205	393
MIDDLE ATLANTIC										
Ammonium Sulfate	2621	1020	3076	4488	3041	1977	2619	3101	4807	3213
NSP	6575	4873	791	1203	254	183	285	88	285	96
16-20-0		2	527	119		4	1	35	1399	1371
Gypsum	985	1395	1110	288	219	213	148	320	177	100
Potassium Sulfate	472	122	135	147	126	229	290	235	86	80
Other	431	25	198	729	659	41	63	50	124	165
Total	11084	7437	5837	6974	4299	2647	3406	3829	6878	5025
SOUTH ATLANTIC										
Ammonium Sulfate		1712	3267	6574	6730	4117	3626	4018	5335	5194
NSP	5520	3862	1922	2030	4306	2595	3366	2601	3071	2451
16-20-0		76	197			18		2	7	2
Gypsum	21333	24660	26650	41132	43185	45340	55464	45567	40729	48937
Potassium Sulfate	1697	657	208	3367	328	3008	258	240	468	547
Other	1452	622	917	5748	5113	6263	16658	9730	11762	3704
Total	30002	31589	33161	58851	59662	61341	79372	62158	61372	60835
EAST NORTH CENTRAL										
Ammonium Sulfate	14664	11279	12853	11524	13682	12198	10838	13303	15023	10975
NSP	4629	2853	525	223	636	2126	553	3850	3158	3646
16-20-0	9	7	479	99	10	39	16	20	31	16
Gypsum	299	153	209	277	313	184	242	391	629	1081
Potassium Sulfate	380	105	409	634	676	889	816	510	280	577
Other	22	33	437	5106	1904	2783	4004	4187	2403	839
Total	20003	14430	14912	17863	17221	18219	16469	22261	21524	17134

Table 8 Continued

Consumption of Sulfur in Selected Sulfur-Bearing Fertilizers[1]
By Region

Region and Product	1965	1970	1975	1976	1977	1978	1979	1980	1981	1982
	(Short Tons of Sulfur)									
WEST NORTH CENTRAL										
Ammonium Sulfate	3585	3343	4965	4991	8141	8104	7301	9111	9549	8614
NSP	5939	4651	1700	710	919	832	749	1142	828	554
16-20-0	12734	3385	5760	3470	3340	2702	3321	3115	2607	1952
Gypsum	182	174	1025	567	1018	1122	975	9445	8116	4222
Potassium Sulfate	76	131	76	189	84	146	67	69	136	46
Other	263	217	6503	8846	14521	15073	58163	25569	33716	25737
Total	22779	11901	20029	18773	28023	27979	70576	48451	54952	41125
EAST SOUTH CENTRAL										
Ammonium Sulfate		1054	869	1157	1395	913	263	323	1016	437
NSP	7672	3428	2080	1904	1097	1100	762	986	1142	741
16-20-0	31	153	71	8	11	26	7	3	21	3
Gypsum	624	103	329	129	41	9	70	1122	1205	446
Potassium Sulfate	1368	1727	1226	2909	2819	3358	3400	3616	4634	5457
Other	1	86	9	2123	1056	564	141	192	260	75
Total	9696	6551	4584	8230	6419	5970	4643	6242	8278	7159
WEST SOUTH CENTRAL										
Ammonium Sulfate	29549	30110	31743	44987	44520	34478	33098	44782	44639	31309
NSP	8371	3402	1347	1151	834	647	250	168	138	110
16-20-0	27236	17508	13599	15703	17428	15517	12231	20914	11136	7988
Gypsum	431	153	237	5		119		15	48	
Potassium Sulfate	62	87	19	14		1	26	22		2
Other	91	2	105	64	88	235	33	355	633	672
Total	65740	51262	47050	61924	62870	50997	45638	66256	56594	40081
MOUNTAIN										
Ammonium Sulfate	22000	32023	34869	55803	46311	45769	44531	45322	43661	44165
NSP	1519	1210	1101	656	362	237	257	372	551	168
16-20-0	9989	16439	20003	16224	14895	13721	10736	12163	17596	9917
Gypsum	5975	2595	3253	3097	4662	3614	3056	6337	12905	9253
Potassium Sulfate	249	421	282	1443	2795	3853	1244	594	147	1214
Other	3081	15072	8509	9693	20085	20803	14798	15182	13987	12123
Total	42813	67760	68017	86916	89110	87997	74622	79970	88847	76840

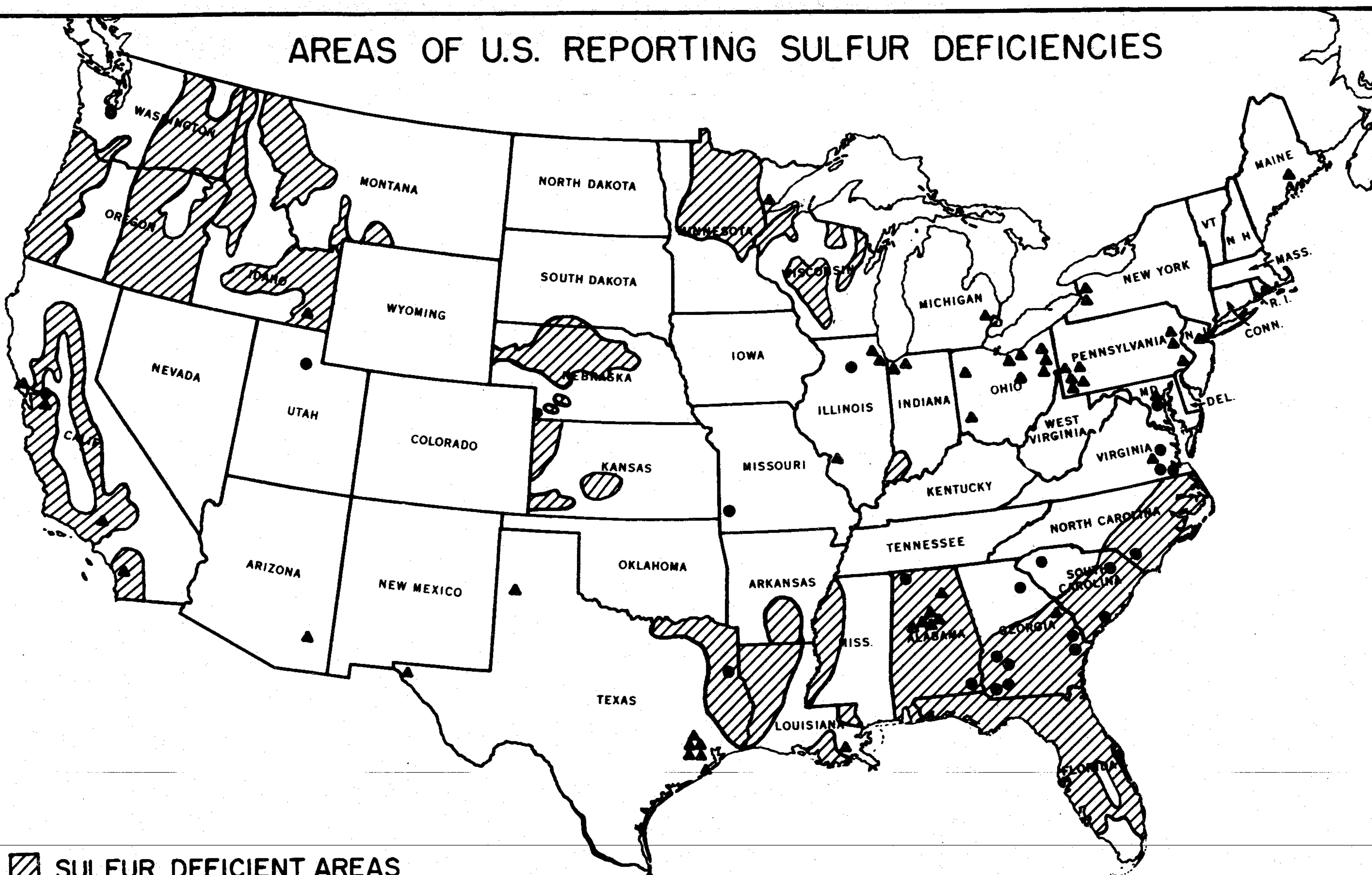
Table 8 Concluded

Consumption of Sulfur in Selected Sulfur-Bearing Fertilizers[1]
By Region

Region and Product	1965	1970	1975	1976	1977	1978	1979	1980	1981	1982
	(Short Tons of Sulfur)									
PACIFIC										
Ammonium Sulfate	104328	105570	103114	126255	127060	105730	77758	79630	68928	62545
NSP	11946	11935	12479	8853	7578	4993	4247	6598	5426	1773
16-20-0	24690	26628	31894	29902	30935	39744	28572	29245	28866	22597
Gypsum	209969	166512	233973	261267	286100	202116	213151	253276	221091	168873
Potassium Sulfate	2223	2686	1187	1524	1583	1567	1882	991	1684	1624
Other	20144	15217	39399	69632	3647	89857	88607	105569	84371	39091
Total	373300	328548	422046	497433	456903	444007	414217	475309	410366	296503
OTHER STATES AND TERRITORIES										
Total	5979	2521	1204	2277	2267	2632	1288	798	924	718
TOTAL UNITED STATES										
Ammonium Sulfate	182020	187650	195789	256790	252140	215856	181112	200266	194682	167238
NSP	54671	37444	22070	16841	16082	12779	10509	15848	14628	9577
16-20-0	74724	64236	72557	65571	66622	71771	54885	65498	61663	43846
Gypsum	239847	195764	266824	306767	335544	252746	273128	316426	299329	232932
Potassium Sulfate	6815	6450	3883	7493	8687	9971	7704	6615	7899	9804
Other	25537	31354	56099	102923	48057	135624	182513	160887	147374	92411
Total	583614	522898	617222	756385	727132	698747	709851	765540	725575	555808

1. Based on direct application materials only. Does not include ammonium sulfate and normal superphosphate used in fertilizer mixtures.

AREAS OF U.S. REPORTING SULFUR DEFICIENCIES



SULFUR DEFICIENT AREAS

▲ AMMONIUM SULFATE PLANTS

● NORMAL SUPERPHOSPHATE PLANTS

Figure I

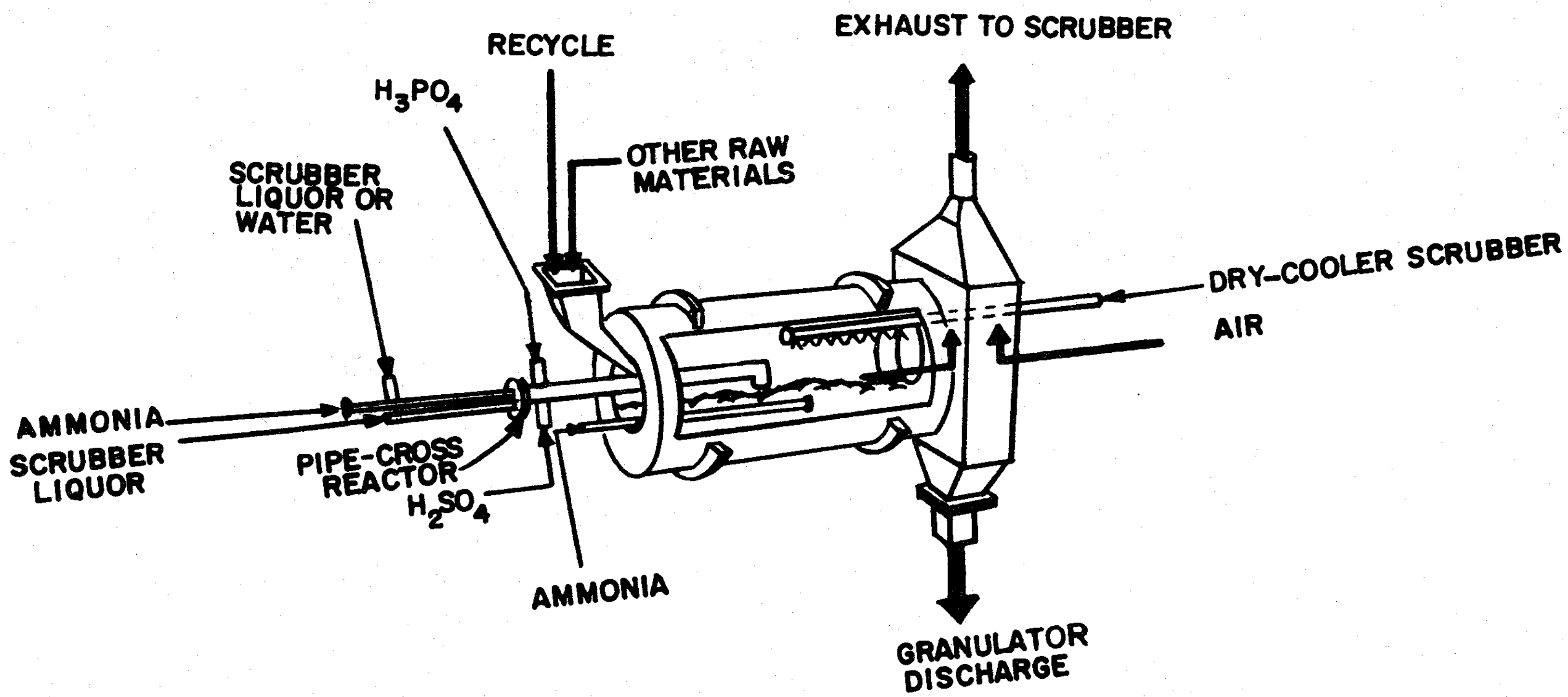
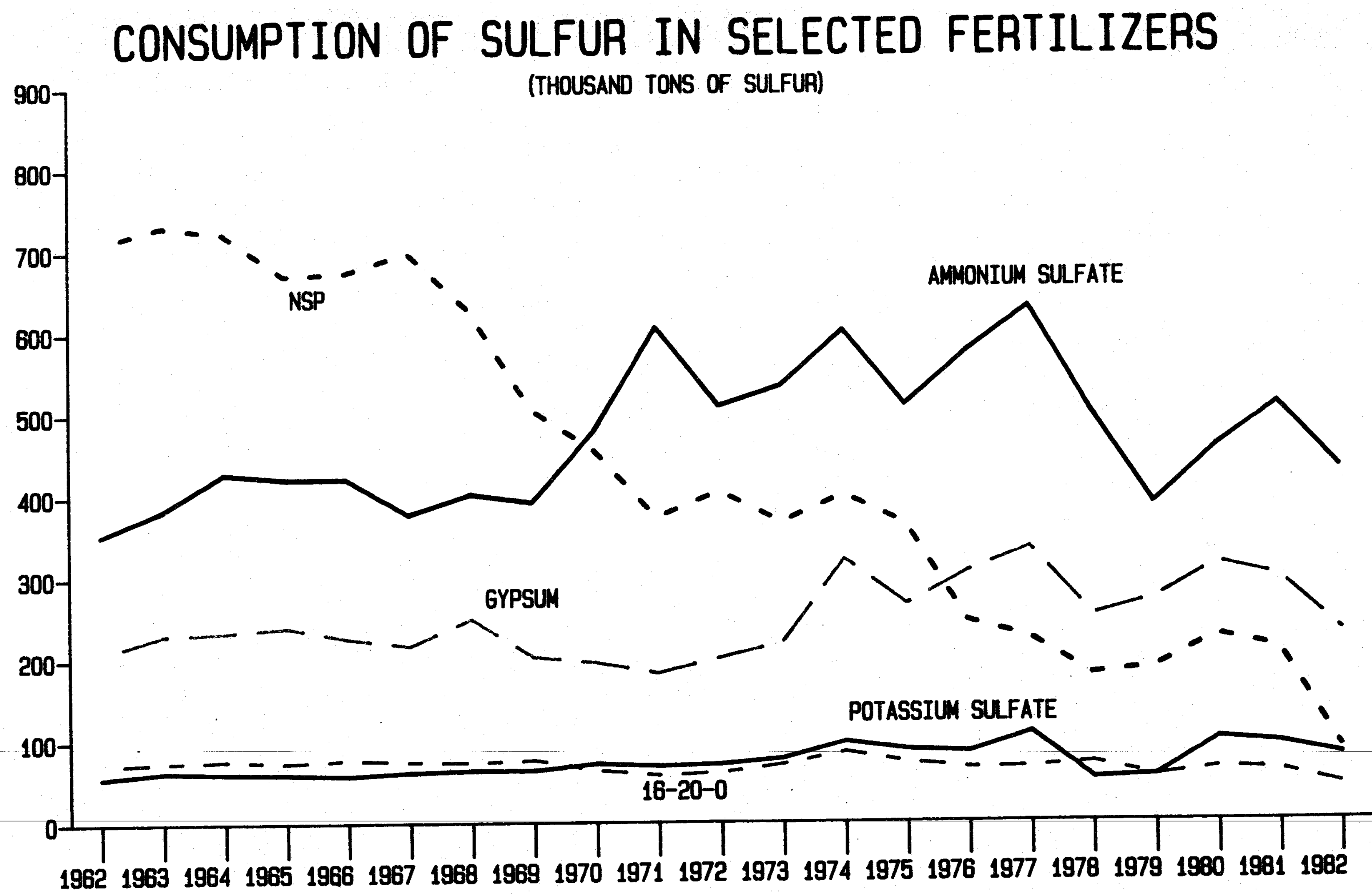


FIGURE 2

PIPE-CROSS REACTOR FOR GRANULATION PLANTS

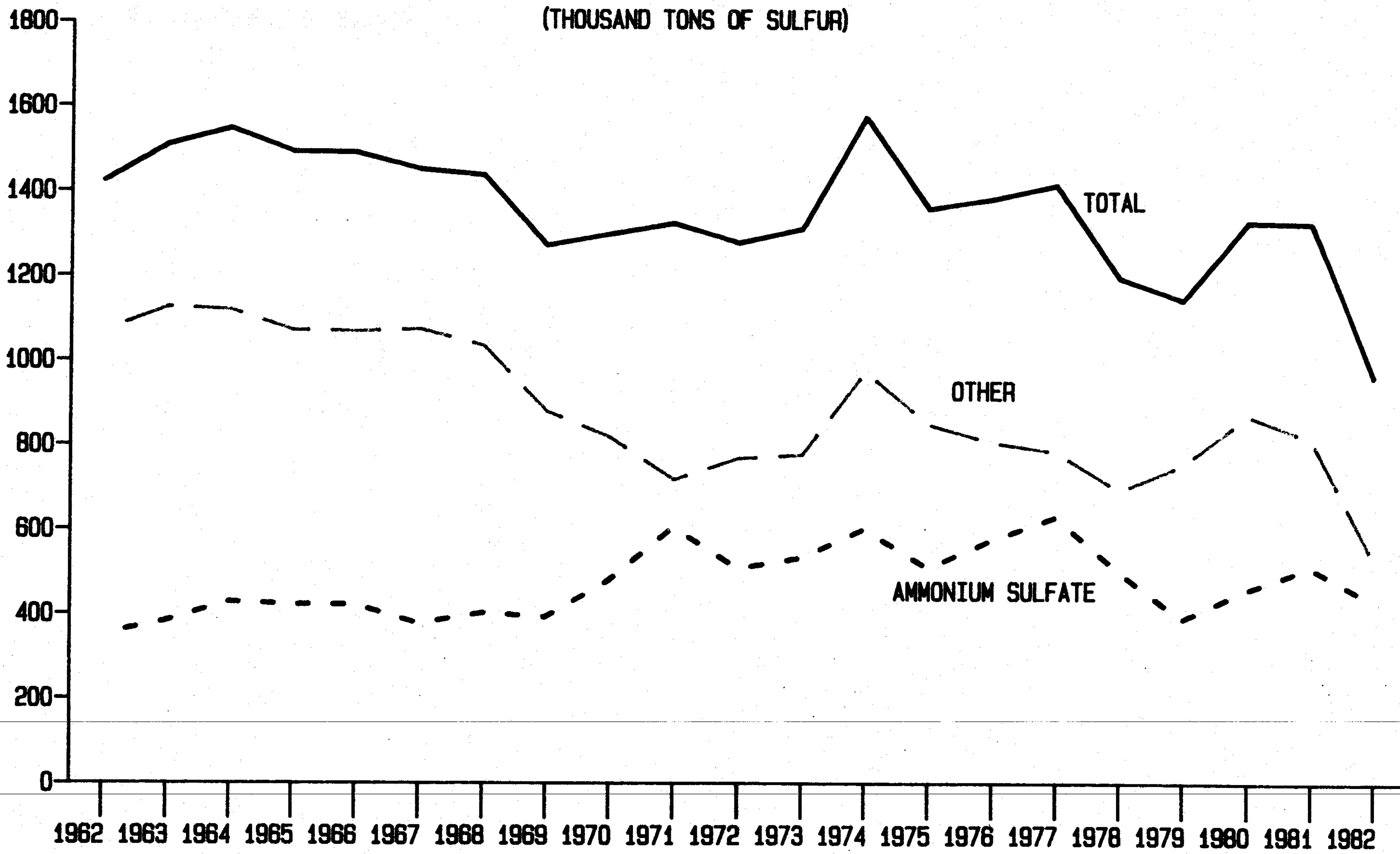


CONSUMPTION OF SULFUR IN SELECTED FERTILIZERS
(THOUSAND TONS OF SULFUR)
900
800
700
600
500
400
300
200
100
0
NSP
AMMONIUM SULFATE
GYPSUM
POTASSIUM SULFATE
16-20-0
1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982

FIGURE 3

CONSUMPTION OF SULFUR IN SELECTED FERTILIZERS

(THOUSAND TONS OF SULFUR)



NOTE: OTHER INCLUDES NSP, GYPSUM, 16-20-0, AND OTHER SULFUR-BEARING MATERIALS.

FIGURE 4