IFA CROSSROADS ASIA-PACIFIC 2007

Bali, Indonesia
17-19 December 2007

CORRECTING SULPHUR DEFICIENCY FOR HIGHER PRODUCTIVITY AND FERTILIZER EFFICIENCY

Ming Xian FAN

The Sulphur Institute (TSI), United States

International Fertilizer Industry Association

The Sulphur Institute (TSI)
1140 Connecticut Avenue, N.W., Suite 612
Washington, DC 20036, United States
Tel: 1 202 3319660 - Fax: 1 202 2932940
E-mail: MFan@sulphurinstitute.org

(content as provided for distribution in Bali)

All the papers and presentations prepared for the 2007 IFA Asia-Pacific Crossroads in Bali will be compiled on a cd-rom to be released in December 2007.

Correcting Sulphur Deficiency for Higher Productivity and Fertilizer Efficiency

Ming Xian FAN and Donald L. MESSICK

The Sulphur Institute (TSI)

Introduction

Sulphur (S) is vital for life, and essential for plant growth. Like nitrogen (N), phosphorus (P) and potassium (K), S is one of the essential plant nutrients. It contributes to high crop yields and quality in three different ways:

1) It provides a direct nutritive value;
2) It improves the use efficiency of other essential plant nutrients, particularly N, P and some micronutrients, like Zn, Fe, Cu, Mn and B;
3) It improves crop product quality by increasing protein and oil percentage in seeds, cereal quality for milling and baking, nutritional value and marketability of vegetables and fruits, quality of tobacco, nutritive value of forages etc.

In general, S has similar functions in plant growth and nutrition as N and plant requirements for S are comparable to P. Most crops remove 15 to 25 kg S/ha. Oil crops, legumes, forages, and some vegetables require more S than P for optimal yield and quality.

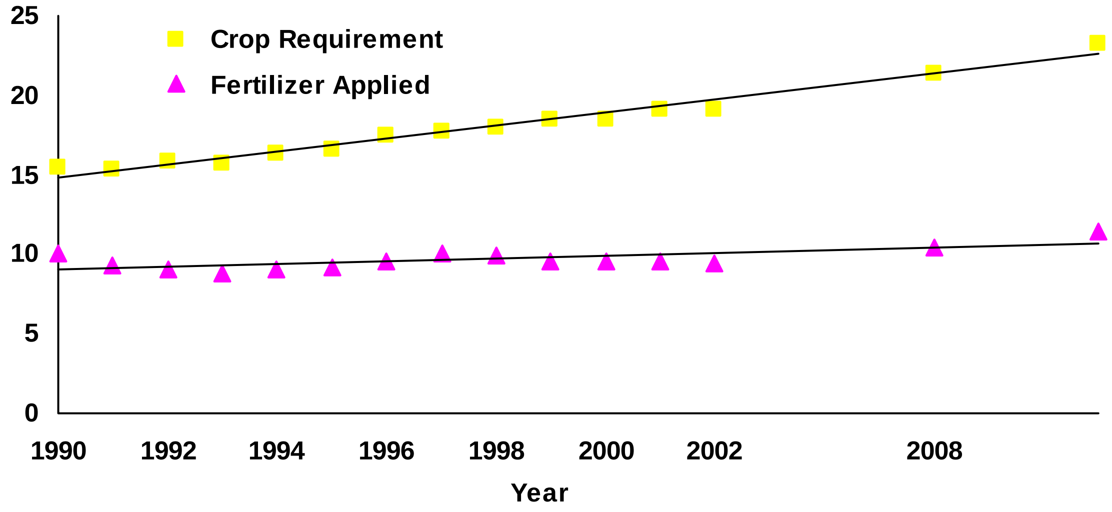
Sulphur Deficiency and Crop Responses to S Fertilizer Worldwide

Sulphur deficiency has become widespread over the past several decades in most of the agricultural areas of the world, becoming a limiting factor to higher yields and fertilizer efficiency. Among the factors relating to nutrient management in agricultural production, the following are the current major causes of increasing S deficiencies:

- More S is removed from the soil as a result of an increase in agricultural production by increasing fertilizer use, intensifying cropping systems, promoting high-yield crop varieties, and improving irrigation;
- Less S is added to soil due to the increasing proportions of high-analysis, sulphur-free fertilizers, decreasing use of traditional organic manures and sulphur-containing fertilizers, and sulphur-containing pesticides;
- The reduction of S dioxide (SO_2) emissions reduces atmospheric S deposition, one of the important S sources of agricultural soils around industrial areas.

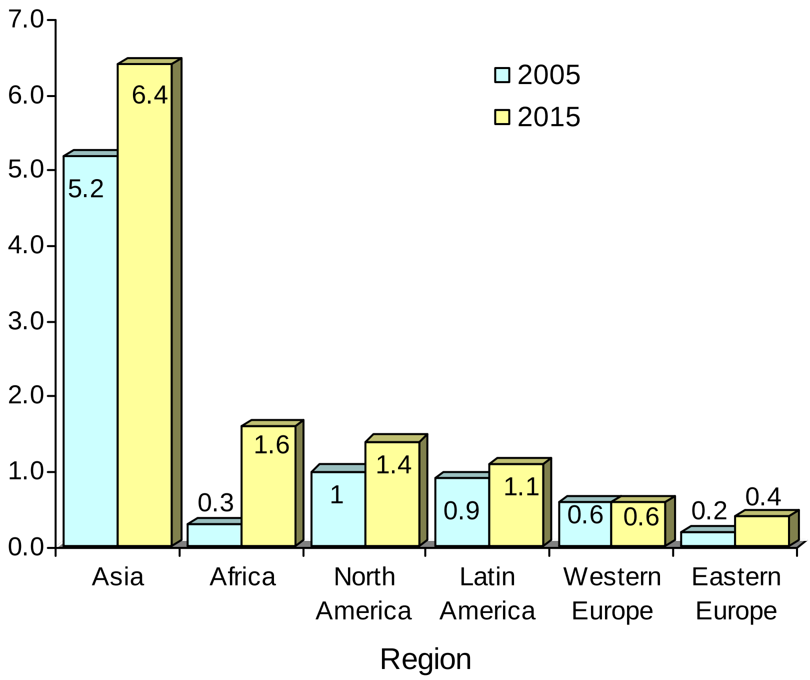
According to estimates of TSI based on crop demand, fertilizer efficiency and current inputs, the current S deficit is about 9.6 million tons annually. With increased food production raising S requirements and assuming slower expansion rates for S application, this S deficit is projected to grow to 11.9 million tons by 2015 (Figure 1).

Figure 1. Plant Nutrient Sulphur Requirement and Deficit (Mt).



A regional breakdown of world S deficits is shown in Figure 2. Asia is the region manifesting the greatest S shortfalls.

Figure 2. Regional Plant Nutrient Sulphur Deficit in 2005 and 2015 (Mt).



Western Europe: S deficiencies became significant in agriculture of Western European countries in 1980s, due to the significant drop in S dioxide emissions since the 1970s, coupled with intensive agronomic practices including the use of high-analysis, S-free fertilizers.

Many European countries now have S recommendations including Denmark, France, Germany, and Italy, but the evolution of S deficiencies in the United Kingdom provides the best example of the "S story":

- In 1973, S applications in fertilizers for the United Kingdom were 75,000 tons. By 1992, this figure had dropped by one-third;
- Until recently, atmospheric deposition in the United Kingdom contributed more than 40 kg/ha of S, dropping to less than 10 kg/ha at present, which was at about 15% of the 1980 levels;
- In December 2000, the ministry upgraded its recommendations to reflect the scientific findings indicating that S fertilization at 15 to 25 kg S/ha rate is needed on a variety of arable crops throughout the country;
- Research findings at the Institute of Arable Crop Research of Rothamsted indicate that cereal growers stand to lose £30 million per year if S deficiency is not remedied. Furthermore, an estimated 50% of wheat and 70% of oilseed rape is at risk and could benefit from S fertilizer application.

North America: Although S deficiencies have been known in North America, for decades, with the growing depletion of atmospheric S, the region is following the Western European example.

.

- It is estimated that, about 20% of the cultivated land in this region is S deficient.
- Crop responses to S fertilizer in yield range from 10 to 40% for cereal crops; up to 100% for legumes grown on extremely S-deficient soils.
- Maximum response in cereals usually is obtained with 11 to 22 kg S/ha; however, 17 to 34 kg S/ha is recommended for cereal crops, and from 44 to 56 kg S/ha is recommended for legumes.

Latin America: Agricultural production increased significantly over the last decade, which in conjunction with the rising use of high-analysis fertilizers leads to increasing instances of S deficits. The largest fertilizer consumer, Brazil, is an important and growing user of ammonium sulphate and SSP. In Argentina production of SSP and ATS has also started. The current market opportunity in Latin America is estimated at 800,000 tons, and is projected to rise to at least 1.1 million tons by the end of the decade.

Oceania: Early recognition of S deficiency in Australian agriculture was obscured by the extensive use of ammonium sulphate and SSP to correct widespread N and P deficiencies. Increased use of high analysis S-free fertilizers has aggravated the S deficiency problem in lowland rice and in other cropping systems. By the 1970s, it became apparent that S fertilizer was beneficial in many parts of temperate Australia. Sulphur deficiencies now are known to occur throughout Australia.

In New Zealand, S deficient soils are mostly found on the central part of the North Island, and on the both sides of the Southern Alps of the South Island. Sulphur application has greatly increased pasture yield, ranging from 20% to 200%. An estimated 4 million ha of pastures on the North Island and a further 2 million ha on the South Island received annual S fertilization in the form of SSP at a rate of 20 to 25 kg S/ha. Total S fertilizer use fluctuated between 110,000 tons to 230,000 tons per year since 1980.

Because of the widespread deficiencies of S in Australia and New Zealand, a wide-range of S containing crop and pasture fertilizers have been developed with a wide ratio between sulphate and elemental forms of S for different crop and soil conditions.

Africa: Sulphur deficiencies have been reported in many African countries; however, fertilizer consumption has generally been low. It is expected that as agriculture intensifies, S deficiencies will become more apparent and increase in frequency.

Clearly, the results generated from extensive research conducted around the globe have provided solid evidence that S deficiency is limiting crop production, affecting crop yield and quality as well as economic return. Sulphur fertilization is essential to the sustainable development of agriculture, with both agronomic and economic benefits.

Asia: In the late 1990s and early 2000s, intensified agricultural production, pressured by the backdrop of food self-sufficiency goals and limited land resources in the globe's two most populous nations, China and India, has created the S nutrient imbalance. This imbalance is expected to grow due to the widespread gap between available production and supply and crop requirements. Asia's annual S fertilizer deficit is projected to increase from over 5 million tons currently to 6.4 million tons by 2014, with over 70% represented by China and India. This creates both opportunities and challenges for the agriculture and fertilizer industry to explore the huge food production and market potentials in this region**.**

China: Since 1993, a TSI initiative and cooperative network of Chinese agencies established throughout China has achieved significant advances in evaluation of S fertilizer effects/requirements and promotion of S fertilizer use in Chinese agriculture:

- More than 30% of arable soils in China, equivalent to about 40 million hectares, are S deficient with a similar amount potentially deficient. Sulphur fertilizer significantly increased crop yields in 87% of the 572 total trials completed, with average yield increases from 7% to 30%;
- Sulphur fertilizer also improved fertilizer economic efficiency, with a high Value Increase to Input Cost Ratio (VCR), ranging from 10 to 40; and increased agronomic efficiency from 8 kg of soybean to 368 kg of sugarcane per kg S fertilizer;
- Balanced fertilization including S increased nutrient uptake and fertilizer use efficiency, from 4% to 39.2% in N use efficiency and from 5.4% to 10.5% in P use efficiencies;
- Sulphur fertilizers were included into fertilizer recommendations in some major agricultural provinces as part of the balanced fertilization as 20 to 40 kg S for cereal crops, 30-60 kg S/ha for legume, oil and vegetable crops (Table 1);
- In 2006, the total S-based NPK compound fertilizer output reached 9.0 million tons, providing 900,000 tons S.

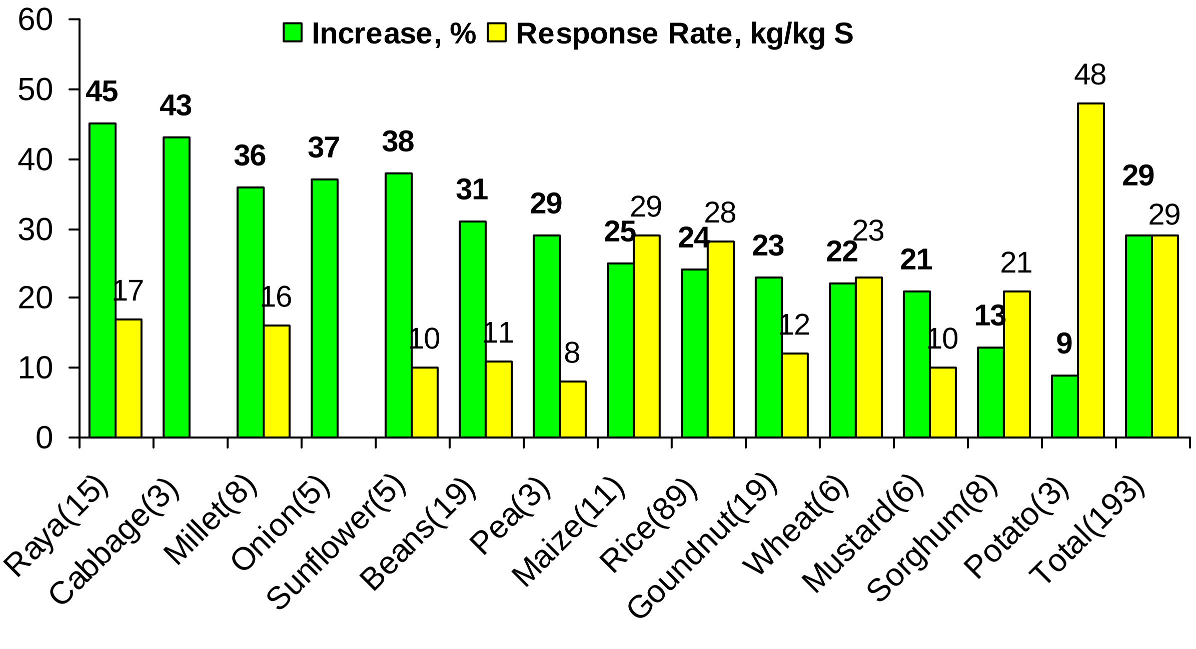
Table 1. Sulphur Fertilizer Recommendation Highlights Worldwide.

Crop	Recommendation, kg S/ha				
	Australia	China	Europe	India	North America
Cereal	10-20	20-40	20-40	24-40	17-34
Legume	20-30	30-60	25-35	25-50	22-64
Oil	40-60	30-60	30-45	20-50	25-60
Vegetables	-	30-60	-	25-60	-
Sugar	-	40-80	30-60	30-50	-

India: Since 1980, TSI, in collaboration with various international organizations, like IFA, and Indian organizations, like FAI, has conducted an integrated research and development program in India to delineate S deficiencies in Indian agriculture and to advance S fertilizer use for a more balanced fertilization. **The project results prove that the S deficiency situation in India is critical:**

- From over 49,000 soil samples that were analyzed to determine soil S fertility levels in 18 Indian states, the results showed that 75% of cropped soils were S deficient or potentially S deficient, eq. about 80 million ha of S deficient arable land which requires about 1.6 million tons S fertilizer nationwide for sustaining agricultural production;
- Sulphur fertilization significantly increased crop yields in over 90% of 193 field trials completed by an average of 29%, and ranged from 9% to 45% in the 18 states (Figure 3). Assuming a yield increase of a conservative15%, the total grain yield increase, for example, of rice of 48 million tons in India, would rise food production from current 200 million ton to 248 million ton and food supply level per capita by 20%;
- Sulphur fertilizer could increase soil S fertility, resulting in higher yield for the following crops. Residual effects of S fertilizer were recorded in 163 field trials completed from 1998 to 2005, with average crop yield increases of 6% to 48% (Figure 4);
- Sulphur fertilization also improved crop quality by increasing protein content for fodder and wheat, and oil content for mustard;
- The effect of S fertilization on crop yield and quality resulted in high fertilizer efficiency and high economic returns to farmers in all tested crops, with the average Value to Cost Ratio (VCR) ranging from 24 for Bean-Mustard cropping system, to the highest of 76 for Groundnut-Wheat cropping system (Table 2).

Figure 3. Average Crop Responses to Sulphur Fertilizer in Field Trials Conducted during Kharif season of 1998 to 2005 (numbers in parentheses represent the number of field trials).



* Note: The average response rate for cabbage and onion is 476 and 159 kg/kg S, respectively.

Figure 4. Average Residual effects of S Fertilizer on Crop Yield and Response Rate in Field Trials Conducted during Rabi season of 1998 to 2005 (numbers in parentheses represent the number of field trials).

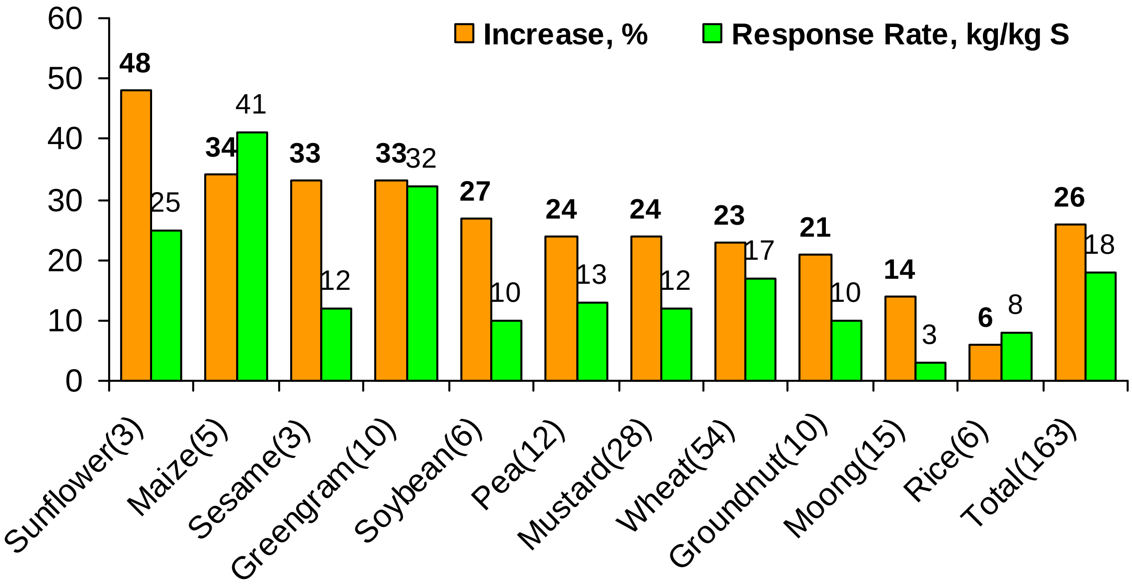


Table 2. Economic Returns to Sulphur Fertilizer in Cropping Systems in India. IFA-TSI-IFA Projects Phase III, 2003/2004 – 2005/2006

Crop Systems	State	Field trials	VCR 1st Crop	Total VCR In Crop system
Raya-Moong	Punjab	15	13	17
Bean- Mustard	Rajasthan West Bengal	9	7	24
Millet -Mustard	Uttaranchal	6	17	68
Millet-Wheat	Rajasthan	3	14	40
Groundnut-Wheat	Rajasthan	3	45	76
Bean-Wheat	Rajasthan	3	30	57
Garlic-Maize	Himachal Pradesh	3	28	39
Onion-Maize	Himachal Pradesh	3	38	59
Rice-Rice	Kerala	6	35	58
Rice-Beans	Kerala	9	31	42
Rice-Sesame	Kerala	6	21	25
Wheat-Soybean	Uttaranchal	3	34	46
Wheat-Rice	Uttaranchal	3	30	34
Total		72	26	45

In recent years, the importance of S in Indian agriculture has become increasingly apparent to Indian governmental policy makers in fertilizer and agricultural industries. The Indian government, recognizing the benefits of S fertilizer in agriculture from extensive S research project, officially approved S as an essential fertilizer nutrient, to be added to the Fertilizer Control Order (FCO), and included the S content of fertilizers as a part of product specifications. Therefore, for all fertilizers containing S listed in the FCO, manufacturers can specify the minimum guaranteed S content for its inclusion and print the S content on the fertilizer bag. This change in the FCO has helped bring S into the mainstream of balanced nutrient application.

Sulphur-Containing Fertilizers

In order to correct the increasing S deficiencies in agriculture and bridge the projected S gaps, there is a need to recognize S as a fertilizer nutrient and increase S fertilizer supply worldwide. The fertilizer industry developed many methods of introducing plant nutrient S into many of fertilizer products for correcting S deficiency and increasing fertilizer efficiency in agriculture.

Many fertilizer materials contain significant quantities of S. It can generally divided into two groups: 1) Fertilizer containing sulphate, and 2). Fertilizer containing sulphur.

Sulphate-Containing Fertilizers

Sulphate-containing fertilizers provide most of the fertilizer S applied to soils. These materials have the advantages of supplying S primarily as a component of multi-nutrient fertilizers in a form of SO_4^{2-},that is immediately available for plant uptake. The most significant and popular sources are Ammonium sulphate (AS), SSP, potassium sulphate, potassium and magnesium sulphate and gypsum. But more new sulphate containing fertilizers are produced for correcting S deficiency through balanced fertilization.

Ammonium Nitrate-Sulphate

Ammonium nitrate sulphate can be produced by neutralizing nitric and sulphuric acids with NH_3; or by granulating ammonium sulphate in the presence of an ammonium nitrate solution. The major grade is 26-0-0-14S in European market. Other specialty grades with differentiated N/S ratios also exist. Ammonium Nitrate-Sulphate has several advantages, including less hygroscopic than either constituent individually, a satisfactory N/S ratio for director application purposes, and a combination of ammonium and nitrate forms of N. It has been very successfully for direct application to forage, grass seed crops, and small grains.

Urea-Ammonium Sulphate

Granular urea-ammonium sulphate has been made by coating ammonium sulphate fines with urea in a granulator and by air prilling. Grades range from 40-0-0-14S to 31-0-0-13S. Urea-ammonium sulphate granules tend to be more resistant to physical breakdown and less hygroscopic than urea prills. The N/S ratio may be varied from 3:1 to 7:1, resulting in considerable flexibility in the correction of N and S deficiencies in most soils. The acid-forming reaction of $(NH_4)_2SO_4$ in soil can reduce urease activity and NH_3 volatilization by reducing pH rising from urea hydrolysis.

Ammonium Phosphate-Sulphate

Ammonium phosphate sulphate (APS) is a complex of ammonium sulphate and ammonium phosphate. The most common grades of ammonium phosphate-sulphate in India are 20-20-0-13 to15S and 16-20-0-13 to 15S. Other products of this type include 13-39-0-20S, 19-9-0-20S, and 23-20-0-7S. They are made by several processes, including reaction a mixture of phosphoric acid and sulphuric acid with ammonia, and introducing ammonium sulphate solutions and H_2SO_4 into a H_3PO_4 reaction circuit.

In 1993, China developed a new technology of producing S-based NPK compound fertilizers using phosphate rock, sulphuric acid, ammonia, urea and potassium chloride as raw materials. This new technology combines all the three technical processes for producing ammonium phosphate, potassium and NPK(S) together, greatly simplifying the production process, and reducing production cost. The major product contains 14.5%N, 16% P_2O_5, 14.5% K_2O, and 11%S ($(NH_4)_2SO_4$ and K_2SO_4).

Potassium Magnesium Sulphate (K_2SO_4 , $MgSO_4$)

Potassium magnesium sulphate is a double salt and contains 18% K (22% K_2O), 11% Mg and 22% S. It has the advantage of supplying both Mg and S and is frequently included in mixed fertilizers for the purpose on soils deficient in these two elements. They are particularly useful when low levels of chloride are desired, as is often the case for crops such as tobacco, potatoes, peach, some legumes and turf grass.

Magnesium Sulphate and Sulphate of Micronutrient

Magnesium Sulphate containing 13% S and 9,8% Mg has limited use as a source of Mg in clear liquid fertilizers and foliar sprays. Significant amounts of S will also be provided when it is used to supply Mg.

Micronutrient sulphate salts are also incidental carrier of S. For example, in the group consisting of Cu, Fe, Mn, and Zn, concentration of S varies between 13 and 21%.

Fertilizers Containing Elemental Sulphur

Elemental S based fertilizers are the most concentrated S carrier. Modern technologies increased their use in direct applications or as additives to N-P-K fertilizers.

Granular Sulphur-Bentonite

A variety of S-bentonite fertilizers have been produced to improve the effectiveness of granular elemental S products by incorporating 5 to 10% by weight of a swelling clay such as bentonite. Particles of S-bentonite are sized for blending with solid N, P and K fertilizers. When it is applied to soil, this bentonite component imbibes soil moisture, causing fertilizer granules to disintegrate into finely divided S, which is more rapidly converted to SO_4^{2-}. This material has gained wide acceptance as a source of plant nutrient S for high analysis, bulk blend formulations because it provide elemental S in an acceptable physical form that can be converted easily in to SO_4^{2-} form in soil.

In Canada, two granular S-bentonite products has put into market. In addition of 10% of bentonite, it contains some ammonium sulphate, and has 60% elemental S, 8% SO_4, and 7% N. The product, containing both SO_4 and elemental S, is designed to provide farmers with immediate and reserve availability of S.

Elemental S Modified N/P Fertilizers

Elemental S can be readily incorporated into N/P fertilizer materials to provide 5 to 20% S. Monoammonium and diammonium phosphates (MAP or DAP) containing from about 5 to 20% S can be made by applying a hydraulic spray of molten elemental S during drum or pan granulation. Recently, a new sulphate and elemental S-enriched MAP fertilizer was developed in North America, containing 15% S, 13% ammonium-N and 33 to 35% of phosphate. This granular fertilizer containing 50% elemental S and 50% sulphate-S provides readily available S for early plant uptake and residual S for later in the growing season. They are excellent sources of N, P and S, and satisfactory for bulk blending with other granular fertilizers or direct application, particularly for topdressing legumes when both P and S are required.

Sulphur enriched SSP, containing 18 to 35% S are popular in some countries, such as Australia and New Zealand. The added S is superior in its residual effect to the $CaSO_4$ already in the SSP. This S-enriched SSP has received attention in the area with high leaching losses of plant nutrients because of its potential for reducing SO_4^{2-} leaching loss and also providing available SO_4^{2-} to meet crop needs during the whole growing season.

Sulphur Coatings

Sulphur coated urea (SCU) fertilizer is formulated for increased efficiency in the use of urea consisting of an S shell around each urea particle. It contains 77 to 82% of urea (36 to 38% N) and 14 to 20% S coating. Although S in the coating may not be sufficiently available to correct deficiencies during the early season of the first year after application, it will become an important source of plant available S in the latter growing season and succeeding year.

Liquid Sulphur Fertilizers

Ammonium thiosulphate solution (ATS) is a popular source of S for use in liquid fertilizers because of its solubility and compatibility with various ions. Fertilizer-grade ATS is in a 60% aqueous solution with a 12-0-0-26S analysis. It is compatible in any proportion with neutral to slightly acidic phosphate-containing solutions or suspensions, as well as with aqueous NH_3 and N solutions, to make a wide variety of N-S, N-P-S, and N-P-K-S formulations. ATS can be applied directly by drip, sprinkler or flood irrigation.

Thiosulphate S exists in two oxidation states, making it more suited to the S uptake patterns of most plants; it decomposes in the soil to form approximately equal amounts of sulphate and elemental S. The sulphate is available immediately whereas the elemental S is gradually converted to sulphate by bacterial oxidation. ATS has gained prominence in North America and is growing in use in Europe, because of its versatility and high S concentration in fluid formulations; and its effect in increasing N efficiency as a urease and nitrification inhibitor.

Conclusions and Recommendations

Sulphur deficiencies have become a major limiting factor to crop production in many regions throughout the world. The S situation can be successfully addressed, but not without accelerated efforts and investment by all crop and fertilizer production stakeholders. Strides have been made in gaining the recognition and the commercial sector is beginning to recognize that not only can plant sulphur requirements no longer be ignored, but that they provide a great market opportunity. However, it is essential that effective S fertilizer policy and strategies are adopted by governments around the world, and that the industry recognize the role that they must play in education, training, and supplying product where it is required. The following must occur:

- Sulphur fertilizer products must be produced and available. In many regions around the world increasing S deficiency is stimulating farmers' demand for S containing fertilizers and a vast market potential for the fertilizer industry to fill this demand. The fertilizer industry needs to take more active strategies, such as 1) more efficiently produce, distribute and use traditional S fertilizers based on their S content; 2) increase production of sulphate/elemental S enriched high analysis NP/NPK compound fertilizers through iincorporation of low cost elemental sulphur; 3) increase use of micronized elemental S or elemental S enriched compound fertilizers in bulk blended fertilizers. To meet increasing demand for S in agriculture and balanced fertilization technology, increasing S fertilizer production and accelerating commercialization of S products will provide significant benefits to both fertilizer manufacturers and farmers;
- Governments and regional authorities will need to ensure that their fertilizer policies, at a minimum, do not impose obstacles on S fertilizer manufacturing and application, and more importantly are proactive to ensure that S is easily accepted in fertilizer regulations and crop S fertilizer recommendations are in place;
- Education, training and promotion will need to be implemented by all sectors, including government extension agencies, and fertilizer manufacturers and dealers;
- Sulphur needs to be included in fertilizer supply and consumption statistics by all government and industry associations producing fertilizer statistics.

Finally, S must take its rightful place as a major plant nutrient alongside N, P, and K by all stakeholders in balanced fertilization for higher productivity and fertilizer efficiency.