

Agricultural Demand for Sulphur – The Challenges, The Future

TFI– FIRT’s Outlook and Technology Conference

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The Sulphur Institute**

Savannah, Georgia

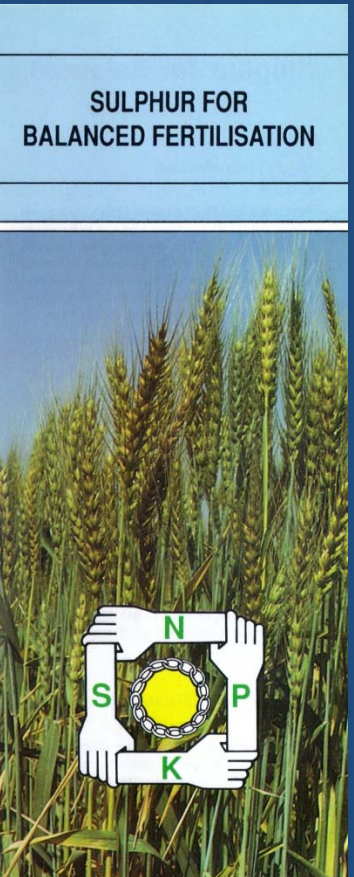
November 19, 2014

Sulphur in Agriculture: Raw Material and Valuable Nutrient

- Sulphur is not only a raw material to produce phosphate and ammonium fertilizers, it is an essential nutrient:

Deficiencies are increasing with:

- Reduction in traditional S-containing materials
 - Cleaner air programs
 - Intensified agriculture increasing crop demand
- Sulphur is gaining prominence as a major nutrient with N-P-K.




A Question:

- Nitrogen, phosphorus and potassium are established large-volume materials in agriculture. What nutrient remains holding the largest potential volume in consumption for the fertilizer industry?

Sulphur: A SECONDARY NUTRIENT? NOT ANYMORE!

Sulphur deficiency was rare in European crops until about two decades ago. However, with the rapid decline in S deposition from the atmosphere due to controls on acid rain, the situation is changing rapidly. Today, sulphur has become one of the most limiting nutrients for agricultural production in many countries in Europe as it also has in the Indian Subcontinent and in South East Asia. In Australasia, sulphur has been known to limit crop production for a long time while in North America crop responses to sulphur application are increasingly reported. A recent conference on sulphur organized by the International Fertilizer Society (IFS) provides a very timely




David Nelson

Sulphur (S) is one of the oldest elements known to man. It is the 16th most abundant element in the earth's crust. Its deficiency was first detected in Iceland in the 1970s, and has since spread to many crops of oilseed rape and later cereals in Europe. In fact, England in the 1990s, S deficiency developed in cereals in Germany and the UK.

AN ELEMENT CRUCIAL TO PROTEIN SYNTHESIS

Some people may have only recently discovered the role of sulphur as a major plant nutrient. However, the fundamentals have never changed: sulphur is essential for the production of cysteine & methionine, two amino acids that in turn are the building blocks in the synthesis of many proteins. All enzymes require S, including RuBisCO (the C3D fixation). It is essential to chlorophyll synthesis (although not a constituent of chlorophyll), enters in the composition of vitamins (notably B₆, biotin and thiamine in vitamin B1), it is required for some lipids in membranes. If it is involved in some redox reactions in the soil



Sulphur deficiency (chlorosis) in corn plants in the Netherlands. Photo: J. J. van der Meer

Stilling of the larger pool. However, plants, atmospheric concentration

Our Mission:

- TSI is the global advocate for sulphur, representing stakeholders producing, buying, selling, handling, transporting, or adding value to sulphur.



Members of The Sulphur Institute

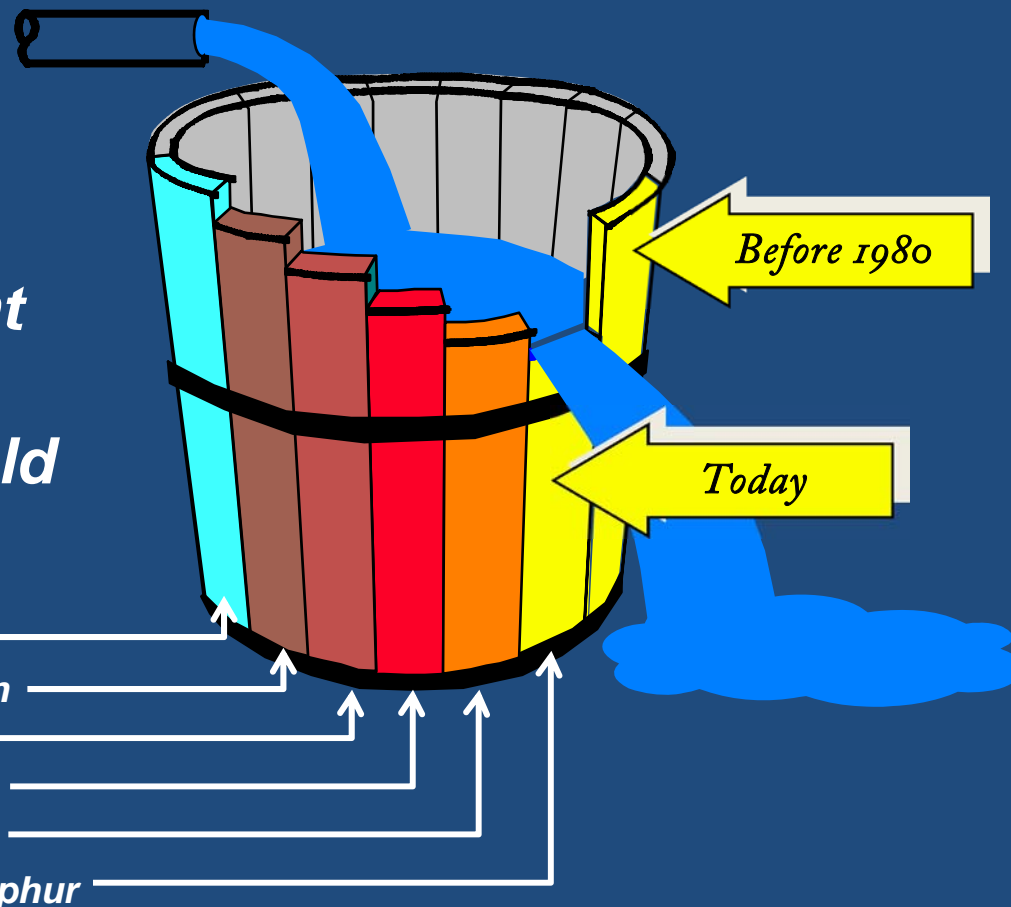
Blue Sky Agrisource, LLC
BP Products North America, Inc.
California Sulphur Company
Chemtrade Logistics
Chevron
CITIS SA
Con-Sul Inc.
CTI Consulting, LLC
Devco USA LLC
Dillon Transport
Enersul Inc.
Etihad Rail
ExxonMobil Corporation
Franz Fischer Spedition GmbH
GATX Corporation
H.J. Baker & Bro., Inc.
Importadora Santa Alicia Ltda. (ISA)
Inter-Chem
Jupiter Sulphur L.L.C.
Koch Sulfur Products Company LLC
Martin Operating Partnership, L.P.
Mitsubishi Corporation
Mitsui & Co. (U.S.A.), Inc.
Occidental Petroleum Corporation

Oxbow Sulphur Inc.
Phillips 66
PotashCorp
Primary Resources Inc.
Sandvik Process Systems
Savage Services Corporation
Schiber Truck Company
Shell Sulphur Solutions
Shrieve Chemical Company
solvadis commodity chemicals GmbH
Sultran Ltd.
Sulvaris
Suncor
Tessengerlo Kerley, Inc.
The Mosaic Company
TradeCorp
Trammo, Inc.
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Sulphur Deficit: Limiting Crop Yield in Agriculture; Creating Market Potential for Fertilizer Industry

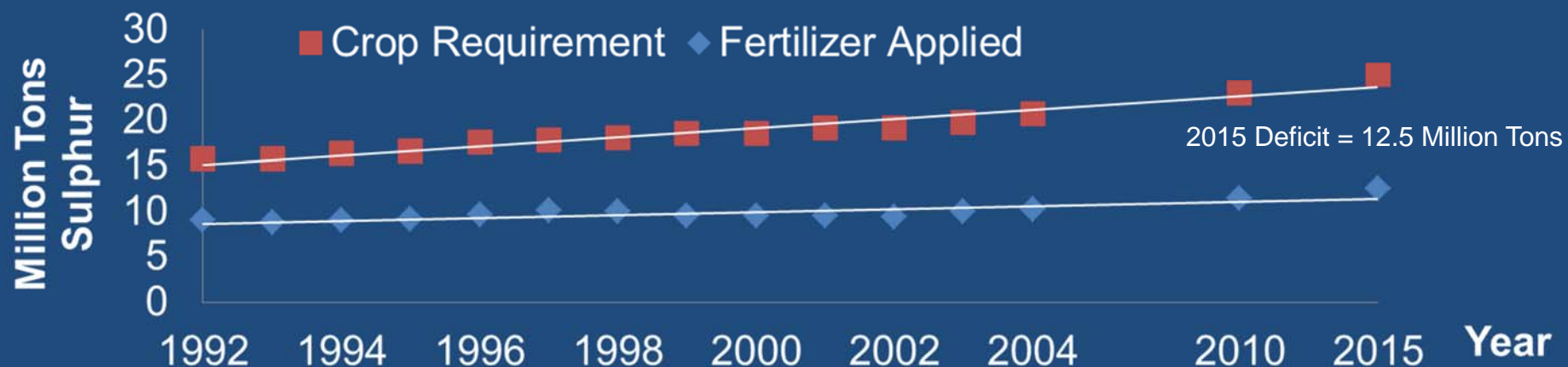
Water height
=
Achieved Yield

Climate, soil, water
Phosphate and Potash
Magnesium
Micro Nutrients
Nitrogen
Sulphur



Sulphur Deficit and Requirement: Global

Plant Nutrient Sulphur Requirement and Deficit



- Sulphur is the fourth major nutrient, required in similar amounts as P, about 20.6 million tons S in 2010.
- 10 million tons S applied worldwide
- An additional market potential for 10.6 million tons S exists today, mainly in Asia and the Americas.

Regional Plant Nutrient Sulphur Deficit Worldwide

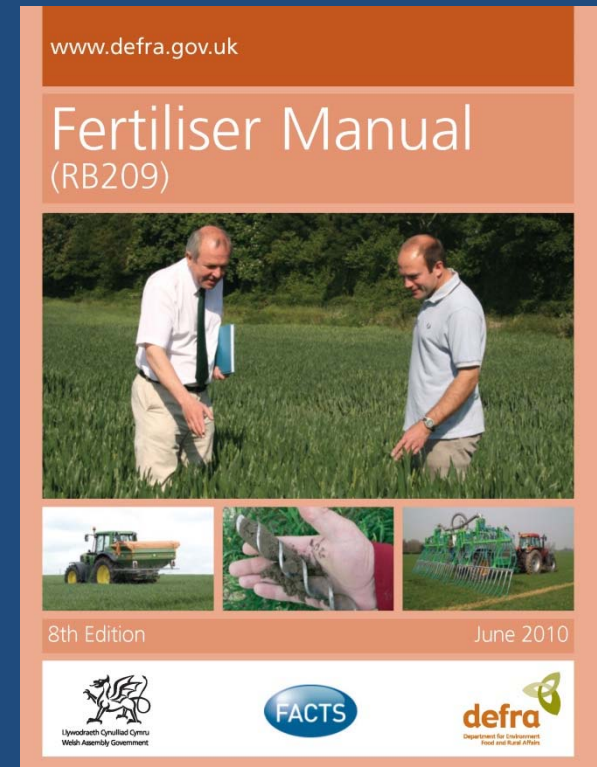


The European Situation

- Due to emission controls in the last ten years, sulphur deposition in West Europe has dropped below the requirements of many crops.
- Coupled with the earlier change to low sulphur fertilizers, heavy leaching loss and intensive crop production resulted in decreasing soil sulphur fertility status.
- For example, in the UK about 50% of the land area has high or medium risk of sulphur deficiency for winter wheat and rape.
- Crop responses to sulphur fertilizer are now common in most countries in West Europe.

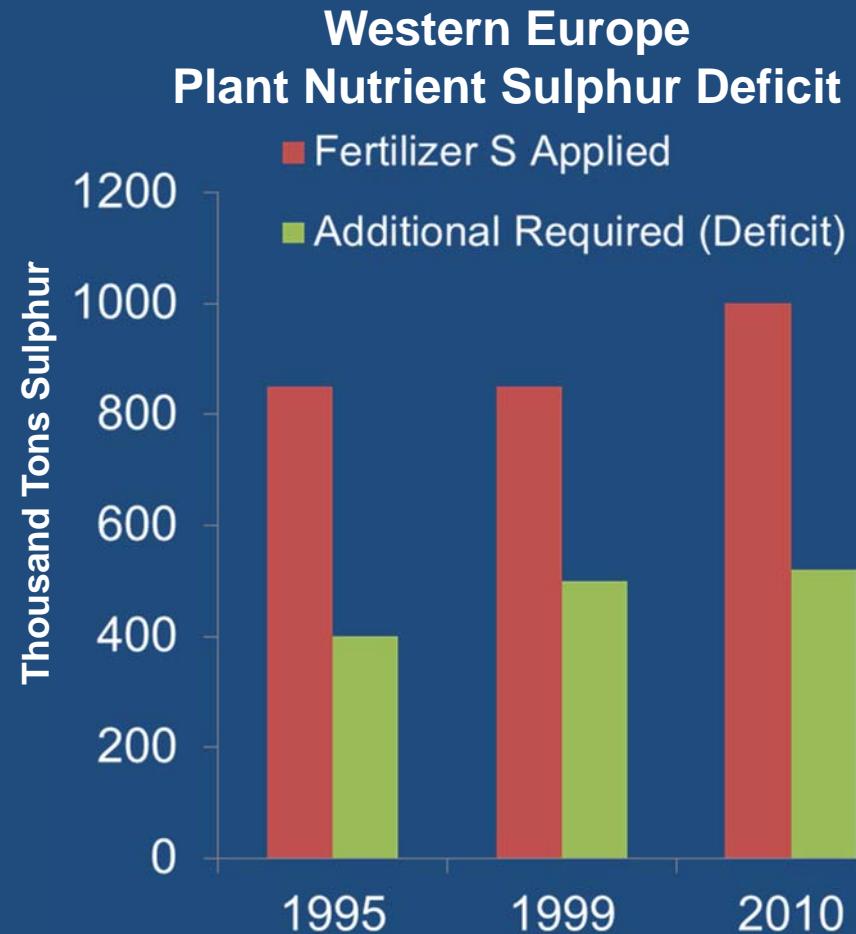
The European Situation

- Sulphur fertilizer increased cereal grains yield ranging from 10% to 30% and from 20% to 40% on oilseed crops. Crop quality and economic returns of fertilizer are also improved.
- New Sulphur Fertilizer Recommendation for optimal yield:
 - Oil crops 20 to 40 lbs S/acre
 - Legume Crops 20 to 30 lbs/acre
 - Cereals 20 to 35 lbs/acre



Direct Impact of Market Development on the Western European Sulphur Fertilizer Market

- **Ammonium Sulphate consumption: about 750,000 tons S/year**
- **UK recommendation change increased S fertilizer rate: 100,000 tons S/year**
- **Sugar beet campaign: 115,000 tons S/year**



The European governments and fertilizer industry recognize the need...



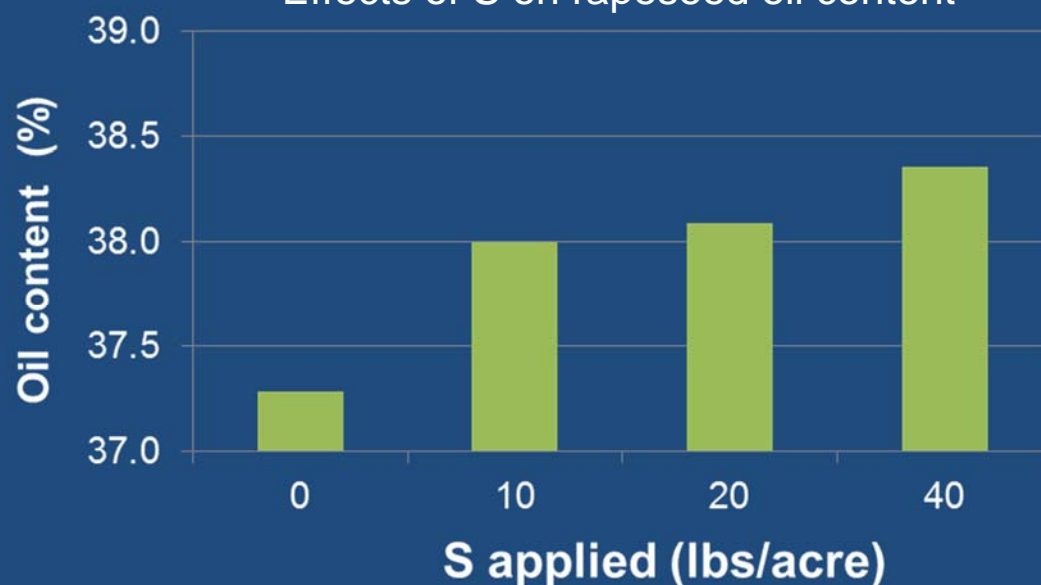
- 16 countries
- 25 products
- 500,000 tons S consumed annually
- France, Germany and Spain represent the largest diversity of companies and products involved, including micronized, sulphur bentonite, liquids, sulphate carriers and compounds with S
- Increase of oilseed rape production for biofuel increases S fertilizer demand

Sulphur Fertilizer Effect on Crop Quality

- Sulphur Fertilizer Effect on Synthesis of Oil:

- Sulphur fertilization increased oil content of rapeseed oil content in the UK by 3.02%

IACR, Rothamsted Research Group, UK
Effects of S on rapeseed oil content

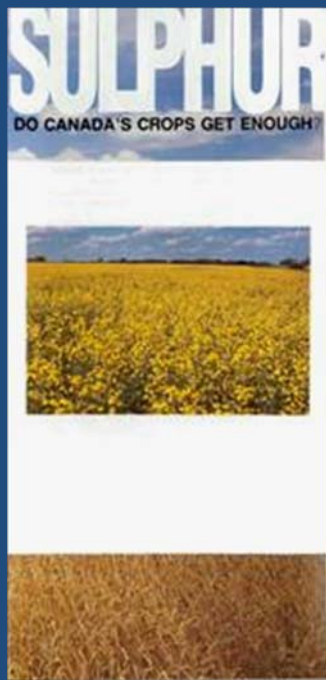


North American Situation



- The U.S. Clean Air Act is impacting crop sulphur requirements
- Today, significant areas of the southern and northwestern United States have sulphur recommendations.
 - Mid-Atlantic 20 to 40 lbs/acre
 - Southern states 10 to 20 lbs/acre
 - Forages 25 to 50 lbs/acre

North American Situation



- In Canada, canola frequently has yield increases ranging from 10% to 40% and from 10% to 30% on other crops, with some variance depending on province.
- Common sulphur recommendations include:
 - Non-Irrigated Oil and Legume Crops 40 to 50 lbs/acre
 - Irrigated Legume Oil and Crops 20 to 60 lbs/acre
 - Cereals 15 to 30 lbs/acre

Sulphur Fertilizer Market in North America



- Current consumption about 1.6 million tons S annually.
- New sulphate and elemental S fertilizers are coming on the market.

Latin American: Another Big Sulphur Fertilizer Market



- Agricultural production recovery driven by strong demand for food and biofuel: soybean, corn and sugarcane
- S fertilizer requirements increase to 2.6 million tons S, second biggest market only to Asia
- S fertilizer consumption increases to 1.8 million tons
- Still large deficit
- More sulphate and ES fertilizers come to market also ammonium thiosulphate

Australia and New Zealand

Widespread S deficiencies resulted in the development of a wide range of crop and pasture S-containing fertilizers.



Fertilizer manufacturers have introduced new products to meet the increasing demand of S containing NP or NPK compound fertilizers or ES enriched N, P, and NPK fertilizers based on specific crop and soil needs.



The Indian Situation

41% and 36% of Soil Samples (26810) in 11 States in India are Sulphur Deficient or Potentially Deficient

States Name	Samples	Sulphur Deficient <10 ppm	Potentially Deficient 10 to 20 ppm
Andhra Pradesh	1650	54%	36%
Uttar Pradesh	6090	50%	38%
Maharashtra	845	46%	26%
Bihar	1409	43%	30%
West Bengal	4500	42%	34%
Karnataka	1879	39%	32%
Madhya Pradesh	2005	35%	51%

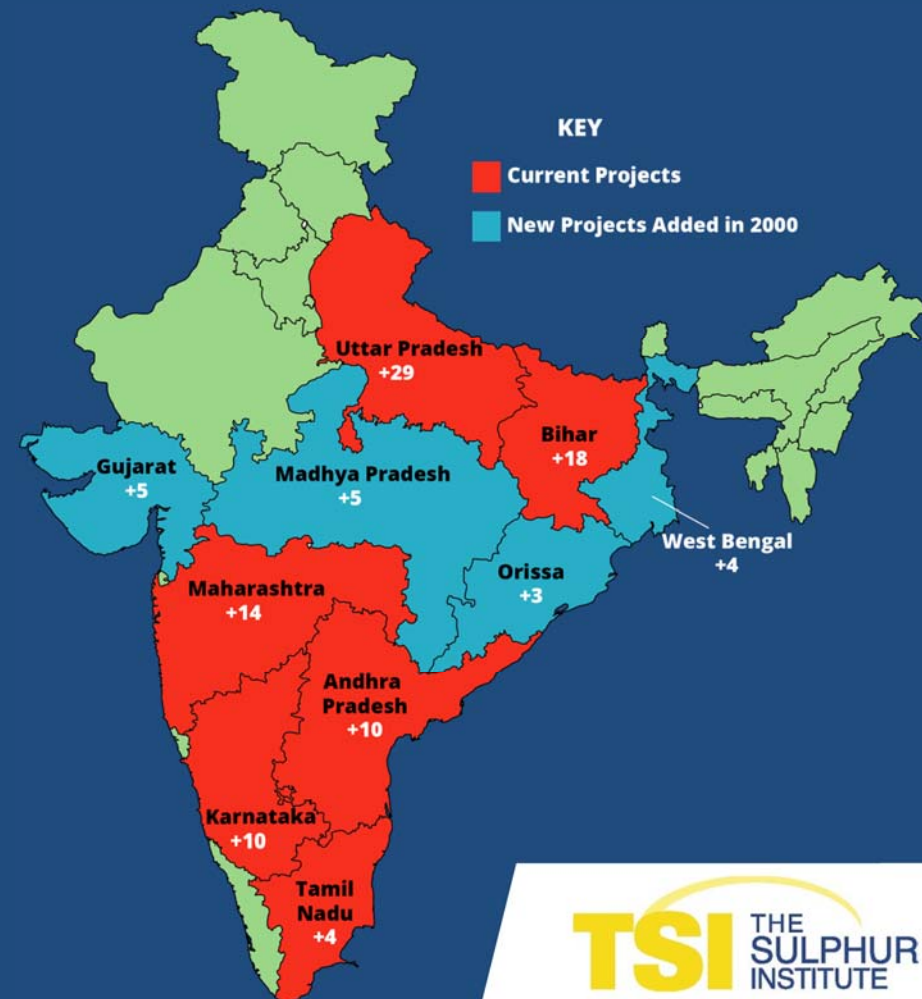
Indicators

- At least 168 million acres, or 40% of India's arable land suffers from varying degrees of S deficiency
- Crop responses to S fertilizers were documented in the major agricultural states



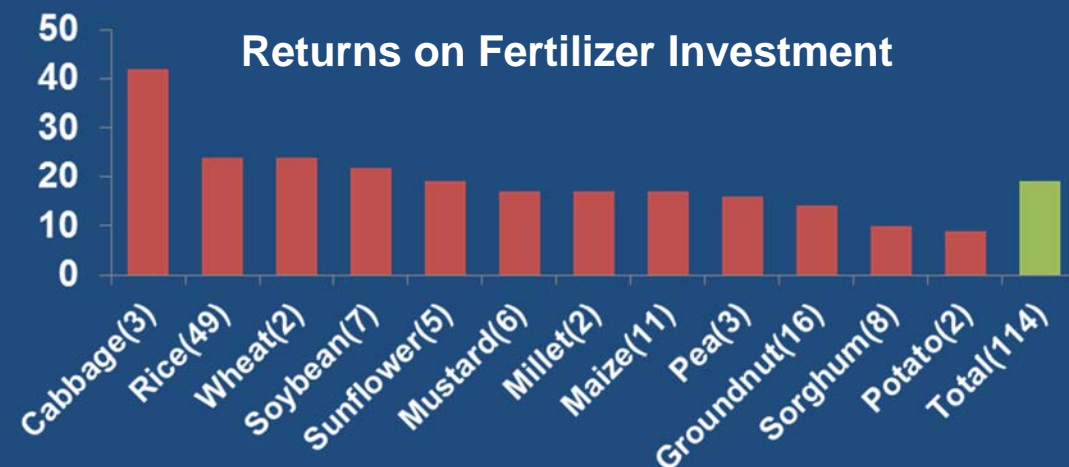
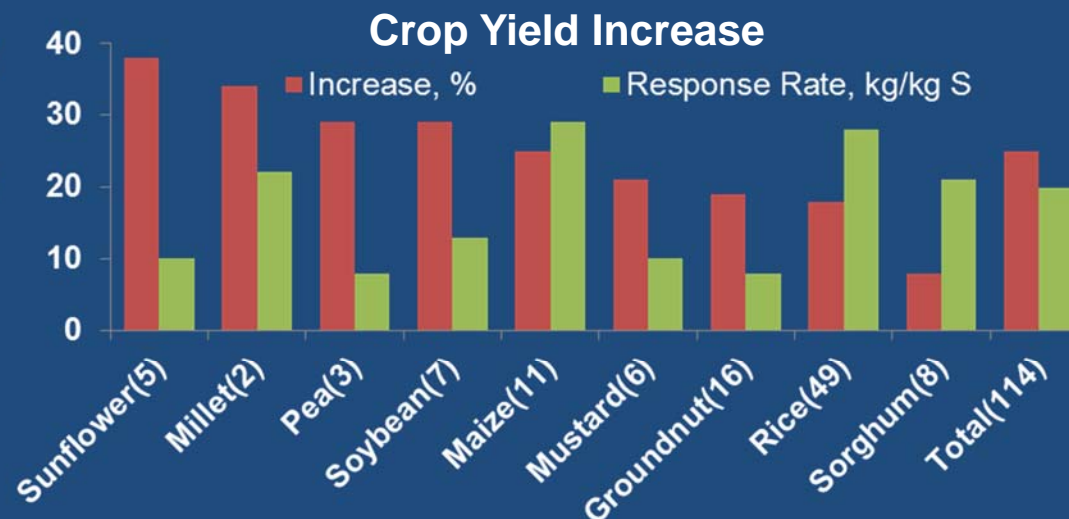
TSI-FAI-IFA Project: Summary

- Network of 22 institutes in 11 states:
 - Andhra Pradesh (A.P.)
 - Bihar
 - Chhattisgarh
 - Gujarat
 - Karnataka
 - Madhya Pradesh (M.P)
 - Maharashtra
 - Orissa
 - Tamil Nadu
 - Uttar Pradesh (U.P.)
 - West Bengal

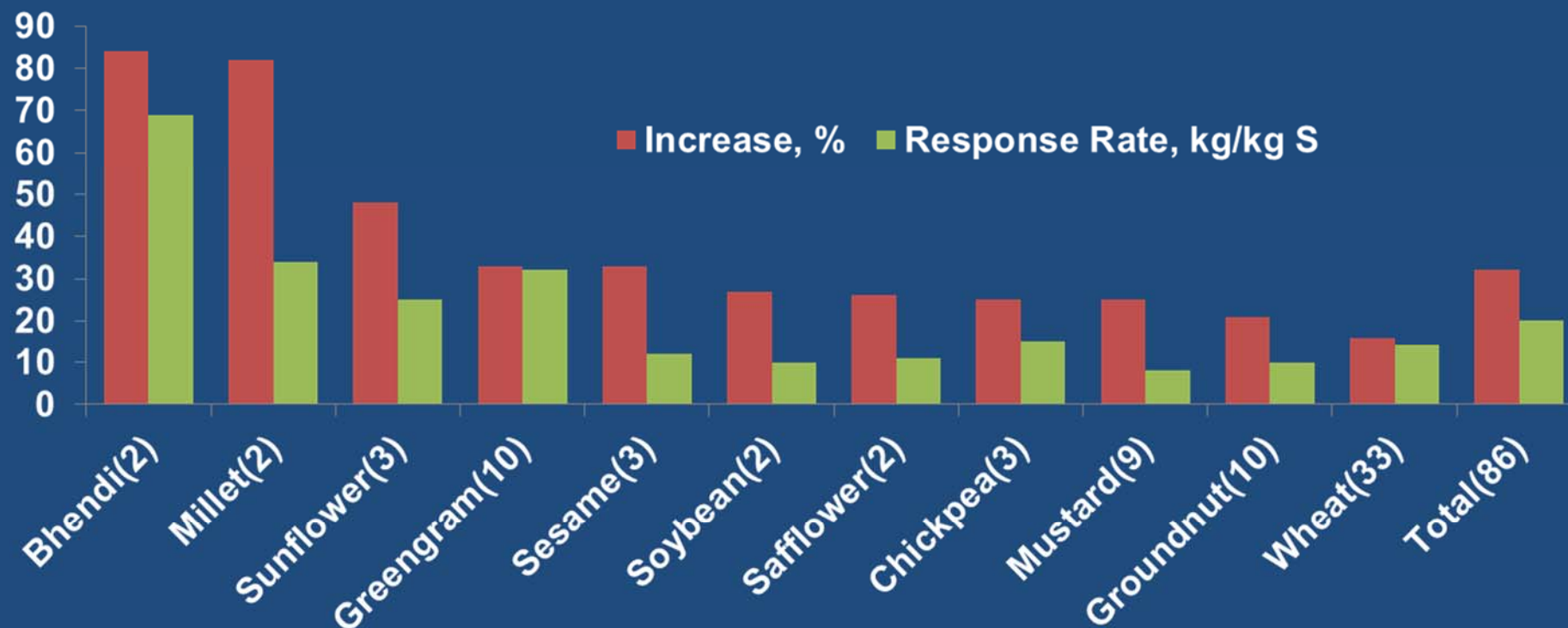


Crop Responses: 1998-2002, Kharif

- A total of 114 field trials were completed in 46 sites on direct sulphur fertilizer effect in Kharif season
- Yield increases up to 38% with greatest responses in oil crops followed by field crops
- Return on fertilizer investment (VCR) ranged from 9 for potato to 42 for cabbage (VCR of 2 to 2.5 usually results in a fertilizer recommendation)



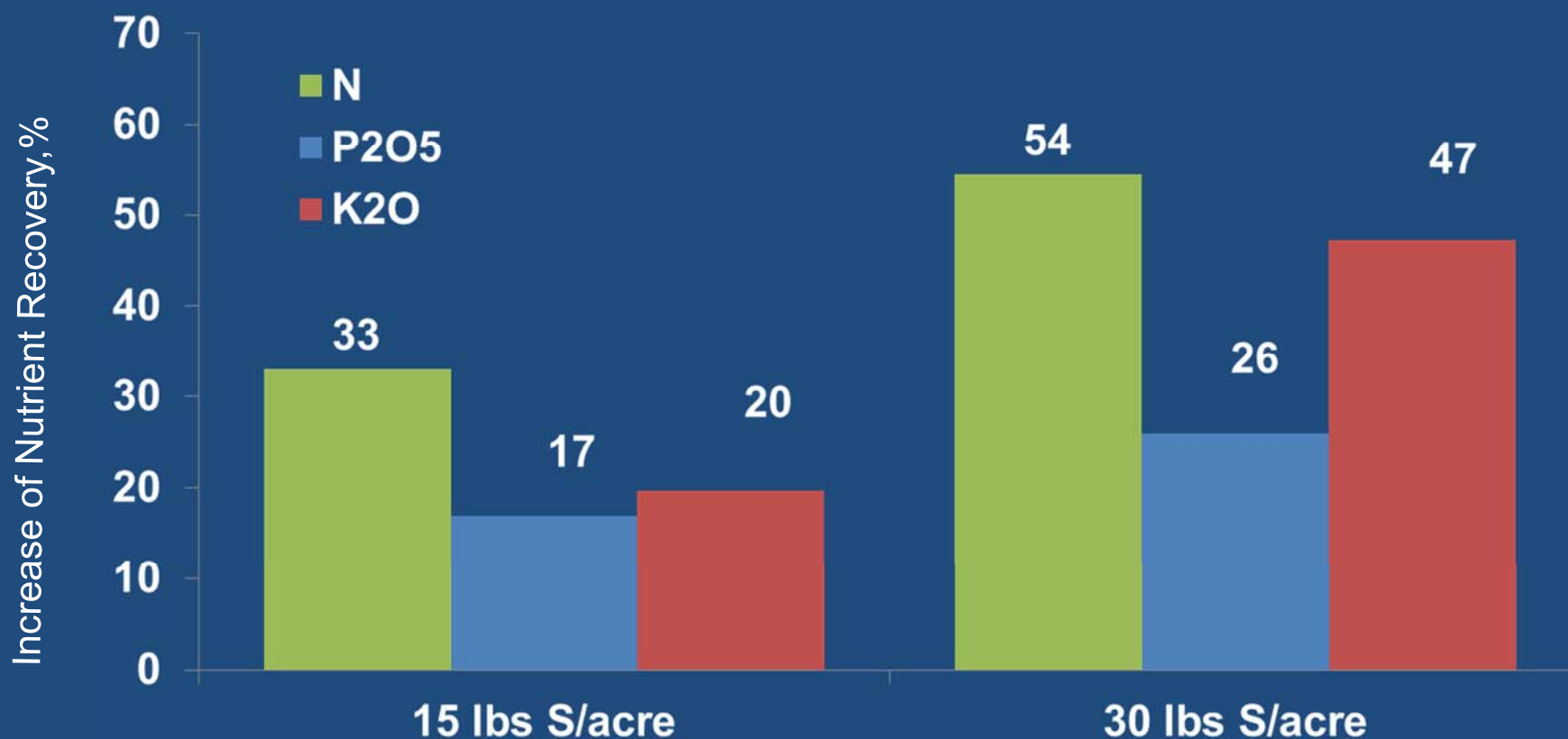
Residual Effects of Sulphur Fertilizer: 1998-2002, Rabi



- 86 field trials were completed on residual sulphur effect in Rabi season
- Yield increases up to 84% with greatest responses in oil crops again followed by field crops

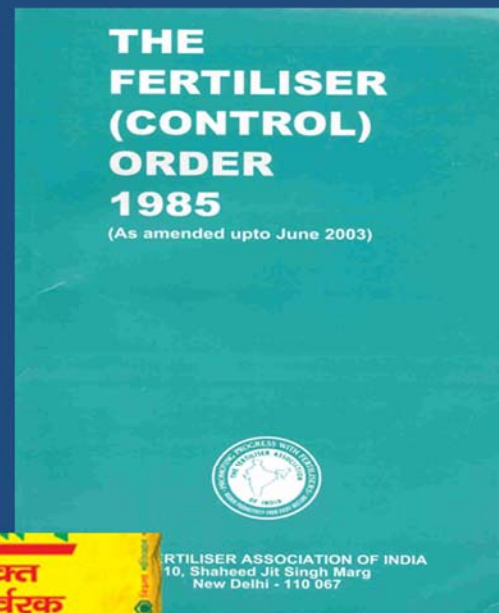
Sulphur Fertilization Increased NPK Fertilizer Nutrient Recovery in Rice-Groundnut Cropping System

(Kasarda, Orissa, 2001)



Formal Recognition of Sulphur – A Big Step for India

- TSI's foundation work and recent TSI-FAI-IFA cooperative project successes have brought sulphur recognition, convincing the GOI Central Fertiliser Committee that inclusion of sulphur is warranted in the FCO. As of June 2003, the industry is now permitted to market the sulphur in listed fertilizers and print sulphur content on fertilizer bag.



Achievements and Benefits from the Project

- Base of information established
- Scientific community supports sulphur fertilization
- Government recognition of sulphur importance by writing it into FCO
- Industry awareness and activity increasing



India: Great Potential, Great Progress, and Great Task

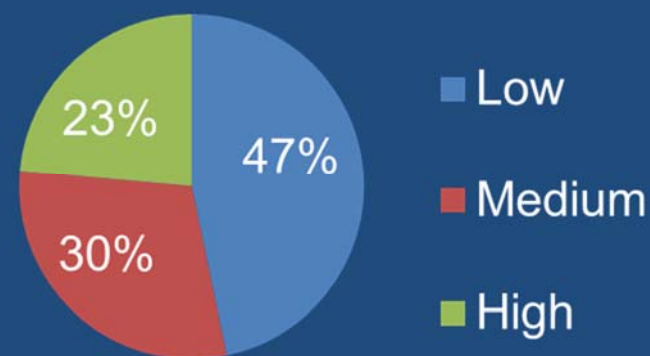
- Limited sulphur fertilizer production in India – 650,000 tons per **year...doesn't touch potential**
- Current deficit: 1.6 million tons sulphur deficit growing to 2.2 million tons by 2015



Achievements and Benefits from the TSI-FAI-IFA Project

- Base of information established: Severe S deficiency with 46% of S deficient and 30% of potential deficient soils,
- S fertilizer increased crop yield by average 29%, ranged from 10% to 60% in over 200 field trials
- Government recognition of sulphur importance by including it into FCO and fertilizer subsidy system
- Industry awareness and activity increasing

All India (49,194 samples)



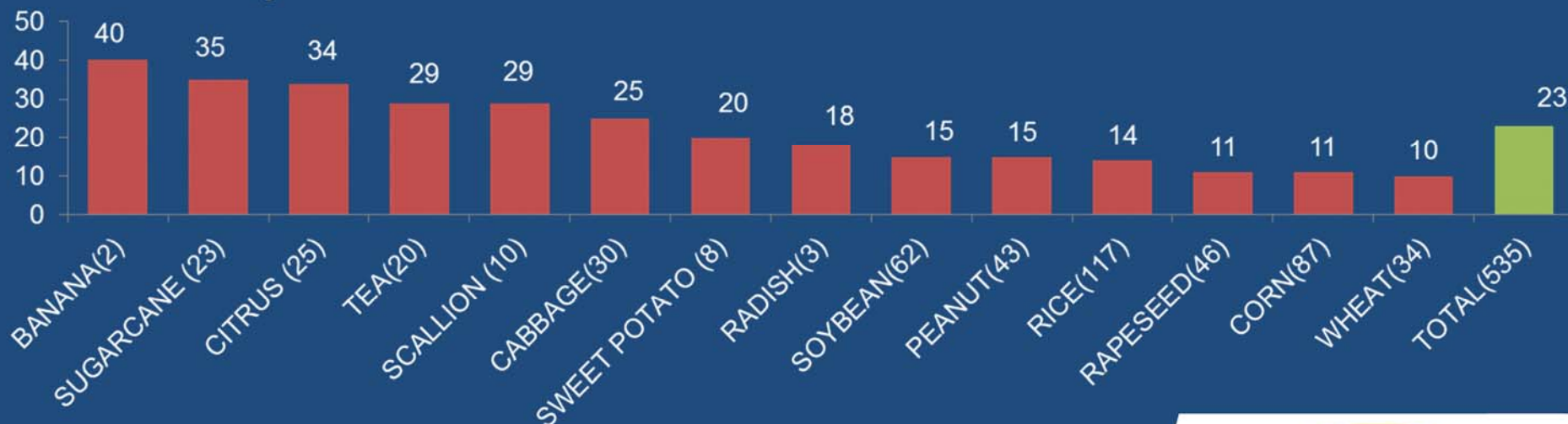
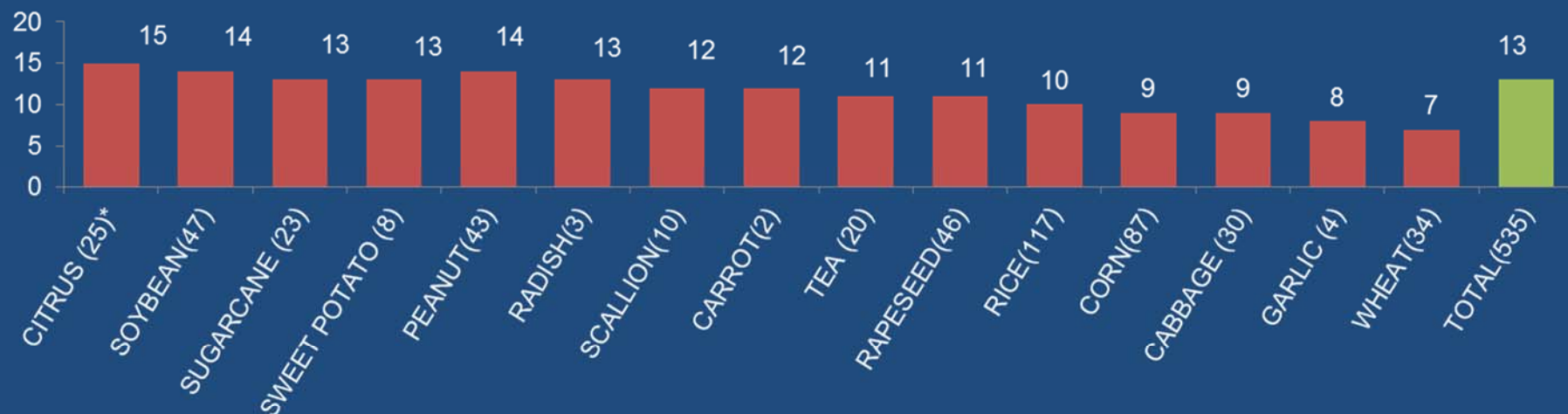
The Chinese Situation

- Sulphur deficient area: 30% of arable soil, eq. about 95 million acres
- Sulphur deficit in 2010: 2.0 million tons S projected to increase to 2.6 million tons in 2015



Crop Responses to Sulphur Fertilizer: TSI Projects in China

Average Economic Returns on Fertilizer Investment: 23 to 1 (Value : Cost Ratio)



Average Crop Yield Increase: 13%

New Sulphur Fertilizers Market Emerge in China

- Single Superphosphate (SSP) adds about 3 million tons of S annually, representing most S applied to soils.
- S-based NPK output has grown exceeding 10 Mt of product.
- New ES based compound fertilizer productions are coming to the market, including tons Sulphur-Urea (15%S), and tons SCU (15 to 20%S).
- ...and here comes the ammonium sulphate.



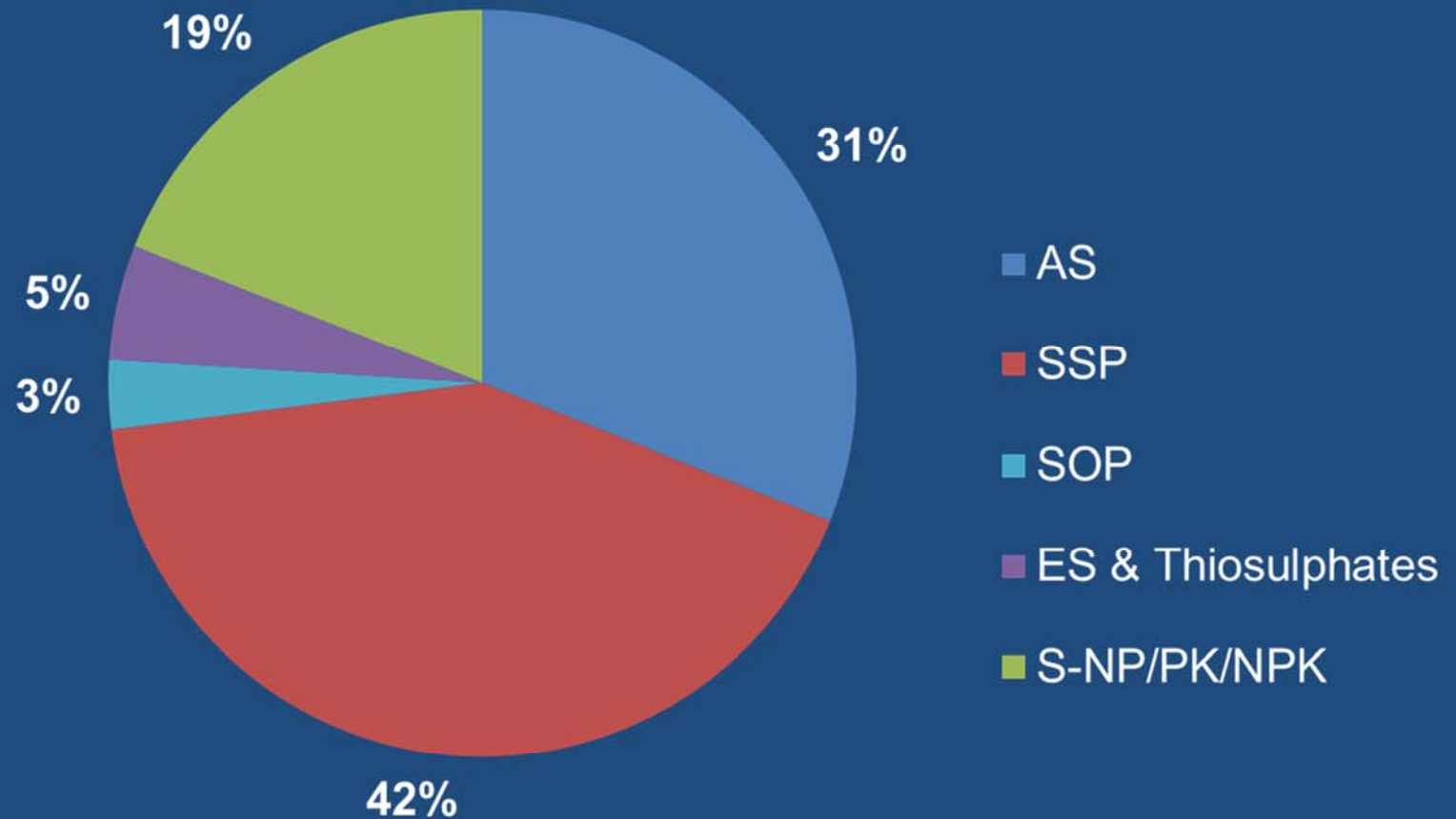
World Plant Nutrient Sulphur Deficit and New Market Potential for Sulphur Fertilizer

**Current Application:
10 Million Tons S**

**Estimated World Annual
Plant Nutrient Sulphur
Deficit In 2015:
12.5 Million Tons S**



Traditional Sulphur Fertilizers Take Major Market Share (2010)



But, new products are emerging and growing in volumes!

Fertilizers Containing Sulphate

- **Traditional:**
 - Single Superphosphate (0-16-0 12S)
 - Ammonium Sulphate (21-0-0 24S)
 - Potassium Sulphate (0-0-50 18S)
- **Emerging:**
 - Ammonium Phosphate-Sulphate (20-20-0 15S)
 - Potassium Magnesium Sulphate (0-0-27 22S)
 - Various Micronutrient Sulphate Salts
 - Ammonium Nitrate-Sulphate (26-0-0 14S)
 - Sulphate-NPK compound fertilizers (15-16-15 11S)
 - Urea-Ammonium Sulphate (40-0-0 9S)

Ammonium Sulphate (21-0-0 24S)

- **World Output in 2010: about 18 Mt, eq. to more than 4 Mt S, most is by-products from caprolactam production in synthetic fiber industry and coke oven gas from steel industry**
- **Most (3.3 Mt S) directly used in Asia, America, and West Europe, but increasing use in blending or manufacture of NP/NPK fertilizers**
- **Market opportunities in Central Europe, FSU, America, and Asia**



Single Superphosphate (0 - 12 to 22-0 10 to 14S)

- World output exceeds 5 Mt S, mostly in China, Brazil, India, Australia and New Zealand. The SSP market is relatively stable with tendency to decline in recent years, except Brazil.
- Reduction of future market of SSP will require more S addition from new sources



Sulphate of Potash (SOP)

(0 – 0 – 50 18S)

- World output now exceeds 4 Mt, eq. 0.8 Mt S, mostly in Western Europe, China, and USA.
- Both demand and production will grow, mostly in China.



Ammonium Nitrate-Sulphate

(26-0-0 14S)

- Made by granulating AS with AN or neutralizing H_2SO_4 with NH_3 in AN solution.
- Less hygroscopic, with a satisfactory N/S ratio, and a combination of ammonium and nitrate forms of N; and sulphate form of S.
- Market is growing in Europe and North America.



Sulphate Containing Compound Fertilizers

- Sulphate Containing Compound Fertilizers can be produced by the mixed acid route (nitric/phosphoric, and sulphuric /phosphoric acid) with flexible ratios of N:P:S.
- Major production: Europe and N. America at about 0.2 million t/a S.
- S-based NPK compound fertilizer production in China has grown significantly in recent years.

Elemental S: Emerging Fertilizer Product and Market

- Elemental Sulphur
- Micronized Granular Elemental Sulphur
- Elemental Sulphur Enhanced/Enriched Nitrogen/Phosphate Fertilizers
- Sulphur Coated Fertilizers



Improving Fertilizer Efficiency

- Elemental sulphur (S^0) is a slow release fertilizer because it is water insoluble.
- Must be oxidized by microbes to SO_4^{2-} to be available for plant uptake.
- Ideal where SO_4^{2-} leaching is serious.
- Most concentrated S-fertilizer with lower transportation, handling, and storage costs.
- Beneficial reactions in soil improve major nutrients efficiency to plants.



Granular Dispersable Elemental Sulphur (90 to 99% S)

- Dispersible in soil and water, releasing finely micronized S particles (40 to 150 μm), effectively converted into sulphate by soil microorganisms in the early growing season.
- Season long S supply with minimized risk of leaching loss.
- Increases in production and marketing in America (N+L), Europe, Oceania, Asia, and Africa.

Elemental Sulphur Enriched Nitrogen/Phosphate Fertilizers

- Liquid S is added into NP or NPK fertilizer product with various technologies to provide 5-20% S.
- New ES enriched fertilizers: Sulphate and ES enriched MAP; ES enhanced DAP; ES-enriched SSP.
- Increases in production and marketing in N. America, Europe, Oceania and Asia.

Elemental Sulphur Enriched Nitrogen/Phosphate Fertilizers

- Sulphur-Coated Urea (SCU) and compound fertilizers: Slow or controlled release S and other nutrients
- Sulphur Coated TSP; DAP/MAP
- New products made by coating urea with micronized S using binders
- Huge market potential: >1 million tons S



Fertilizer Containing Other Forms of Sulphur (in Solution)

- Ammonium Thiosulphate (12-0-0 26S)
- Ammonium Polysulphide (20-0-0 40S)
- Potassium Polysulphide (0-0-22 22S)
- Potassium Thiosulphate (0-0-25 17S)

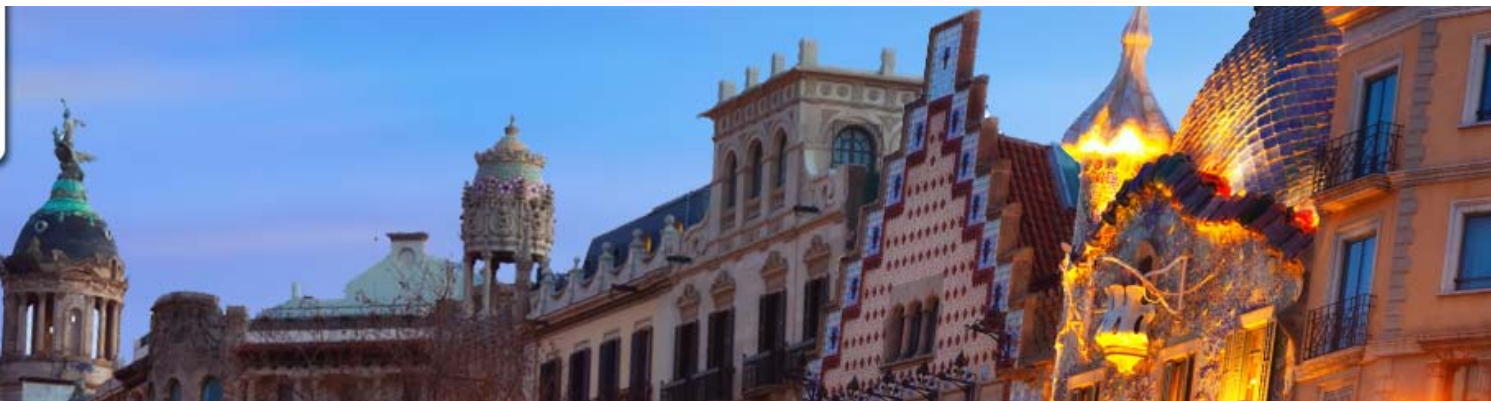
Thiosulphate fertilizers have gained prominence in North America and is growing in use in Europe and Latin America.



Sulphur Fertilizers: New Ground for Fertilizer Industry

- Current production will not meet increasing demand.
- Sulphur fertilizers provide potential market of 10 million tons of sulphur consumption annually.
- Fertilizer producers need to address this new market potential:
 - Product choice/Promotion of new sulphur fertilizer production and use, including elemental sulphur based new fertilizers.





TSI's Sulphur World Symposium 2015

**April 20 – 22, 2015
Barcelona, Spain**

For more information on TSI programs please visit:

www.SulphurInstitute.org/symposium15