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Aspects of sulfur nutrition of plants : evaluation of China's current, future and available resources to correct plant nutrient sulfur deficiencies - report of the first Sino-German Sulfur Workshop

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Aspects of sulfur nutrition of plants; evaluation of China's current, future and available resources to correct plant nutrient sulfur deficiencies - report of the first Sino-German Sulfur Workshop

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Abstract

Sulfur is an essential plant nutrient that must be supplemented through fertilizer application when quantities in the soil are insufficient or when other natural inputs are not available. Besides just being involved in producing yield, sulfur-containing compounds are responsible for numerous aspects of crop quality and the natural resistance of plants. As a result of increasing crop yields and removal, growing use of sulfur-free fertilizers and increased attention to air quality standards leading to continuing reductions in atmospheric sulfur contributions, the need for the application of plant nutrient sulfur is accelerating in China. In order to stimulate networking between plant sulfur-related research initiatives in China and Germany, the first Sino-German Workshop on "Aspects of sulfur nutrition of plants; evaluation of China's current, future and available resources to correct plant nutrient sulfur deficiencies", was held on May 24-29, 2004 in the Institute of Applied Ecology, Shenyang, China. During the workshop the China's current, future, and available resources to correct plant nutrient sulfur deficiencies were evaluated.

Keywords: Crop yield, crop quality, food quality, Sulfur deficiency, sulfur fertilization, sulfur metabolism, sulfur nutrition

Introduction

Sulfur is one of the mineral elements essential for plant life. Starting from the amino acid cysteine (Cys), higher plants synthesize a complex spectrum of S compounds with diverse physiological functions. Among these are the tripeptide glutathione (GSH), which is central to the response against abiotic stressors (reactive oxygen species, heavy metals). In addition, there are several sulfur-containing pathogen-directed defense compounds: Glucosinolates as secondary S metabolites, rich pathogenesis related (PR) proteins of the thionin-type, and H_2S released from Cys. As activated sulfate (APS) and Cys are also basic components of primary metabolism and structural compounds (sulfolipids, proteins), plants had to develop strategies to reconcile S availability and S demand during plant development with the requirements of different stress responses. A major goal of the recent research carried out by a DFG research group in Germany is to develop a model for the coordination of S assimilation with the synthesis of GSH, glucosinolates, S-rich defense proteins and H_2S, using an integrated approach based on the tools of molecular physiology and cell biology. The comparative approach with plants of different physiotype (*Arabidopsis thaliana, Brassica napus/juncea, Populus tremula/alba*) will allow to address general and species-specific mechanisms, in particular the role of a luxuriant secondary metabolism (glucosinolates) and the impact of different growth patterns (herbaceous versus non-herbaceous). The use of transgenic plants with changed expression of single genes will allow to assess their contribution to the overall stress response. The integration of field experiments will help to evaluate the relevance of S nutrition-mediated defense reactions for resistance under field conditions.

China accounts for one-fifth of the world population, but has only 7% of the world's agricultural land mass. Thus, the country faces a significant challenge to meet food demands for its 1.3 billion inhabitants. China's economic and agricultural policies have changed dramatically over the last 20 years. Seeking to expand its agricultural sector, China has increased importation of fertilizers as well as increased domestic production. Chinese consumption of the three major nutrients nitrogen (N), phosphorus (P), and potassium (K) has expanded significantly at annual growth rates averaging 4, 7, and 10 percent, respectively. Concurrently, agricultural production has made considerable gains. As N, P, and K demands have been increasingly met, deficiencies of other nutrients have arisen and sulfur has become of increasing interest since it is typically required in quantities ranking fourth behind N, P, and K.

This paper reports on the objectives, presentations and topics of the first Sino-German Workshop on "Aspects of sulfur nutrition of plants; evaluation of China's current, future and available resources to correct plant nutrient sulfur deficiencies", May 24-

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29, 2004, Institute of Applied Ecology, Shenyang, China.

Objectives of the workshop

The goals of this workshop were:

- To discuss fundamental, agronomic and environmental aspects of sulfur in higher plants, to promote and better coordinate sulfur-related research in plants.
- To stimulate networking between plant sulfur-related research initiatives in China and Germany.
- To provide optimal training of young scientists (PhD students, post docs, junior group leaders) in a complex research field with state-of-the-art approaches in physiology, biochemistry and molecular biology of plants.
- To evaluate China's current, future, and available resources to correct plant nutrient sulfur deficiencies through the next 10 years.

List of speakers and participants (within groups alphabetical order):

The delegates came from German universities in Braunschweig, Frankfurt, Hanover, Hamburg, Mainz and Groningen, The Netherlands. Scientists from the Max Plank Institute and the German Agricultural Research Centre participated. The Chinese delegates came from the Institute of Applied Ecology, CAS, the Institute of Soil Sciences, CAS, the Chinese Academy of Agricultural Sciences, Jiangxi Academy of Agricultural Sciences, Tianjin Academy of Agricultural Sciences and Anhui Agricultural University. Scientists from The Sulfur Institute, Washington, DC, also participated in the workshop.

Speakers from Germany:

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Speakers from the German DFG-Research Group 383 (Sulfur metabolism in plants):

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Foreign speakers

Dr. Ming Xian Fan, TSI, Washington, E-mail: agmarkt@sulphurinstitute.org
Dr. Luit J. De Kok, Chairman of the European COST Action 829 "Fundamental, agronomical and ecological aspects of sulfur in plants", University, Groningen, E-mail: l.j.de.kok@rug.nl
Mr. Donald Messick, TSI, Washington, E-mail: DMessick@sulphurinstitute.org

Speakers from China:

Former holders of German research fellowships granted by the Max Planck Society

Dr. Fan Xiaohui, ISSAS, Nanjing, E-mail: xhfan@issas.ac.ch
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Former holder of a DAAD fellowship:

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Former holder of several fellowships granted by NFSC and the bilateral cooperation programmes between MoAs:

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Other speakers from China:

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Prof. Luo Qixiang, Academy of Agricultural Sciences, Jiangxi,
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Synopsis of the scientific contributions

Kesselmeier presented the auditorium a view to the global sulfur cycle and China's contribution to atmospheric sulfur loads. On Wednesday, March 20, 2002 “Peoples Daily” published a headline “China Fighting Acid Rain, Sulfur Dioxide”. The article revealed that China has decreased the release of sulfur dioxide by 1.86 million tons over the past two years as a result of its efforts to combat acid rain and sulfur dioxide control. In 1998, the State Council designated 11.4 percent of China's land, covering 175 cities in 27 provinces, autonomous regions and municipalities as acid rain and sulfur dioxide control regions. The sulfur dioxide release in these regions accounted for 60 percent of China's total. Over the past two years, the number of Chinese cities that have met the national standards has increased from 81 to 98, and the amount of sulfur dioxide has decreased from 14.08 million tons to 11.14 million tons. Beijing and Shanghai have taken the lead to set up areas without coal burning. By the end of last year, the output of high sulfur coal decreased by 32 million tons. Some 250 thermoelectric generating sets were shut down. China plans to shut down another 4,000 high sulfur coalmines, 135 thermoelectric generating sets and 1,300 small-sized cement and glass production lines this year. The annual Chinese emissions projected for 2020 are 40-45 Tg yr^{-1} S by 2020. However, there are already trends towards a lower figure for emissions observed, which is due a reduction in industrial coal use and a slow-down of the Chinese economy and a closure of small and inefficient plants.

Lu made a downscaling of the global to the Chinese S situation**.** This contribution revealed that the total S content in soils of China ranges from 100-500 mg kg^{-1} S. The organic S in soils of southern China accounts for 86-94% of the total S. The inorganic sulfur is mostly the easily soluble and the adsorbed sulfur. The content of the total S, organic S and available S in the cultivated soils of southern China is 299, 266 and 34 mg kg^{-1} S respectively. In southern China the sulfur input into the soil comes mainly from sulfur fertilizers (28.2 kg ha^{-1} S), rainfall (13.4 kg ha^{-1} S), and irrigation water (9.2 kg ha^{-1} S), with a total input of 50.6 kg ha^{-1} S. Balanced with sulfur removed from the soil by crop uptake (25.3 kg ha^{-1} S), sulfur leaching (19.9 kg ha^{-1} S) and runoff.

As a general introduction to the biology of S compounds **De Kok** refreshed the knowledge of the auditorium concerning the basic facts of plants' S metabolism and the main steps in the regulation of uptake, transport and storage of S compounds. In addition, the significance of S in physiological functioning of plants was reviewed. For instance, S-containing metabolites as glutathione (GSH) plays a key role as an important redox-system and precursor for many other S containing metabolites.

Glucosinolates are a special metabolic pathway for S in a number of plant families like for instance cruciferous crops. **Selmar** explained in his lecture the metabolism and catabolism of glucosinolates. The significance of glucosinolates for the subject of the workshop have to be seen in their role as an active principle in chemical plant defense, which stimulation either by altered genetics or environment bears challenges for improving plant health without pesticides.

“Sulfur-rich Proteins” are also involved in stress resistance and supposed to be an important part of SIR. **Hell** demonstrated that thionins and defensins are ubiquitous elements of innate defense in plants, which are encoded by large gene families and are differentially expressed. The inducibility of at least some Thi and Def genes by pathogens depends on optimal sulfur supply. Membrane damage by sulfur-rich proteins can be exploited to enhance resistance to pathogenic fungi using transgenic approaches and possibly also breeding.

Not only agricultural crop plants but also forests may suffer from S deficiency. **Herschbach** explained their view to the sulfur nutrition of deciduous trees at the whole plant level during stress.

A new field for extended plant S research are aspects of so-called sulfur-induced resistance (SIR), which were brought to the attention of the auditorium by **Salac**. Because of a number of evidences on the interaction of S with plant health, research has been stimulated in this field in order to understand the relationship between the S status of plants and resistance mechanisms. The significance of S fertilization for crop resistance has coined the term Sulfur Induced Resistance, abbreviated SIR. The fungicidal effect of elemental S on pests and diseases is long known while the significance of soil-applied S for crop resistance became evident a century later. Nevertheless, the fungicidal effect of foliar applied S has to be distinguished strictly from the health promoting effect of soil-applied S. Therefore, in what follows the significance soil-applied S fertilization on plant health will be highlighted. These recent findings clearly indicate that S supply has a strong influence on plant resistance by stimulating directly the biochemical processes in the primary and secondary metabolism. Nevertheless, future research is necessary in order to understand the efficacy of individual S metabolites involved in the activation and strengthening of plant defenses by S fertilization.

As representatives of the S fertilizer industry **Messick** and **Fan** stressed the increasing demand for S fertilizers and their use in Chinese agriculture, a fact which provides significant benefits to both fertilizer manufacturers and farmers. The estimated annual need of S for plant nutrition in China is 1.7

million tons S. It has been estimated that 30% of Chinese farmland, mainly in the counties Ji and Baodi are responding to S fertilization. Yield losses in rice, wheat and corn caused by S deficiency are 6% - 24%, particularly S demanding crops like Chinese cabbage, garlic, turnips and scallion responded to S fertilization of 60 kg ha^{-1} S with yield increased around 20%. **Messick** and **Fan** expect a deficit in S supply from 2011 on. Assuming that 20% of the market is captured (340,000 tons S) and a price of t 180 US$ per ton S for fertilizer this corresponds to a financial volume of 61.2 Million US$. The average yield increase potential in Chinese crop production by sulfur fertilization is estimated to 10% on 40 million ha of S deficient land. The additional yield is estimated to a total of 24 million tons for which the additional sulfur fertilizer demand amounts to 1.2 million tons of S. At the same time with yield increases an improved efficiency for nitrogen fertilizers of at least 2% is expected which saves a minimum of 5.5 million tons of N from being lost to the environment.

Despite its distinctive effects of crop yield S fertilization also improves the quality of plant products. **Hagel** demonstrated this by the example of the baking-quality of bread-making wheat. He carried out that in modern breeding (unconsciously) varieties with a higher demand of vitalizing sulfur were selected. This affects primarily the content of high molecular weight (HMW-)glutenin. This not only affects the technological features of the dough prepared from S deficient wheat grain, but also the digestibility of the wheat bread in the human intestine.

Paulsen stressed the special role of S nutrition and S application in organic farming. Besides a plant nutrient, S in elemental form may have a negative impact on rice roots, which are sensitive to low levels of sulfide. H_2S can derive from superfluous S in rice soils due to the nocturnal decline in the degree of oxidation in the rhizosphere, since the stomata of the rice plants are closed at night.

Under severe S starvation plants develop more or less characteristically deficiency symptoms. **Brauer et al.** demonstrated the symptomatology of visual symptoms of S-deficiency. They showed that symptoms of S deficiency can occur in all crops and in all growth stages and they concluded that the identification of such symptoms are an important tool in crop management. S deficiency symptoms can be diagnosed comparatively reliable in oilseed rape, while in cereals (including corn) and sugar beet this is only possible together with hydrological and other site parameters.

Ma demonstrated that a combination of information technology, soil-fertilizer and plant-nutrition technology can be used as a tool for managing S fertilizers throughout larger regions. By this system, soil S-deficiency status, effects of S fertilizer application and soil S balance of input and output in Chinese different regions could be directly queried. With increasingly maturation and popularization of the internet technology, attention is paid to WebGis (World-Wide-Web Geography Information System). It not only solves the problem of expensive price for GIS software, but also reduces the cost of collecting geography spatial data and improves the sharing degree and extension of the geography information.
Organic farming has its special requirements to the quality of fertilizers: no soluble P sources are allowed in fertilization. **Fan** demonstrated a technology where available P could be produced from compounds of elemental S and rock phosphate fertilizers in soils directly.

Finally **Schnug** highlighted the significance of S fertilization as a part of sustainable development of agriculture. Understanding “sustainable development” as development that meets the needs of the present without compromising the ability of future generations to meet their own needs (The Brundtland Commission, 1997) sulfur fertilization contributes to sustainability because it, improves production performance, reduces the environmental impact of nitrogen and pesticides, improves the efficiency of non renewable resources (P), improves crop quality.

General conclusions and further actions

All participants addressed the workshop as a great success. Both German and Chinese scientists discussed the content of future cooperative projects to introduce advanced research technologies and methods, genetic research on sulfur-induced crop resistance to stresses, aspects of sulfur fertilizer use in conventional and environmentally-sound agriculture, GIS technology and its use in diagnosis of sulfur deficiency and sulfur fertilizer recommendations in different regions.

Further actions will be the proposal of two workshops to the Center, addressing the specific interests of science and society in organic farming and genetic engineering. Individual research collaborations between partners have been initiated already and seeking for funding will also involve approaches to the Center.

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