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Responses of Atomospheric Sulphur aerosol in wheat (*Triticum aestivum*. L)

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Abstract
Air pollution specifically particulate matters (aerosols) affect global warming. Air pollution is caused by gases, dust, fumes or odor in harmful amounts. Aerosols are a subset of air pollution that refer to the tiny particles suspended everywhere in our atmosphere. These particles can be both solid and liquid, and are collectively referred to as 'atmospheric aerosol particles'. In modern days, most of these are produced from human industrial and agricultural activities. In clear air, particles of sizes of approximately 0.1 to 1 micron interact with the solar beam. Particles containing little carbon are effectively 'white.' They reflect solar radiation, making the air and Earth surface below them a bit cooler than they would otherwise be. In contrast, particles containing substantial amounts of black carbon (e. g., soot, which is typically produced from combustion of fossil fuels, bio-fuels, and biomass burning) warm their surroundings by absorbing solar radiation before it reaches the ground. When water vapor clings to water soluble particles in the same size range (~0.1 to 1 micron), it creates cloud droplets in the lower troposphere, but literatures on Sulphur use efficiency of wheat crop under varying level of Sulphur applied as aerosol as well as foliar feeding, are inadequate. Here, an attempt has been made to introduce about the aerosols, and particularly, to reflect the roles of Sulphur aerosol on various processes of plant growth and development with special emphasis on its use efficiency.

Keywords: sulphur, aerosols, wheat, carbon, yield

Introduction
Wheat is one of the most important cereal crops globally, and it is a staple food for about one third of the world's population (Hussain. *et al*., 2002) [24]. Wheat in Indian Agriculture is second importance next to the rice. Wheat provides more protein than any other cereal crops (Iqtidar *et al*., 2006) [25]. In India, wheat occupies an area of 24.23 million hectares with a production of 70.26 million tons. In parts of Assam Nagaon and Darrang districts wheat is grown during the period between November and April. Presently areas under wheat in Assam is 0.1 million ha (Das and Guha, 1998) [8] and gradually newer areas are being covered by this crop. The productivity of wheat in Assam is a meager i.e., 1219 kg/ha (Anonymous 2004) [2], which is far lower as compared to the national average of 2900 kg/ha. However, the global challenge for wheat nutrition is to increase grain yield while maintaining its protein.

Overview of Aerosols on environment
(Gu *et. al.,* 2002, 2003) [20, 21] found that Aerosols decrease the solar radiation reaching the surface, especially in the 0.45 to 0.75 μm wavelength range (known as photosynthetically available radiation, or PAR), which may have an impact on plant productivity, and therefore on the carbon cycle. Aerosols can also increase the diffuse radiation reaching the surface, which is known to enhance plant productivity. It has been suggested by several authors that the increase in diffuse radiation due to stratospheric aerosols following large volcanic eruptions may be responsible for an additional uptake of carbon dioxide by terrestrial ecosystems. This effect was modeled by (Mercado *et al.,* 2009) [35] who opined that aerosols due to anthropogenic emissions are responsible for an enhancement of the terrestrial carbon sink. If natural aerosols were to change over vegetated areas, then the same process would apply. This process can provide a negative climate feedback if natural aerosols increase in response to climate change.

(Cape, 2008) [6], reported that the wet and dry deposition of particulates to the Earth's surface may contribute a significant nutrient source to some ecosystems, but in polluted regions excessive deposition of acidic particles can damage vegetation and lead to acidification of soils. Deposition of particles on leaf surfaces can also alter leaf-surface wetness, altering ecosystem water**,** CO_2 uptake and the risk of pathogen attack. Biomass burning is also a significant source of carbon, Sulphur, Nitrogen and Phosphorous containing compounds to downwind ecosystems. Biomass burning may result in significant deposition of Sulphur to downwind ecosystems (Fabian *et al.*, 2005) [13].While the deposition of phosphorous on a global scale is dominated by dust (82%) and primary biological aerosol particles (13%) (Mahowald *et al.*, 2005, 2008)[32, 33], biomass burning may be the dominant source of phosphorous to the earth. Deposition of Phosphorous to the oceans may also fertilize phosphorous-limited waters (Mills *et al.*, 2004)[36]. Such natural aerosol nutrient sources are likely to be much less important than anthropogenic aerosol in more polluted environments. (Driscoll *et al.*, 2001)[10], but the impact on the global carbon cycle has not been quantified. Sulphate deposition also impacts natural wetlands and rice paddies resulting in suppressed methane emissions (Gauci *et al.*, 2008) [17]. The future deposition of particulates to ecosystems will depend on both changes to anthropogenic emissions and climate.

Mechanisms of foliar nutrients uptake in plant

The processes that regulate the uptake of foliar substances have been studied in detail as the movement of nutrients into the plant through the leaf involves different mechanisms of nutrient transport into plant. Most notably, plant leaves have thicker cuticles which are coated with a waxy layer making penetration of solutes difficult. For foliar fertilizers to be utilized by the plant for growth, the nutrient must first penetrate the leaf surface prior to entering the cytoplasm of a cell within the leaf. Penetration of foliar nutrients occurs through the cuticle the stomata, leaf hairs and other specialized epidermal cells. There was ongoing debate as to which of these penetration pathways plays a most important role in nutrient uptake (Fernandez and Eichert, 2009 [16]; Oosterhuis, 2009) [38].

The cuticle is the first route available for penetration of solutes into leaves upon contact with the leaf, and the cuticle layer partially extends across the stomatal cavity forming cuticle ledges. These cuticle ledges will also interfere with the ability of the stomata to take up solutes. The cuticle is a structurally complex waxy layer and, on the basis of urea and glucose absorption studies (Dickison, 2000) [9]. Epicuticular waxes are a barrier to the retention and penetration of foliar fertilizers into plant organs. Almost, all plant surface waxes are hydrophobic and repel water-based sprays. The cuticle itself is a lipid layer making slightly permeable to both water and oils. This is one reason why the timing of foliar sprays is often targeted to stomatal opening (Jenks and Ashworth, 1999) [27].The stomatal pore is enveloped by two guard cells which regulate the opening and closing of the pore. Stomata also provide the major pathways for evaporative loss of water, exchange of gases during photosynthesis and for controlling the transport of water across the epidermis (Raven and Johnson, 1999) [39]. Schonherr, (1976) [40] pointed out that liquids could penetrate through cuticular pores up to 0.9 nm in diameter. The permeability of cuticles to ions is dependent on similar environmental factors to stomatal uptake. Research to date suggests that both stomata and the cuticle play a role in nutrient uptake. However, stomatal penetration appears to be more complex and dependent on more environmental factors than cuticular penetration. But, stomatal penetration is quick and rapid, when it occurs, whereas cuticular penetration is a slower process.

Foliar fertilizer of Sulphur for cop productivity

Sulphur is one of the essential macronutrients (Hawkesford, 2005) [22]. It plays important role in plant metabolism as it is a constituent of essential compounds such as cysteine, methionine, several co enzymes (biotin, coenzyme A, thiamine pyrophosphate and lipoic acid), thioredoxins and sulfolipds (Ernst, 1993) [12] (Mazid *et al.*, 2011) [34]. Sulfur fertility has historically not been a major concern for growers on most soils, as soil organic matter, atmospheric deposition, manure application and incidental sulphur contained in fertilizers have typically supplied sufficient sulphur for crop production. Sulphur may be decreasing in soil due to the increasing proportions of high analysis and sulfur free fertilizers, decreasing use of traditional use of organic manures and sulfur containing fertilizers or due to reduced atmospheric S deposition. However, reductions in the amount of sulphur contributed by these factors combined with increased sulphur removal with greater crop yields have made sulphur deficiencies more common. Modern agriculture requires adequate fertilisation of S to achieve maximum crop yield and performances (Crawford *et al.*, 2000) [7]. Deficiency of Sulphur in plant may reduce growth and photosyntheiss (Giordano *et al.*, 2000) [18], with a substantial decline of rubisco and chlorophyll a/b binding protein (Jamal, 2006) [26].

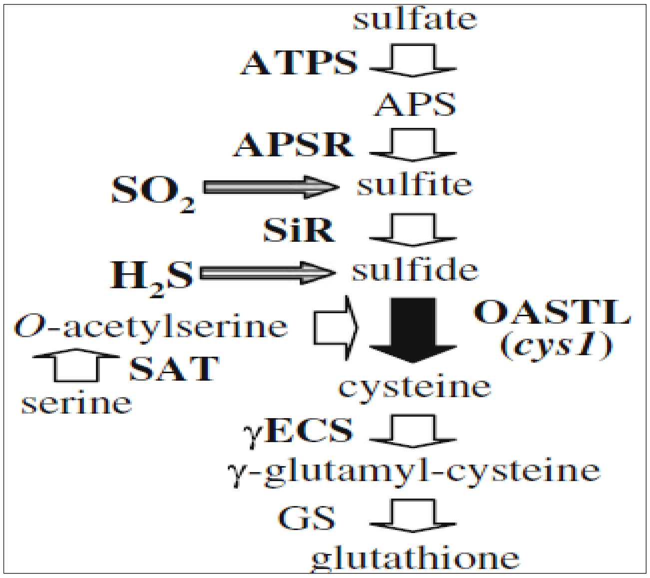

Fig 1: Simplified sulphur assimilatory reduction pathway in plants. Only main substrates and enzymes, but not side reactions, are shown. Stripped arrows show the points at which sulphur dioxide (SO2) and hydrogen sulfide (H2S) are thought to enter the pathway. The step catalyzed by cys1 expression is shown by the black arrow. Transcripts of genes encoding enzymes used in this study are shown in bold. APS adenosine 50-phosphosulfate, ATPS ATP sulfurylase, APSR adenosine 50-phosphosulfate reductase, SiR sulphite reductase, SAT serine acetyltransferase, OASTL O-acetylserine (thiol)lyase, cECS c-glutamylcysteine synthetase, GS glutathione synthetase.

Structural and functional roles

(Lunde *et al.*, 2008) [31]. Reported that Sulphur plays varied structural and functional roles in plants and plants exhibit diverse responses to sulphur deficiency. Sulphur deficiency leads to yellowing of young leaves of plants and also decrease biomass. Toxicity of sulphur (caused by SO_2) produces chlorosis and interveinal necrosis in plants (Farooq and Hans, 1999) [15], which ultimately reducing growth and yield. Application of sulphur has been reported to benefit different crop production. Sulphur is taken up by plants as inorganic sulfate from the soil and its transportation is also in the form of sulphate. The primary uptake of sulfate is done by roots and then it is translocated to different organs through xylem. Sulphur deficiency leads to an enhanced capacity for sulfate uptake. Sulphur stress does not increase the export of sulfur from mature leaves to young leaves (Adiputra and Anderson, 1995) [1]. Different plants attain different range of critical concentration of sulphur in leaves. Sulphur is assimilated in the form of cysteine which behaves as a precursor or reduced sulphur donor of most other organic sulfur compounds in plants. Cysteine also plays a critical role in protection against biotic/ abiotic stress (Noctor *et al.*, 2002) [37]. Sulfur also plays an important role in carbohydrates metabolism. Carbohydrates provide the acceptor of sulfide for in vivo synthesis as they are the source of reductant for sulfate reduction in non-photosynthetic tissues (Kopriva and Rennenberg, 2004) [29]. A significant increase in carbohydrates (starch) was observed in leaves of sulphur deficient rice plant. Toxicity of sulphur (caused by exposure of SO_2) results an enhancement in carbohydrate concentration. Sulphur regulates the seed metabolism in terms of carbohydrates and storage proteins.

On the other hand, S seems to be more or less toxic to plants at higher concentration (Goldbol and Huttermann, 1985) [19]. Some macro-elements are significant environmental pollutants and their availability in soils depends on natural processes *viz.*, anthropogenic factors such as mining, combustion of fossil fuels, urban waste disposal, soil run off, metal working industries etc. In fact, yield of most crop plants increases linearly with the amount of fertilizers that they absorb ((Hill, 1997; Loomis and Conner, 1992) [23]. Mineral elements those acquired primarily in the form of inorganic ions, continuously cycle through all organisms and their environments.

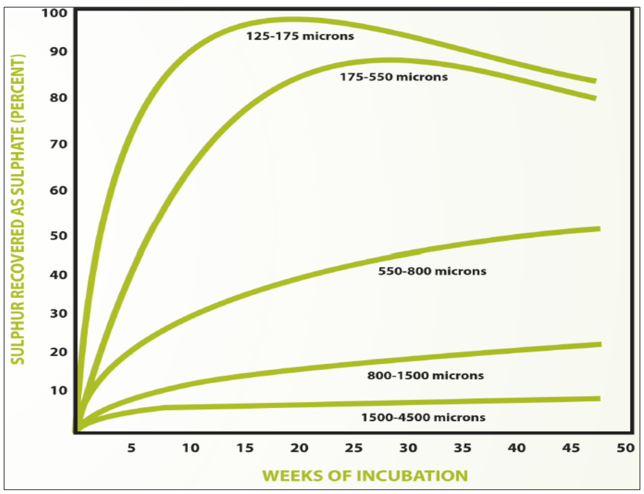

Fig 2: S particle size and conversion to sulphate with time study of the effect of particle size in microns on recovery of sulphate ions over time from 1000ppm of elemental S incubated in soil at room temperature

Sulphur aerosols common fertilizers

The sulfur contents of several common fertilizers are variable *Viz.*, Ammonium thiosulfate (26%), Ammonium sulfate (24%), Potassium-magnesium sulfate (22), Calcium sulfate i.e. gypsum (18%), Potassium sulfate (18), Magnesium sulphate (14), Ordinary superphosphate (12%). Sulfate-containing fertilizers provide sulfur in a form that is readily available for plant uptake and can be used to quickly correct a sulfur deficiency. Elemental sulfur must be oxidized in the soil before it can be taken up by plants, which increases the amount of time needed for it to be available, but provides sulfur in a slow-release form that is less susceptible to leaching losses than sulfate fertilizers. Some fertilizers have the potential to lower soil pH, especially sulfur and phosphorus combined with the ammonium-based nitrogen fertilizers, like ammonium sulfate, monoammonium phosphate (MAP) and diammonium phosphate (DAP). The oxidation process of sulfur releases acidity, as does the nitrification of ammonium (conversion of ammonium to nitrate in the soil by bacteria). Monitoring pH with soil testing is recommended to determine lime needs if sulfur and ammonium-containing fertilizers are used often.

Industrial pollution, despite its myriad negative effects, has provided a benefit to agricultural production in some areas as a source of sulfur. Sulfur is emitted into the atmosphere primarily through burning of fossil fuels. These emissions can travel long distances in the atmosphere and are eventually deposited as sulfur dioxide or as sulfates, often in precipitation. A mere change in the gaseous composition of the atmosphere has many different impacts on terrestrial plants. Sulfur dioxide pollution is known to have a substantial effect on agricultural production and is still of great significance in many developing countries. Conversely, due to strict regulatory control on SO_2 emissions, the level of atmospheric SO_2 in developed countries has radically declined causing S-deficiency symptoms in crop plants, resulting in a drastic reduction in crop productivity and quality. Increased uptake of SO_2 can impair plant metabolism leading to reduced growth and productivity due to accumulation of sulfite and sulfate within the plant.

SO_2 concentration in plants

Phytotoxicity of SO_2 is determined by the environmental conditions, the duration of exposure, the atmospheric SO_2 concentration, the sulfur status of the soil, the genetic constitution of the plant, and the developmental phase of plants. Plants form a sink for atmospheric SO_2, which is taken up by the foliage. Since the internal (mesophyll) resistance to SO_2 is low due to its high solubility and rapid dissociation in the cell sap, foliar SO_2 uptake is determined by its diffusion through the stomata. Foliar injury may be caused by the negative effects of acidification of tissue/cells after the dissociation of the absorbed SO_2 and the reaction of the formed sulfite with cellular components. There is also a wide inter- and intraspecific variation in susceptibility between species; however, the physiological basis for the variation in air pollution response is still largely unresolved. Paradoxically, atmospheric SO_2 may also be used as plant nutrient where SO_2 absorbed by the leave can enter the S assimilatory pathway directly or after oxidation to SO_4^{2-} and be reduced to sulfide, incorporated into cysteine and subsequently, organic S compounds, and utilized as S nutrient. Plants may also benefit from SO_2 exposure given that it can contribute to the plants' S nutrition, and result in enhanced crop productivity, especially in plants growing in sulfur-deficient soils.

The effects of aerosols on atmospheric temperature and climate are studied elaborately. In the past, considerable research on the effects of air pollutants on plants had been studied (Bharali *et al.*, 2002, 2006, 2010.)[3, 4, 5]. But, little information is available on the direct impacts of sulphate-S aerosols on physiological responses of wheat crops. As concerned to the sources of Sulphur, the responses of crops to rate of soil applied sulphur have been studied previously elsewhere. The possibilities of Sulphur nutrition as by foliar feeding with aerosols of sulphur (Sulphate) rather than soil supplied Sulphur, pertaining to the responses of wheat crop to Sulphur are explored in the present investigation.

Impacts Aerosols on crops

Nitrogen (N) and sulfur (S) supplies have a strong influence on the quality and quantity of wheat storage proteins, which play an important role in the bread making process. Nitrogen derived from urea, S from micronized elemental sulfur, and a mixture of both (N+S) were applied at anthesis stage on wheat by foliar spray. To relate N and S incorporation in storage proteins to the quality of dough, their incorporation into each storage protein fraction was measured in terms of low molecular weight gluten in subunits (LMW-GS), and high molecular weight gluten in subunits (HMW-GS). Then protein fraction quantities, molecular weight distribution (MWD), polymerization index (PI), and molecular dimensions of extractable polymeric protein (UPP), as well as dough mixing properties were determined. Fertilizers N and S were differentially incorporated into each storage protein fraction, influencing protein synthesis. Moreover, after the N+S fertilization, the increase of the polymeric proteins induced an increase in molecular weight and compactness, as well as in dough strength and consistency. These results provide evidence that N and S fertilizers applied by foliar spray route at anthesis, simultaneously, play an important role in controlling the storage protein synthesis and the degree of polymerization, which in turn influence dough mixing properties.

Foliar application of micronutrients

Fageria *et al.,* (2009) [14] found that foliar application of nutrients is an important crop management strategy in maximizing crop yields. It can supplement soil fertilization. When nutrients are applied to soils, they are absorbed by plant roots and translocated to aerial parts. In case of foliar application, the nutrients penetrate the cuticle of the leaf or the stomata and then enter the cells. Hence, crop response occurs in short time in foliar application compared to soil application. The rate, by which an ion passes through the cuticle, and generally the epidermal tissues of the leaves, depends on many factors, including the concentration and the physical and chemical properties of the sprayed ion. Macronutrients, which are required in high amounts by crop plants, are rarely met by foliar application. Hence, so far the most important use of foliar sprays has been in the application of micronutrients. In foliar sprays, macronutrient concentrations of generally less than 2% are used to avoid leaf burning. Macronutrient solution concentrations vary from 0.1 to 1.2% depending on the nutrient. Plant age should also be considered in selecting nutrient concentration. Older plants are more tolerant to higher concentrations of salts compared to younger plants. In foliar fertilization, droplet size and fertilizer solubility should be carefully controlled since it will affect crop response. Foliar fertilization in food crops may not increase yield but may increase protein content of grains, if applied during anthesis or flowering.

Uptake of mineral micronutrients

The uptake of mineral nutrients from foliar fertilization. It was stated that despite many studies carried out on mineral nutrient absorption by leaf tissues, many aspects of foliar fertilization are still unknown. At present, it is believed that such fertilization of plants is a valuable complement to the application of nutrients to the soil. Foliar fertilization is the most effective when soil nutrient availability is low, topsoil dry, and root activity during the reproductive stage is decreased. Foliar fertilization is also successful in increasing content of fruit Ca^{2+} and cereal grain protein. It is proposed that this treatment should be recommended in the integrated plant production, because it is environment friendly and increases productivity and yield quality. In the paper, the penetration of mineral nutrients through the surface leaf layers and their uptake across the plasma membrane of the epidermal cells were discussed. In addition, environmental factors, aspects of plant biology and spray solution properties having a crucial effect on the efficiency of foliar fertilization, were also presented. The mechanisms of foliar absorption and subsequent transport of inorganic nutrients were discussed by Kannan (1986) [28]. The penetration of the nutrient elements supplied to the leaf, through the outermost barrier - the cuticle - absorption by the leaf cells within, and transport form cell-to-cell finally to the conducting system of the leaf, are as complex as those following the root absorption. Yet, foliar supply of nutrients has many advantages over root-feeding. There has been considerable interest in the practical use of this technique, as well as several accomplishments in the understanding of the mechanisms involved in foliar uptake. Fageria *et al.,* (2009) [14] pointed out that essential plant nutrients are mainly applied to soil and plant foliage for achieving maximum economic yields. Soil application method is more common and most effective for nutrients, which require in higher amounts. However, under certain circumstances, foliar fertilization is more economic and effective. Foliar symptoms, soil and plant tissue tests, and crop growth responses are principal nutrient disorder diagnostic techniques. Soil applications of fertilizers are mainly done on the basis of soil tests, whereas foliar nutrient applications are mainly done on the basis of visual foliar symptoms or plant tissue tests. Hence, correct diagnosis of nutrient deficiency is fundamental for successful foliar fertilization. In addition, there are some more requirements for successful foliar fertilization. Foliar fertilization requires higher leaf area index for absorbing applied nutrient solution in sufficient amount, it may be necessary to have more than one application depending on severity of nutrient deficiency. Nutrient concentration and day temperature should be optimal to avoid leaf burning and fertilizer source should be soluble in water to be more effective. Foliar fertilization of crops can complement soil fertilization. If foliar fertilization is mixed with post emergence herbicides, insecticides, or fungicides, the probability of yield response could be increased and cost of application can be reduced.

Conclusion

Foliar fed Sulphur aerosols influence the physiological traits including economic yield of wheat crop positively. The action-mechanism of Sulphur aerosol altering the physiology of wheat crop. Aerosols could be applied as foliar spray to explore the potential economic yield of the selected wheat varieties. Because, the aerosols not only supported S and N-nutrition, but also maintained the CMS with higher retention of intercellular and exchangeable ions in wheat. Therefore, the hypothesis that foliar fed sulphur aerosols influence positively almost all the physiological traits including economical yield of wheat.

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