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Coordinated Role of Nitrogen and Sulfur in Sustainable Plant Development

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Sustainable agriculture

- The economic viability of agricultural production.
- Reduce the adverse impacts on the natural resource base.
- Use of farming system which makes maximum utilization of resources.

Sustainable agriculture also helps to

- Minimize the residues resulting from the use of chemicals in agriculture.
- Maximize the net social benefit from agriculture
- Sustainable agriculture means that we farm in such a way that we can keep farming in the future
- Crop yields will be good, farmers will make money, people will have enough food to eat at a reasonable cost, and the environment will be protected

Mineral nutrition in sustainable agriculture

- All nutrient elements are required in optimum amount to obtain high yield potential.
- However N is more essential because other elements can be adjusted more easily to optimum condition in the soil as they are held by the exchange complex and have low solubility and are not so easily lost from the system.
- N fertilizers are highly soluble, readily leached , volatized as NH_3 form or denitrified when in the nitrate form. Nitrogen is probably the single most important factor limiting crop yield as most plants require it in large quantities.

Nitrogen in plants

- The use of urea , the organic form of nitrogen has always been preferred for crop growth and productivity.
- Another essential activity that takes place in the soil is the fixation of nitrogen. Certain bacteria in the soil or in the roots of plant (most notably legumes) convert atmospheric nitrogen gas into fixed forms of nitrogen that plants and other organisms use to make proteins.
- The amount of available nitrogen strongly influences soil productivity.

- Most plants take nitrogen from the soil continuously throughout their lives
- Nitrogen demand usually increases as plant size increases.
- A plant supplied with adequate nitrogen grows rapidly and produces large amounts of succulent, green foliage.
- Providing adequate nitrogen allows an annual crop to grow to full maturity. A nitrogen-deficient plant is generally small and develops slowly

- A hallmark of high-intensity agriculture is its dependence on pesticides and chemical fertilizers, especially those containing nitrogen.
- Since 1960 the worldwide rate of application of nitrogen fertilizers has increased by seven times, and now exceeds more than 72107 tonnes of nitrogen per year.

Loss of Nitrogen from soil

- The nitrogen cycle contains several routes by which plant-available nitrogen can be lost from the soil.
- Nitrate-nitrogen is usually more subject to loss than is ammonium-nitrogen. Significant loss mechanisms include leaching, denitrification, volatilization, and crop removal.
- The nitrate form of nitrogen is so soluble that it leaches easily when excess water percolates through the soil.

Adverse Affect of N loss

- Nitrate nitrogen (NO_3-N), which is an essential source of nitrogen (N) for plant growth, is now also considered a potential pollutant by the Environmental Protection Agency (EPA).
- This is because excess applied amounts of NO_3-N can move into streams by runoff and into ground water by leaching, thereby becoming an environmental hazard.

Factors causing low productivity in crops

- Biotic and abiotic stress factors
- Nutritional stress
- Hormonal imbalance
- Cultivation of genotypes/cultivars not suitable for a particular area/region
- Cultivation of stress-sensitive genotypes/cultivars

Environmental stress is referred to:

- The extreme environmental conditions that lead

  - To alterations in plant metabolism resulting in decreased rate of plants growth processes

  - To loss in productivity or inducing damaging effect in any of plant's organ/part

  - To alteration in anatomical, biochemical or molecular regulation

Abiotic stress effects on sustainable agriculture

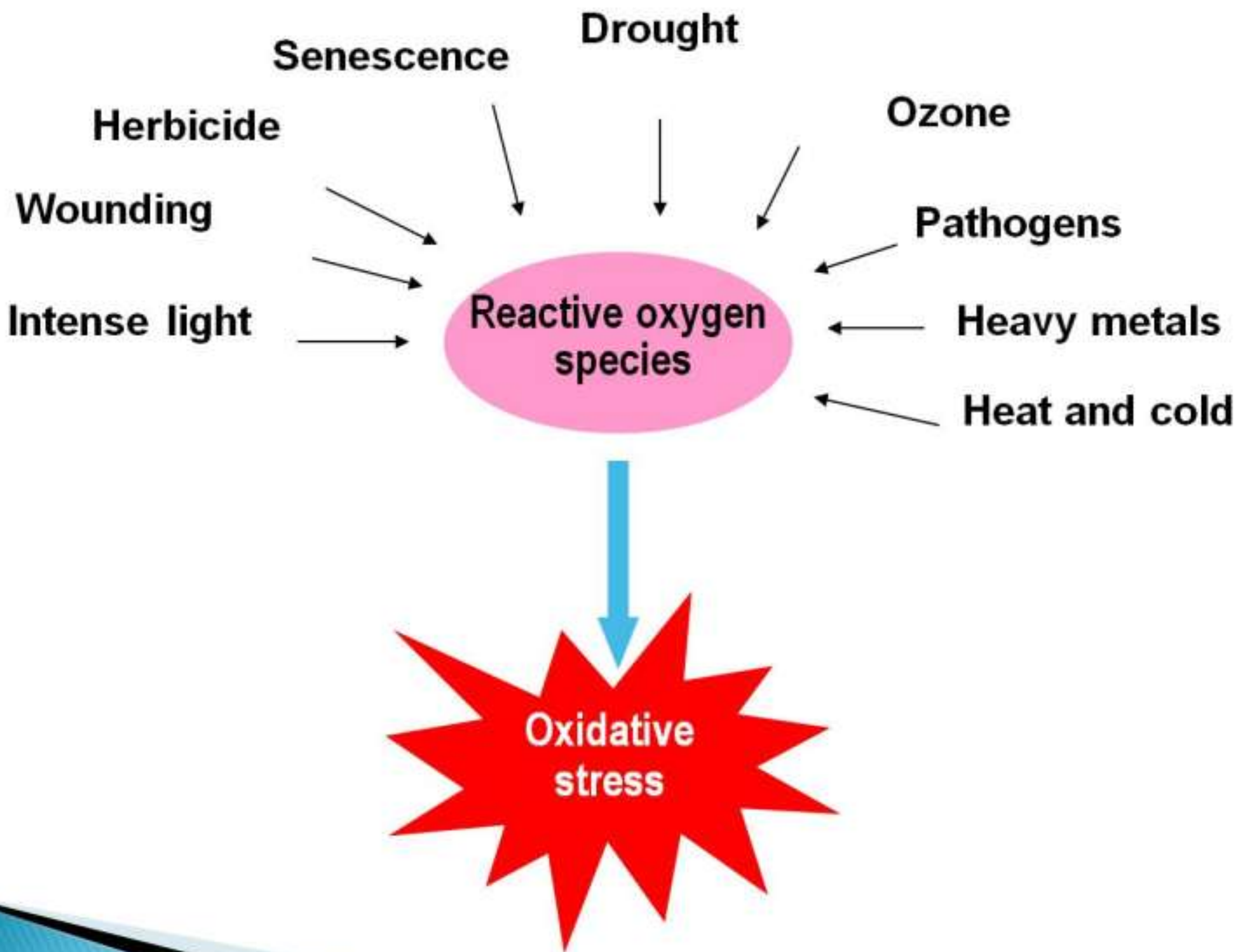
- The sustainability of agriculture is in doubt because of various environmental stresses that plant encounters.
- Stress implies to the adverse environmental conditions that leads to alteration in plant metabolism affecting the productivity of plants.
- Among various stresses that plants encounter abiotic stresses are most significant.
- Every year India loses hundred of millions of rupees from reduction in crop productivity caused by abiotic stresses.

- Abiotic stress such as salinity, drought, nutrient deficiency or toxicity, heavy metal toxicity and flooding limit crop productivity world-wide.
- Abiotic stresses are the major factors of poverty for millions of people.
- In this scenario, it is widely urged that strategies should be adopted which may be used to get maximum crop stand and economic returns from stressful environments.

What does actually occur in plants under stress condition ?

Stress produces reactive oxygen species (ROS)

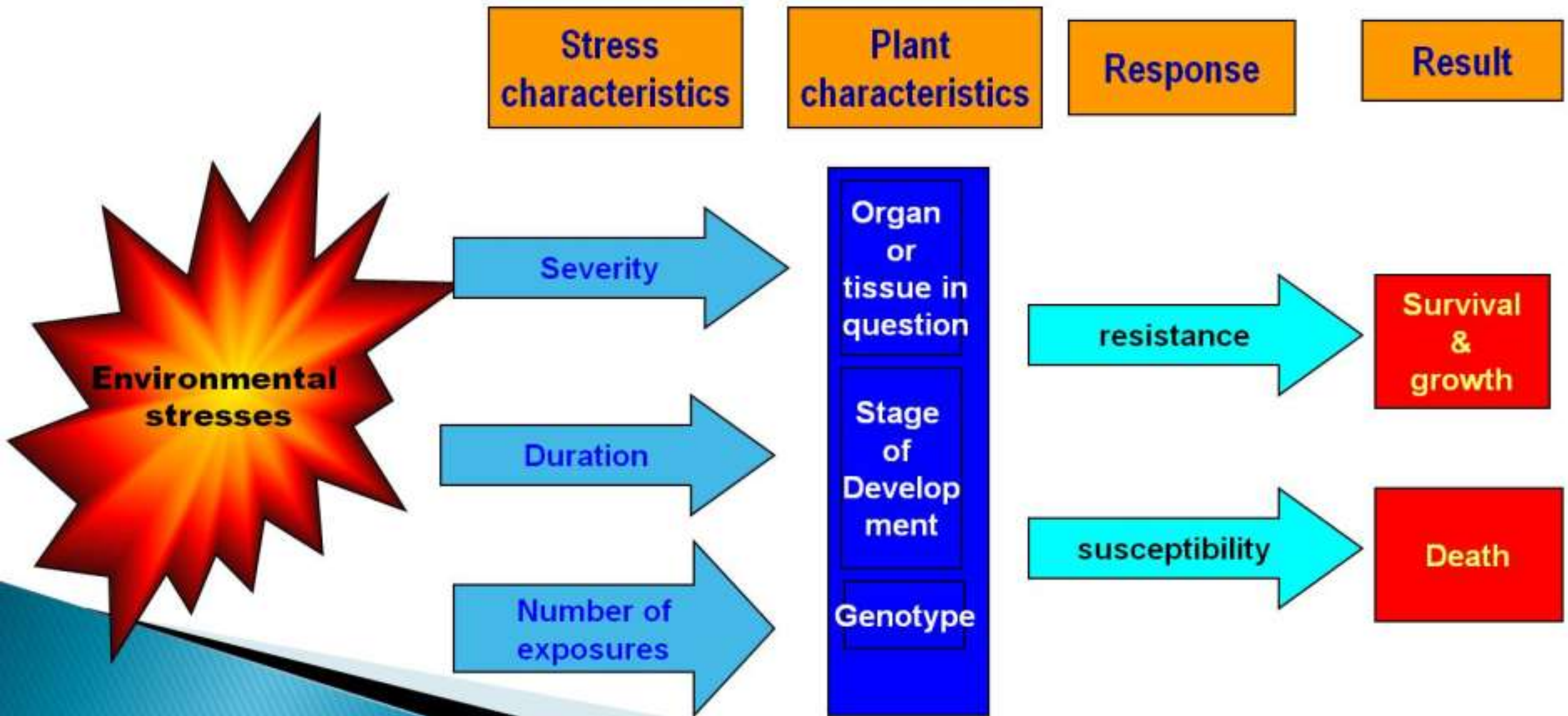
e.g. Singlet oxygen, hydrogen peroxide, superoxide anion, hydroxyl and perhydroxyl radicals


Senescence
Drought
Herbicide
Ozone
Wounding
Pathogens
Intense light
Reactive oxygen species
Heavy metals
Heat and cold
Oxidative stress

Stress resistance mechanisms

- Avoidance mechanisms
  - prevent exposure to stress
- Tolerance mechanisms
  - permit the plant to withstand stress

How plants respond to environmental stress ?



STRATEGIES TO STRENGTHEN PLANT DEFENSE SYSTEM

Increasing N utilization

- Apparent nitrogen recovery is related to the efficiency of N uptake
- Physiological NUE deals with N utilization to produce grain or total plant dry matter. The most suitable way to estimate NUE depends on the crop, its harvest product and the processes involved in it. .
- In crops, an increased knowledge of the regulatory mechanisms controlling plant **nitrogen** economy is vital for improving **nitrogen use efficiency** and for reducing excessive input of fertilizers, while maintaining an acceptable yield.
- Recent developments and future prospects of obtaining a better understanding of the regulation of **nitrogen use efficiency** in the main crop species cultivated in the world could be achieved probably through supplementation of some other nutrient.

Sulfur

- S is the fourth major plant nutrient after NPK
- It is needed by every crop
- Sulphur is essential for the growth and development of all crops, without exception. Most of the plant's requirement of S is absorbed through the roots in the sulphate (SO_4^{-2}) form
- Due to use of urea and other N fertilizers the use of this mineral nutrient has been neglected for a long time
- A few years ago sulphur was considered as a nutrient of academic interest. But today it is of much importance to Indian agriculture

- Based on fertiliser consumption figures for 1999-2000, the S added through common S-containing fertilisers is 775,000 t. Thus:
- Annual S Uptake by Crops = 1,200,000 t
- Annual S Input by Fertilisers = 775,000 t

S Deficit (Shortfall) = - 425,000 t

- **Thus for every tonne of S added through fertilisers, 1.54 tonnes S is being removed by crops.**

The consequences

- Depletion of soil sulphur reserves.
- Decline in S status of even well supplied soils.
- More widespread and more intense sulphur deficiencies.
- Lower returns from investments made in other inputs under S-deficient conditions

Importance of S in plants

- The main function of S is in protein production, primarily because it is a constituent of the three main amino acids (cysteine, cystine and methionine), which are the building blocks of protein. About 90% of plant sulphur is present in these amino acids

- It helps in the formation of chlorophyll, the green substance in leaves and other above-ground plant parts that permit photosynthesis. Plants produce starch, sugar, oils, fats, vitamins and other vital compounds through photosynthesis.

- S helps in activation of enzymes, which act as catalysts in biochemical reactions within the plant.
- Sulphur increases crop yields and improves produce quality, both of which are important for determining the market price a farmer would get for his produce
- It is a major constituent of antioxidants like Glutathione and phytochelatin and therefore is essential in overcoming stress

Role of S in sustainable agriculture

- On S-deficient soils, potential yields, quality and profits are possible only if deliberate S application is made a part of the fertiliser application plan by the farmers on a large scale.

PLANT MINERAL NUTRIENTS – MAJOR ROLES

- Mineral-nutrient status of plants plays a critical role in increasing plant resistance to environmental stress

- Among plant nutrients:
  - S and N are of great importance
  - S and N fertilization can be adopted for the alleviation of abiotic stress-effects in a Sustainable way

SULFUR AND NITROGEN – WHY?

- Sulfur is an essential macronutrient of plants
- Plays a vital role in the regulation of plant growth and development
- It is a structural constituent of several coenzymes and prosthetic groups, such as ferredoxine, which is also important for N assimilation

- Nitrogen is an important component of several important structural, genetic and metabolic compounds in plant cells
- Plant N status is highly dependent on N fertilization
- N is also a major component of chlorophyll and amino acids, the building blocks of proteins
- Increase in N supply can stimulate plant growth and productivity as well as photosynthetic activity through increased amounts of stromal and thylakoid proteins in leaves

N – S coordination and plant growth

- Regulatory interactions exit between assimilatory sulfate and nitrate reduction in plants
- Most of the reduced S and N in a plant are utilized in protein synthesis
- As the nitrate reductase and ATP-sulfurylase enzymes catalyze the first steps of the nitrate and sulfate assimilation pathways, respectively, they can be used as indicators of the states of regulation of these pathways

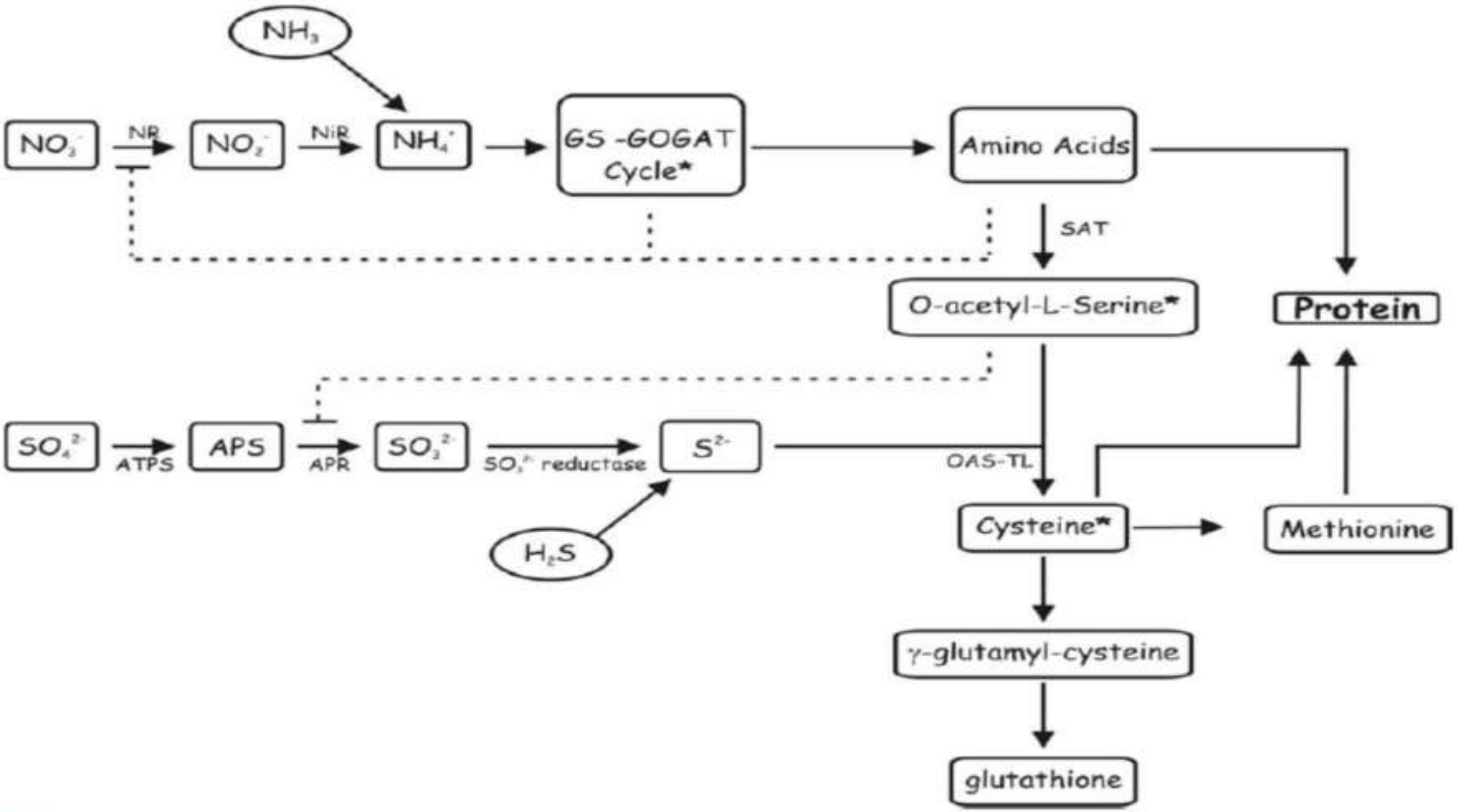
The assimilatory pathways of these elements have been considered convergent and well coordinated and hence a positive role of sulfate in regulating nitrate reductase was found in several reports and role of N in the regulation of sulfate assimilation at the ATP-sulfurylase step was observed

Absence of readily available external N source decreases ATP-sulfurylase activity

The interrelationship of the regulation of nitrate and sulfate assimilation has been found to be an effective mechanism to coordinate and meet the requirement of net protein synthesis.

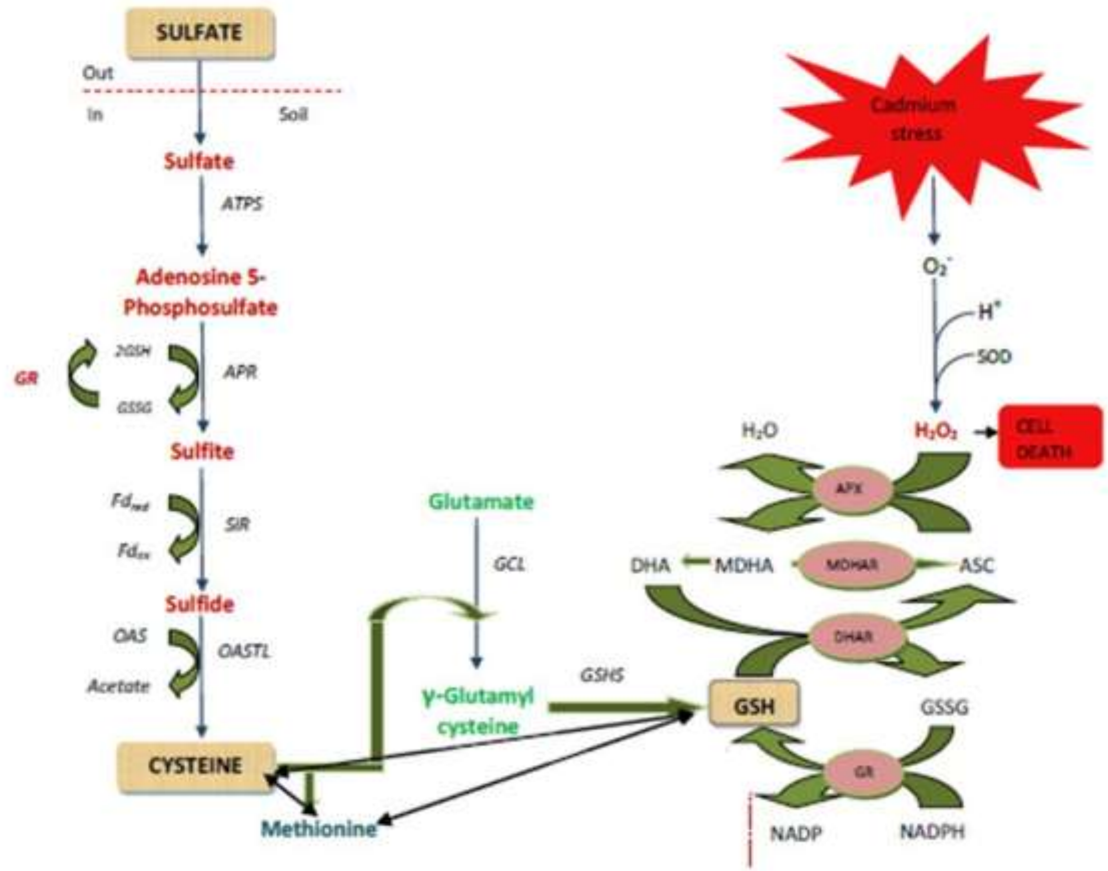
It has also been established through genetic studies that sulfate reduction is regulated by N nutrition at the transcriptional level

Interactions between N and S at a whole plant level



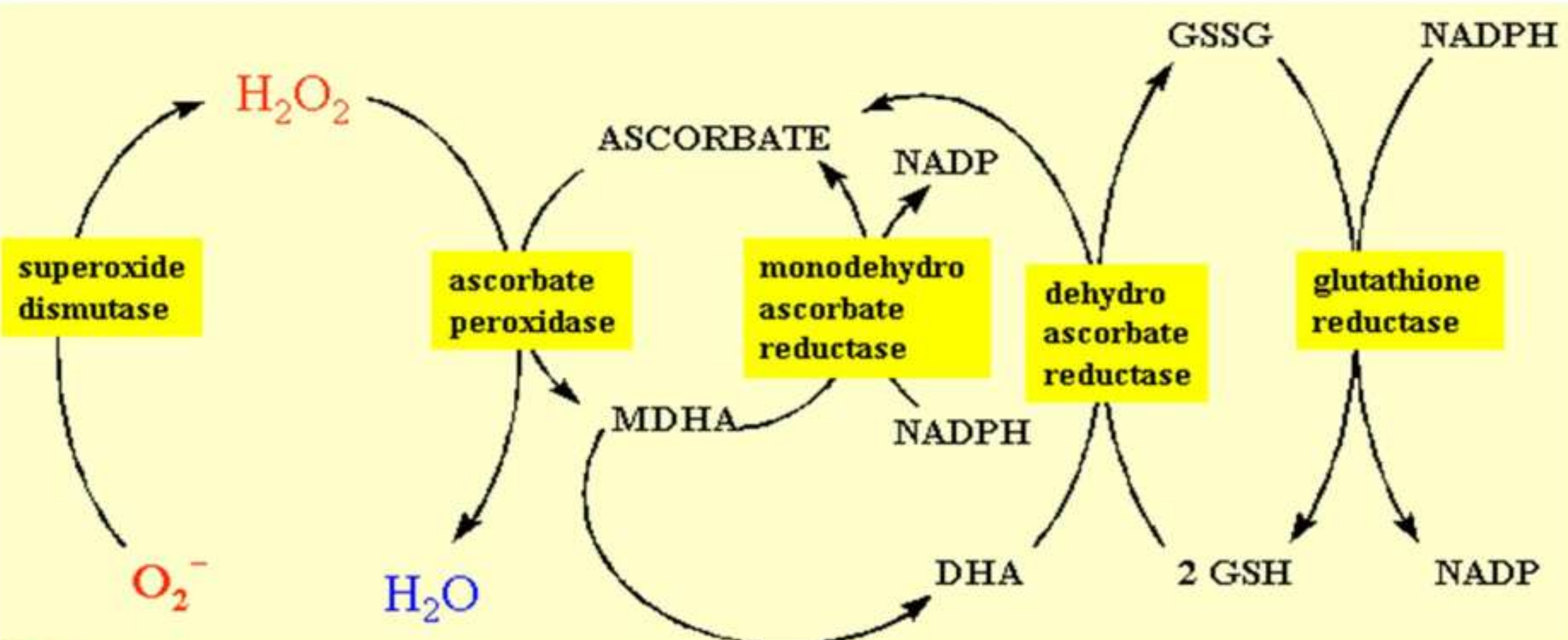
Presumed interactions between nitrogen and sulfur metabolism in plants

* represent the proposed sites of regulation; full arrows represent the main steps of nitrate and sulfate assimilatory pathways; dashed lines represent the rate limiting steps for N and S assimilatory pathways



Schematic representation of regulatory interaction of sulfur assimilation linked to ascorbate-glutathione pathway under Cd stress. ATPS, ATP sulfurylase; APR, adenosine 5-phosphosulfate reductase; SiR, sulfite reductase; ; OAS, O-acetylserine; OASTL, O-acetylserine (thiol) lyase; GR, glutathione reductase; GSH, glutathione reduced; GSSG, Glutathione oxidized; SAM, S-adenosyl methionine; ACC. 1-aminocyclopropane carboxylic acid; ACS, ACC synthase; ACO, ACC oxidase; GCL, Glutamate cysteine ligase; GSHS, GSH synthetase; ASC, ascorbate; DHA, dehydroascorbate; DHAR; DHA reductase; MDHA, monodehydroascorbate; MDHAR, MDHA reductase; APX, ascorbate peroxidase ; SOD, Superoxide dismutase.

COMPONENTS OF ANTIOXIDANT DEFENSE SYSTEM IN PLANTS – AT A GLANCE



Ascorbate-glutathione cycle [THE HALLIWELL-ASADA PATHWAY]

Cadmium – is of Special concern: A case study

- Due to

  \- Its wide availability and potential toxicity to biota at low concentrations

Sources of Cd pollution

- Power stations
- Heating systems
- Metal working industries
- Waste incinerators
- Urban traffic
- Cement factories
- Byproduct of sewage sludge
- Phosphatic fertilizers

- Coordination of sulfur and nitrogen proved effective in mustard cultivation. A package of these nutrients not only helped in increasing crop productivity but also exhibited its potential in the alleviation of Cd effects.

- Among the N levels applied, 80mg N kg^{-1} soil strengthened the effectiveness of 50mg S kg^{-1} soil in the alleviation of 50mg Cd kg^{-1} soil induced reductions in both the cultivars at all growth stages. The effectiveness of the combined application of 50mg S kg^{-1} soil plus 80mg N kg^{-1} soil was different in tolerant and non-tolerant cultivars. In Alankar (tolerant cultivar), the Cd-induced reductions in growth, photosynthetic, biochemical and yield characteristics were completely overcome, whereas, the reductions in these characteristics were only lowered by this combination in RH30 (non-tolerant cultivar).

- Application of 50mg S kg^{-1} soil and 80mg N kg-1 soil to 50mg Cd kg^{-1} soil treated plants increased the ATP-sulfurylase activity and S content and also improved the NR activity and N content to a greater extent.
- Cadmium-induced increase in root and leaf Cd content was lowered by the combined application of 50mg S kg^{-1} soil and 80mg N kg^{-1} soil to 50mg Cd kg^{-1} soil treated plants in both the cultivars at all growth stages. The extent of decrease in Cd content was more in Alankar than RH30.
- The accumulation of TBARS and H_2O_2 due to 50mg Cd kg^{-1} soil was lowered by the combined application of 50mg S kg^{-1} soil and 80mg N kg^{-1} soil in both the cultivars at all growth stages. The extent of decrease in TBARS and H2O2 content was greater in Alankar than RH30

- Application of 50mg S kg^{-1} soil plus 80mg N kg^{-1} soil reversed the reduction in yield characteristics of Alankar and values reached on par to control. Whereas, this combination only lowered the reduction in yield characteristics of RH30

- Nutrients are known to decipher essential role in plant metabolism and augmenting growth and productivity of crops. However, a nutrient package is required for sustainable agriculture under varied environmental conditions.

- Crop cultivars display their inherent potential. The cultivar Alankar surpassed other cultivars tested and tolerated Cd stress to a significant degree. The cultivar RH30 was weak in performance and least tolerant to Cd among the cultivars tested.

- Therefore, Alankar exhibited lesser decreases in growth, photosynthetic and yield characteristics under Cd stress.
- Correspondingly, Alankar also showed lesser oxidative stress and increased antioxidant system than RH30 to protect photosynthetic machinery and consequent effects on other attributes.
- Sulfur proved significant potential in the alleviation of Cd stress in both the cultivars

- The coordination of S and N proved most effective in nullifying the Cd stress effects. The potential of 50mg S kg-1 soil in the alleviation of Cd stress was substantially enhanced by the simultaneous application of 80mg N kg-1 soil.

- A package of 50mg S kg^{-1} soil plus 80mg N kg^{-1} soil appears to be most effective in the cultivation of mustard under Cd stress.

- The effect of this combination was due to coordination of S and N in maintaining plant metabolism and alleviating Cd stress.

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