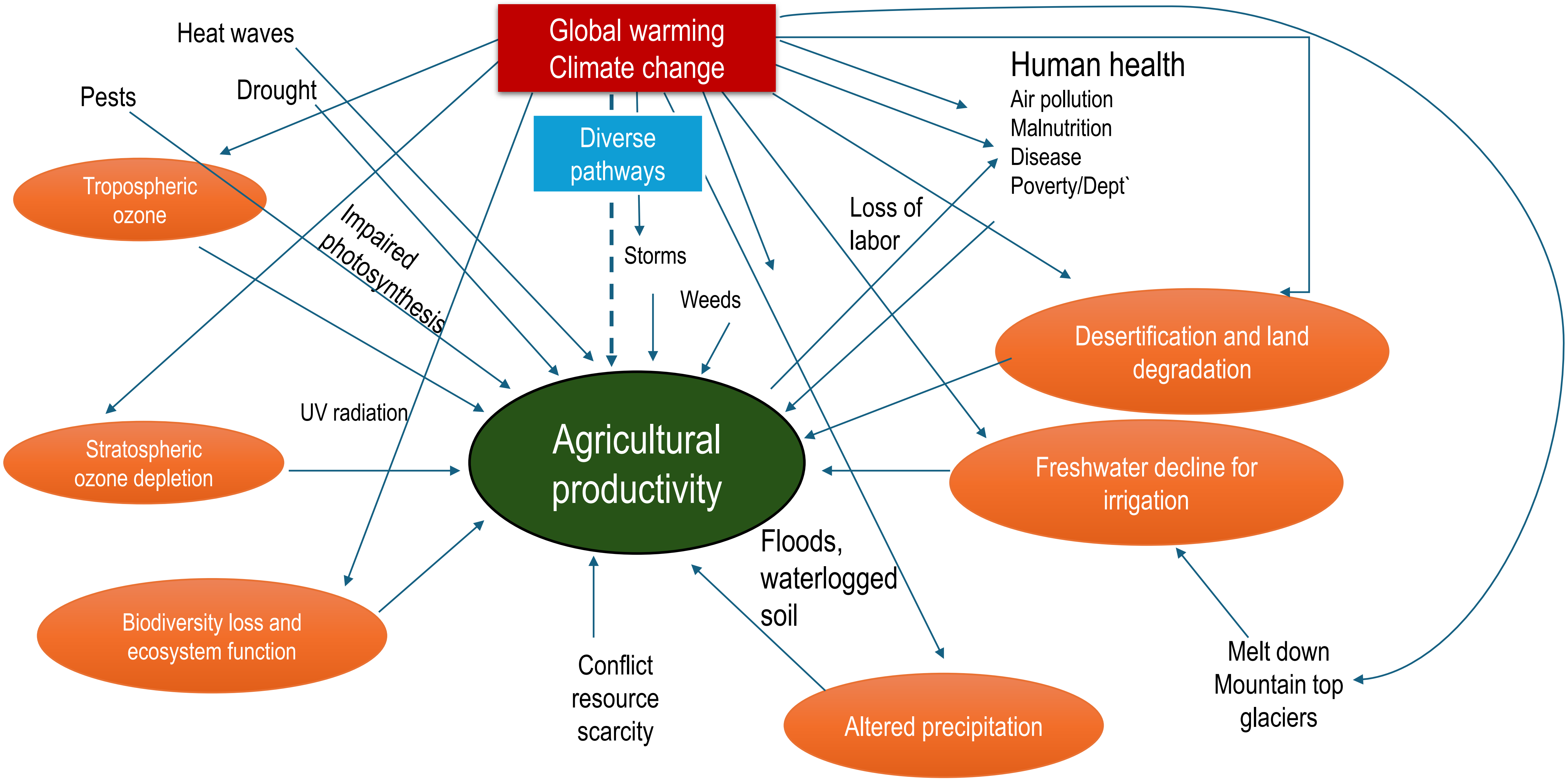
Stress Agronomy

AGRO 451

Prof. Mirza Hasanuzzaman
Department of Agronomy
SAU
mirzahasan.info.bd

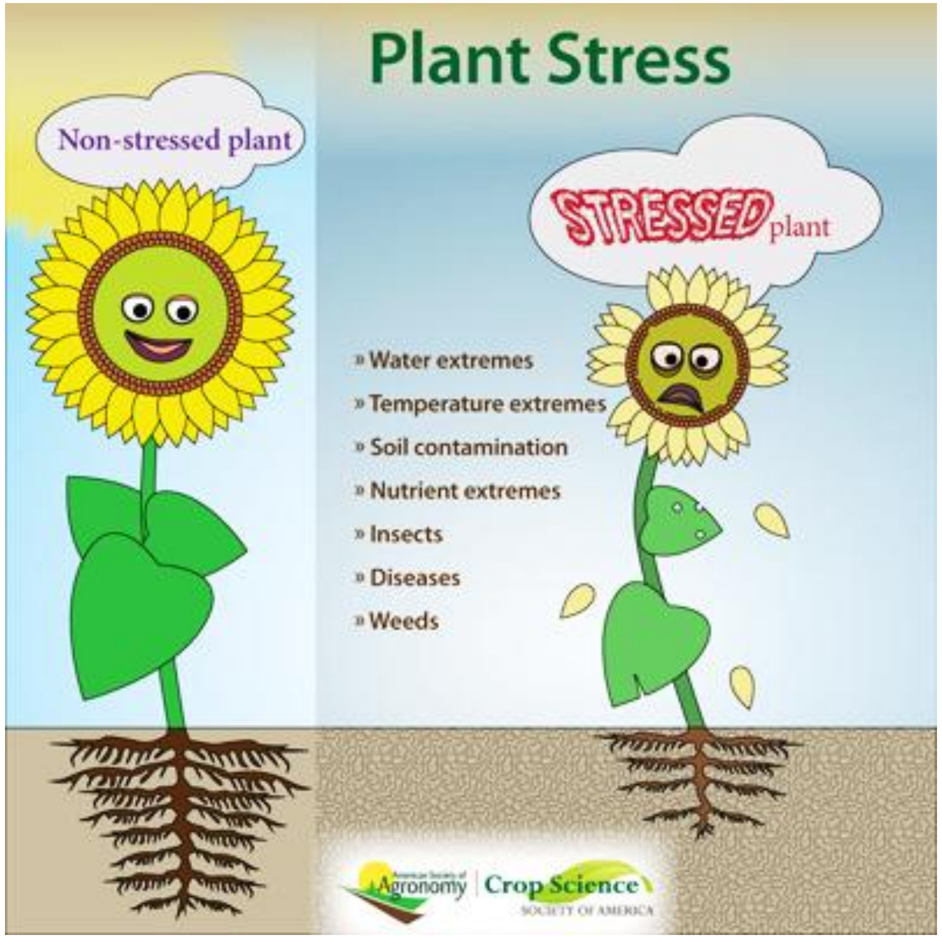
Global warming and climate disruption have multiple impacts on agriculture



What is Stress ?

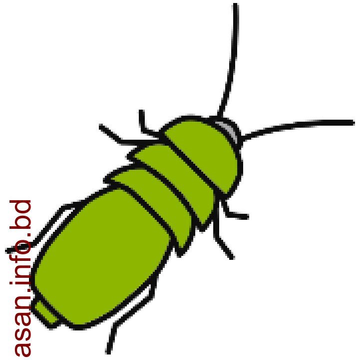
Stress is usually defined as an external factor that negatively influences the plant. Plants are frequently exposed to environmental stresses in both natural and agricultural conditions.

Stress is defined as a phenomenon that **limits crop productivity or destroys biomass** (Grime, 1979).

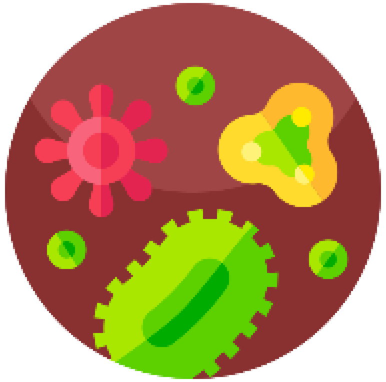


Stressor

A stressor is a chemical or biological agent, environmental condition, external stimulus or event that causes stress to an organism.

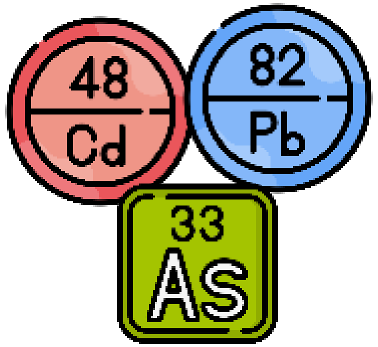


Pest

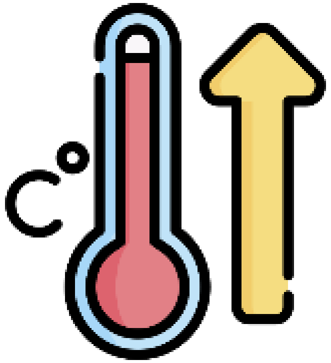


Pathogen

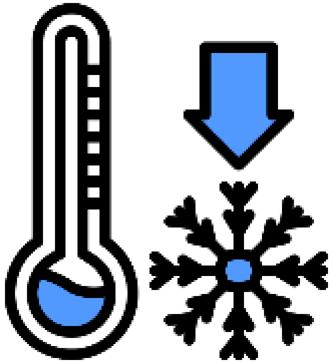
Salt



Toxic metals



High temperature



Low temperature

Excess water

Water shortage

Strain

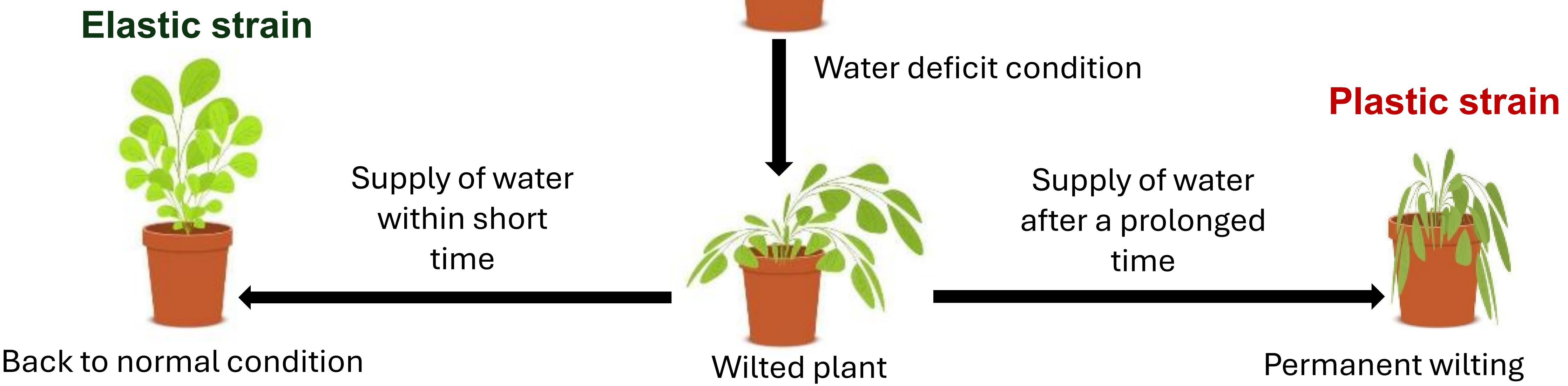
Strain is the biological changes of plants under the influence of plant stress. Strain can be elastic or plastic depending on the degree and lasting time of stress.

Elastic strain

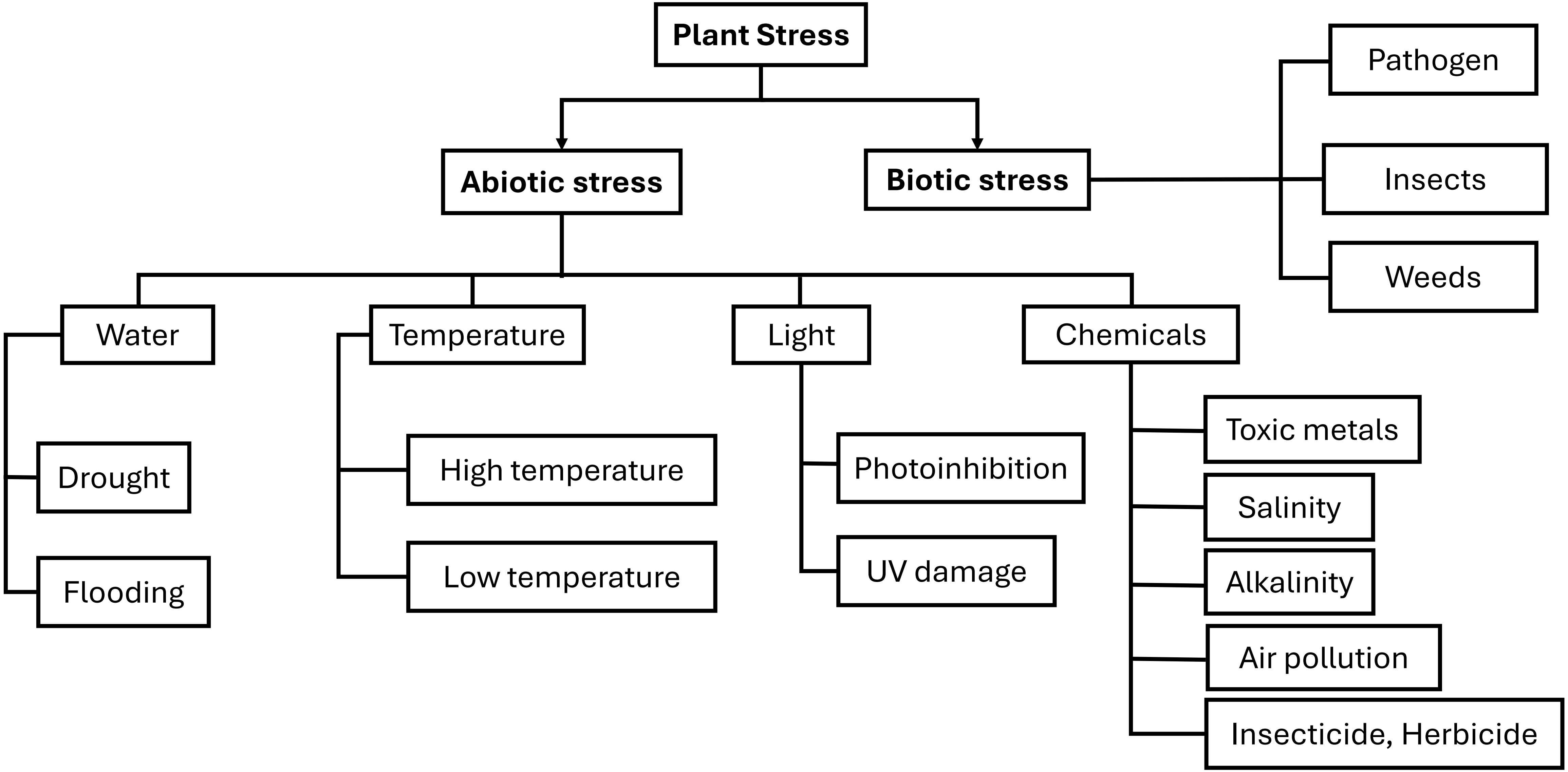
Up to a point, a strain may be completely reversible and when the stress is relieved, the plant becomes normal.

Plastic strain

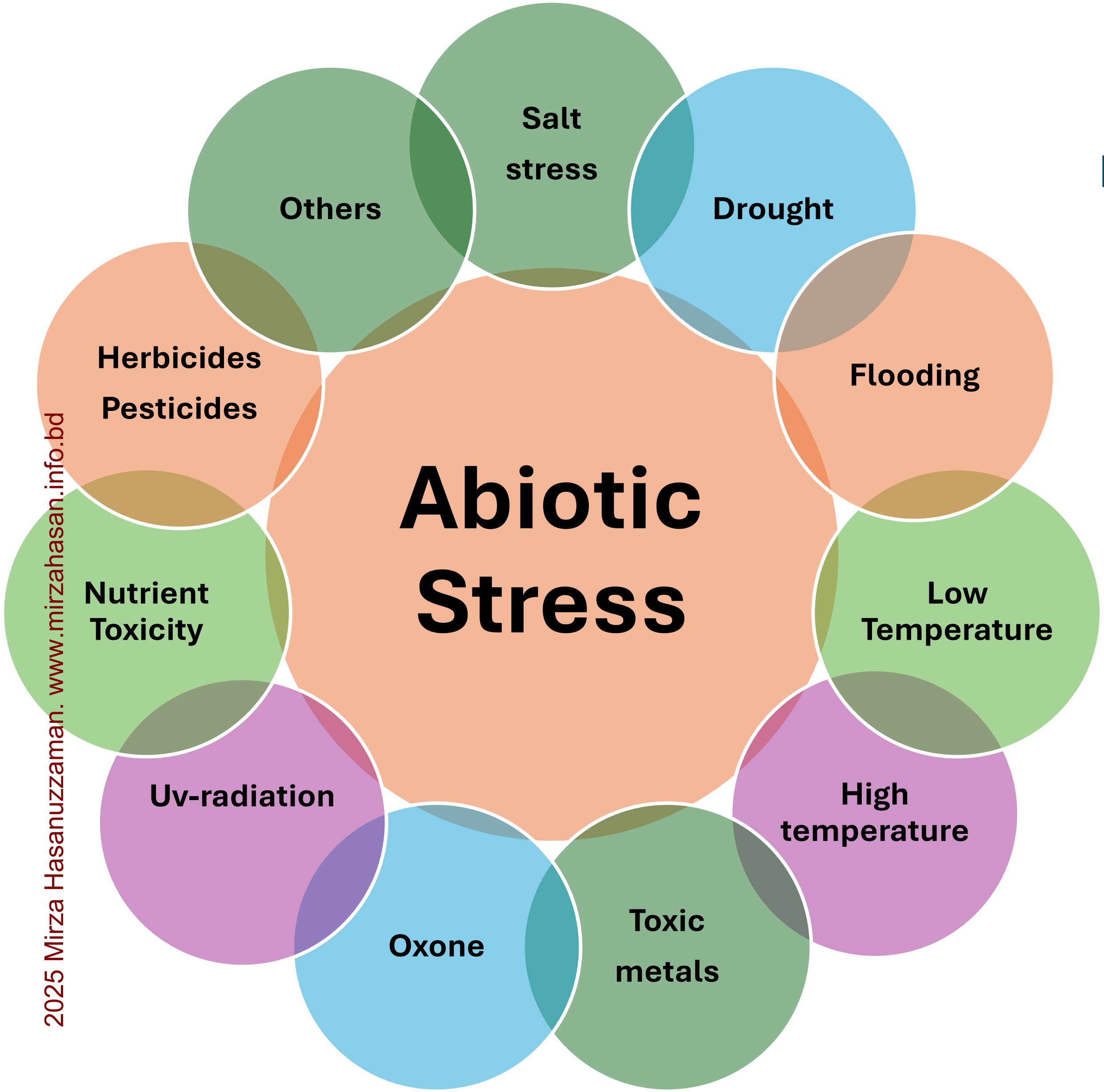
Beyond the elastic strain, the strain may be irreversible on partially reversible irreversible, called plastic strain or permanent set.



Types of Stress



Abiotic Stress



Abiotic stress is defined as the negative impact of non-living factors on the living organisms in a specific environment.

It has been estimated that more than 50% of yield reduction directly results from abiotic stresses. Abiotic stress leads to morphological, physiological, biochemical, and molecular changes that adversely affect plant growth and productivity

Plant Responses to Stress

Abiotic stress responses of plants

Growth

- Germination inhibition
- Growth reduction
- Premature senescence
- Reduction in biomass

Physiology

- Reduction in water uptake
- Altered transpiration rate
- Reduction in photosynthesis
- Altered respiration
- Metabolic toxicity
- Accumulation of growth inhibitors

Molecular Biology

- Altered gene expression
- Breakdown of macromolecules
- Reduced enzyme activity
- Decreased protein synthesis

Salinity

Salinity is defined as the presence of **excessive amounts of soluble salts** that hinder or affect the normal functions of plant growth.

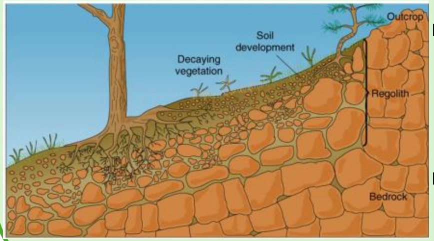
Soil salinity is measured by electrical conductivity (EC), exchangeable sodium percentage (ESP), and pH of a saturated soil paste. A soil is called saline when its EC is more than 4 dSm^{-1}, ESP is below 15%, and pH is less than 8.5 (Waisel, 1972; Abrol, 1986; Szabolcs, 1994). Saline soils contain salts of chloride and sulfate of sodium, magnesium, and calcium, with sodium chloride being the most common.

Types and Causes of Salinity

Causes of salinity

Natural causes

Weathering of parent materials containing soluble salts



Na^+, Mg^{2+}, Cl^-, SO_4^{2-}, CO_3^{2-}

Deposition of sea salt

Anthropogenic causes

Use of agrochemicals

Land clearing

Cropping practices

Types and Causes of Salinity

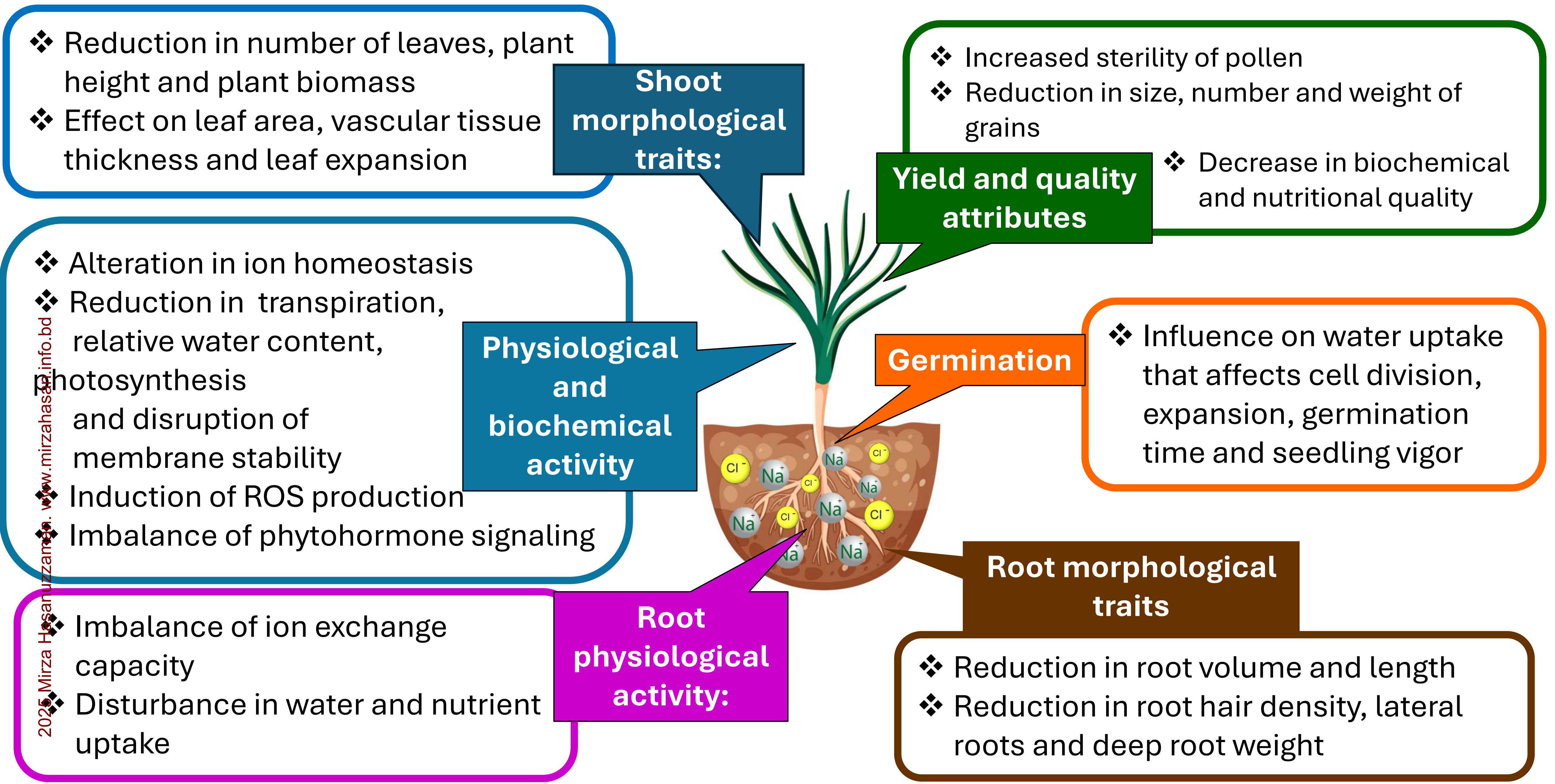
Primary salinity

- **Primary salinity** occurs naturally over a long time.
- Caused by **weathering of rocks** containing soluble salts like Na^{+}, Ca^{2+}, and Mg^{2+}.
- Includes salts such as **chlorides, sulfates, and carbonates**.
- **Sea salt** from wind and rain also increases soil salinity.

Secondary salinity

- Results from **human activities** that disturb the soil's water balance between irrigation/rainfall and crop transpiration.
- Most irrigation systems have led to **secondary salinity, sodicity, or waterlogging**.
- After irrigation, water is **either used by crops or lost via evaporation** from the soil.
- **Salinization** can appear as a **whitish salt layer** on the soil surface.

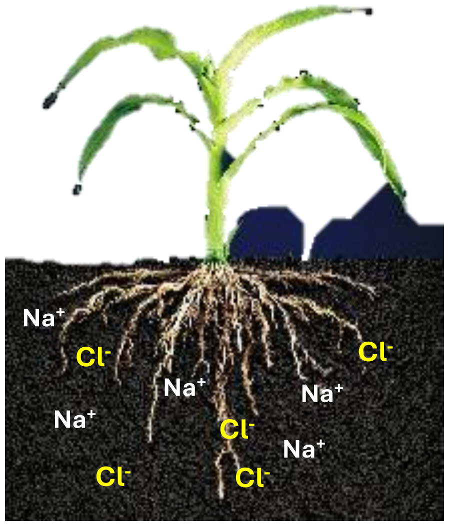
Detrimental effects of salt stress on various plant parts



Effects of Salinity in Plant

Physiological and Biochemical Responses :

Salt Stress !!!!



- Oxidative Stress
- Osmotic Stress
- Ionic Stress

- Reduced cellular and metabolic activity
- Photosynthesis inhibition
- Stomatal closure
- Membrane and protein destabilization
- Disruption of cell organelle
- High Na^+ transport
- Low K^+ uptake
- Enzyme activity inhibition

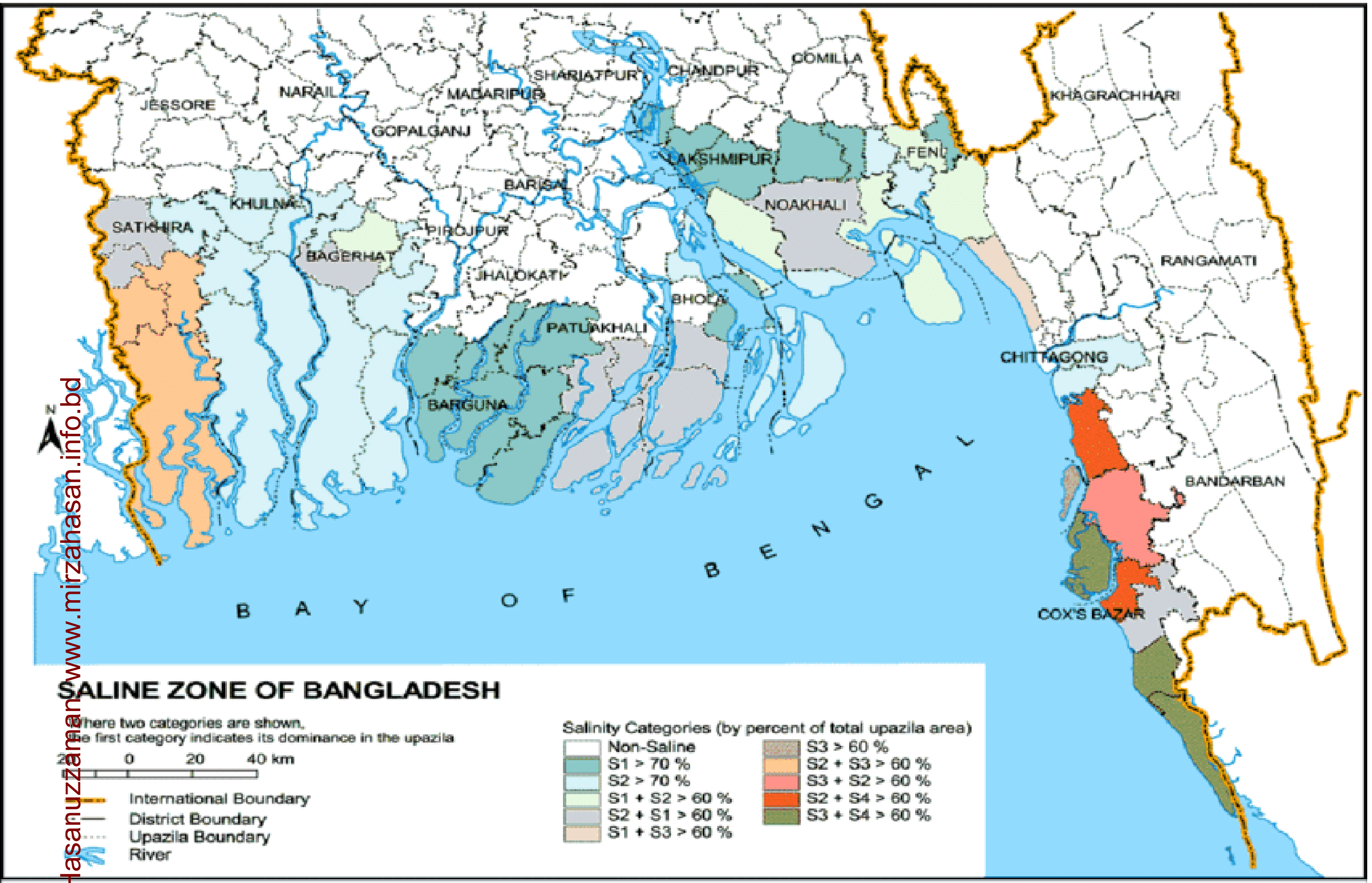
Secondary Effects of Salt Stress

Effects of Salinity in Plant
Yield Responses

- Increased non productive tillers
- Less biomass production
- Reduction in yield
- Decrease in seed quality
- Low harvest index
- Low grain weight

Atta et al. (2023), DOI:
https://doi.org/10.3389/fpls.2023.1241736

Saline Zone of Bangladesh



Source: Bangladesh Agriculture Research Council

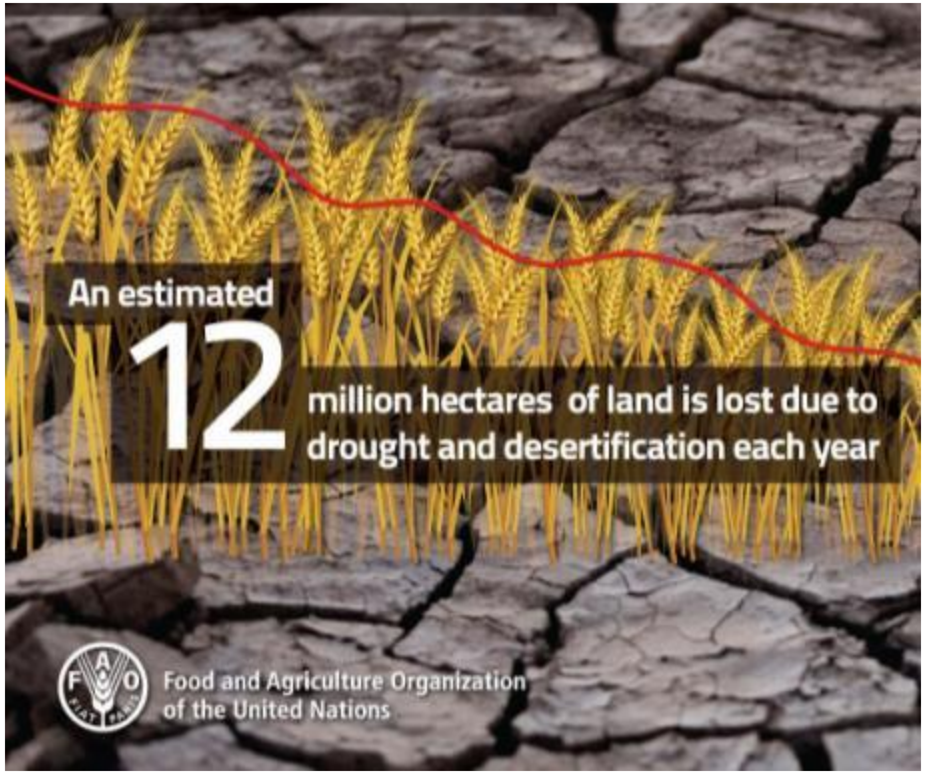
- ❖ Coastal areas cover **about 20% of Bangladesh's total area (147,570 km²)** and extend **up to 150 km inland**.
- ❖ Out of **2.85 million hectares** of coastal and offshore land, **0.83 million hectares are arable**, representing **over 30% of the country's cultivable land**.
- ❖ The **Sundarbans**, a natural mangrove forest, covers **approximately 4,500 km²** of the coastal area.
- ❖ Remaining coastal land is used for **agriculture**, with cultivable areas affected by **varying degrees of soil and water salinity**.

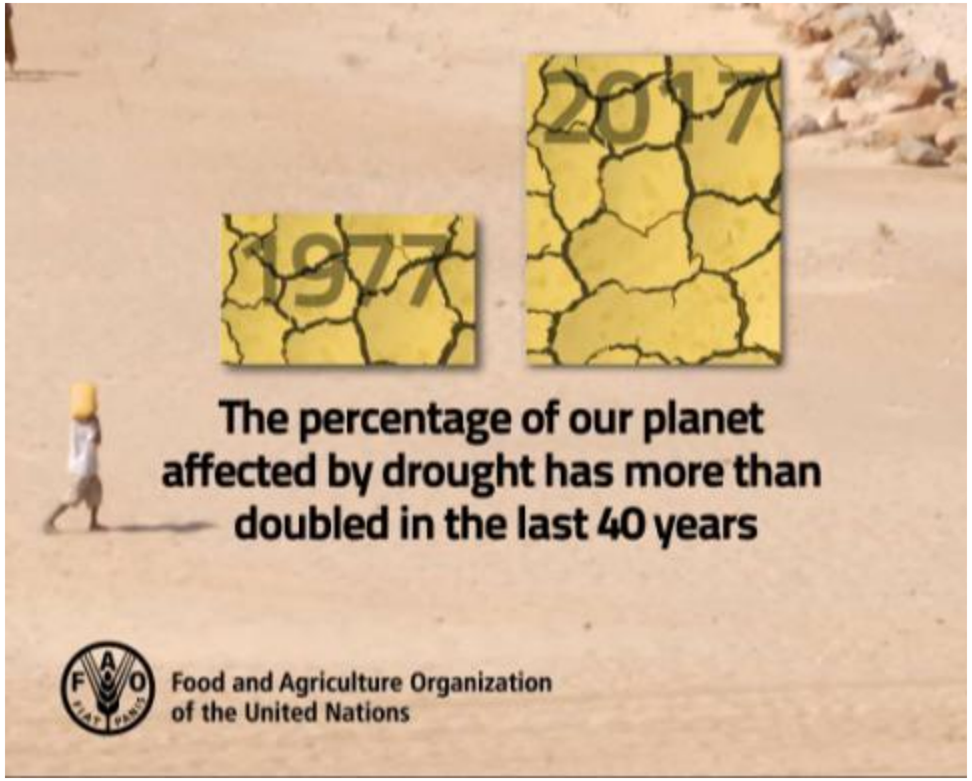
Salt Tolerant Crops

Salt tolerances	Crops
Sensitive	Rice, Sesame, Common bean, Mung bean, Carrot, Black gram, Onion, Strawberry, Apple, Apricot, Banana, Cherry, Mango
Moderately sensitive	Chick pea, Maize, Flax, Groundnut, Sugarcane, Alfalfa, Broad bean, Cauliflower, Cucumber, Brinjal, Garlic, Lettuce, Melon, Okra, pea, Chili, Potato, Pumpkin, Spinach, Grape, Tomato, Papaya
Moderate tolerate	Roselle, Safflower, Sorghum, Soybean, Sunflower, Wheat, Cowpea, Coconut, Jujube
Tolerant	Barley, Mustard, Canola, Cotton, Kenaf, Oat, Rye, Sugar beet, Asparagus
Highly tolerant	Date palm, Stone pine, Saltgrass

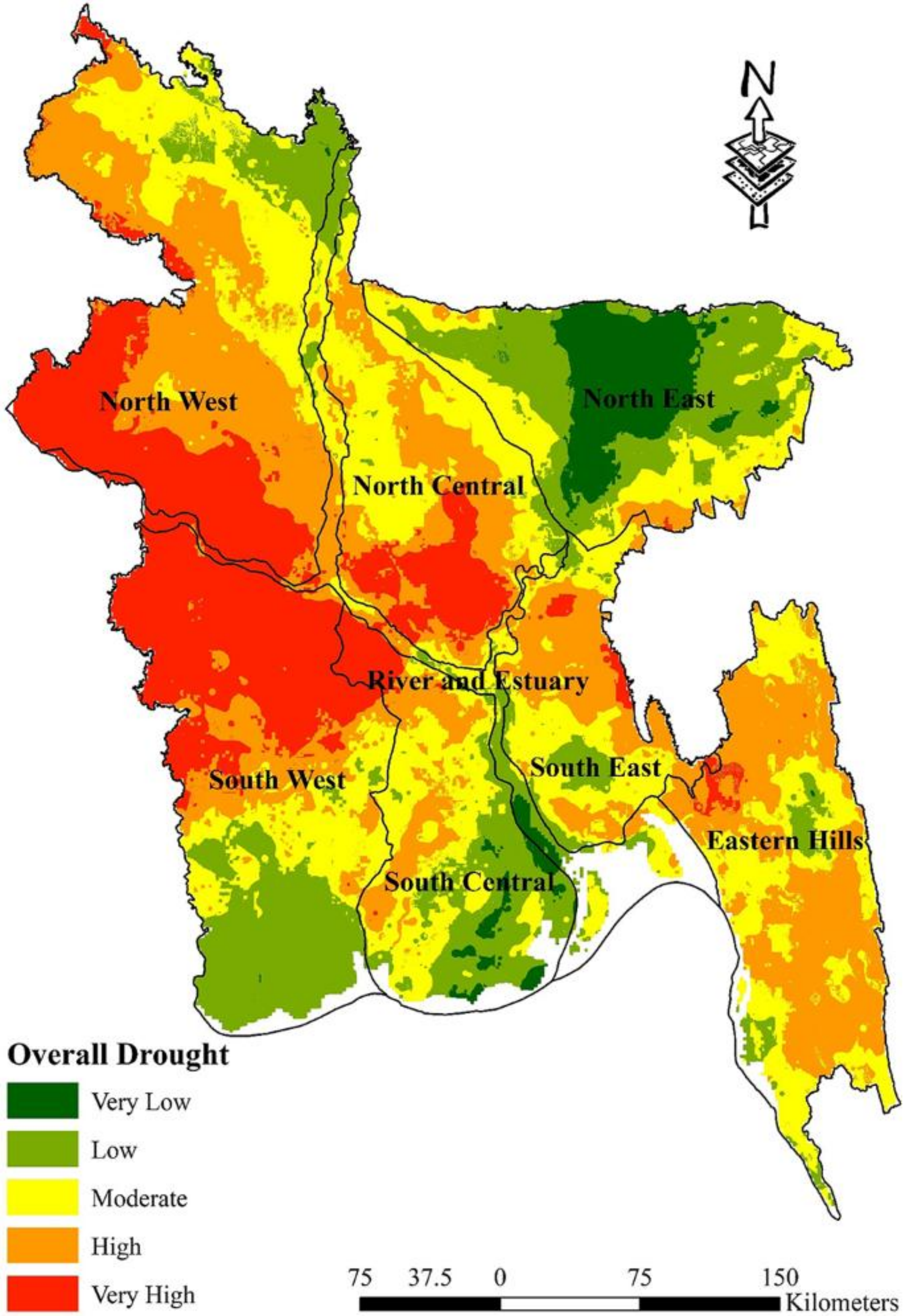
Tanji and Kielen, 2003

Drought

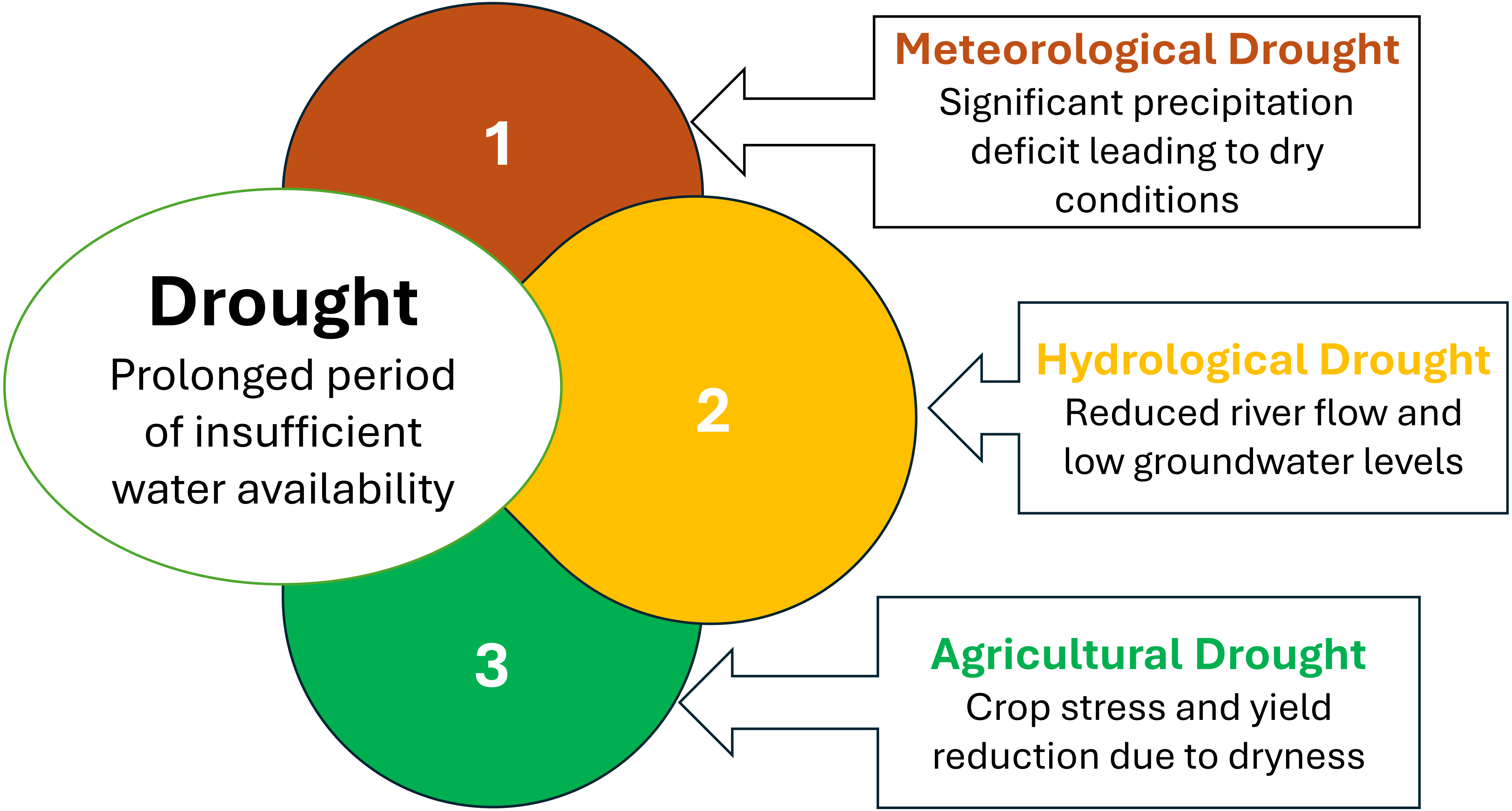

An estimated
12
million hectares of land is lost due to drought and desertification each year
Food and Agriculture Organization of the United Nations

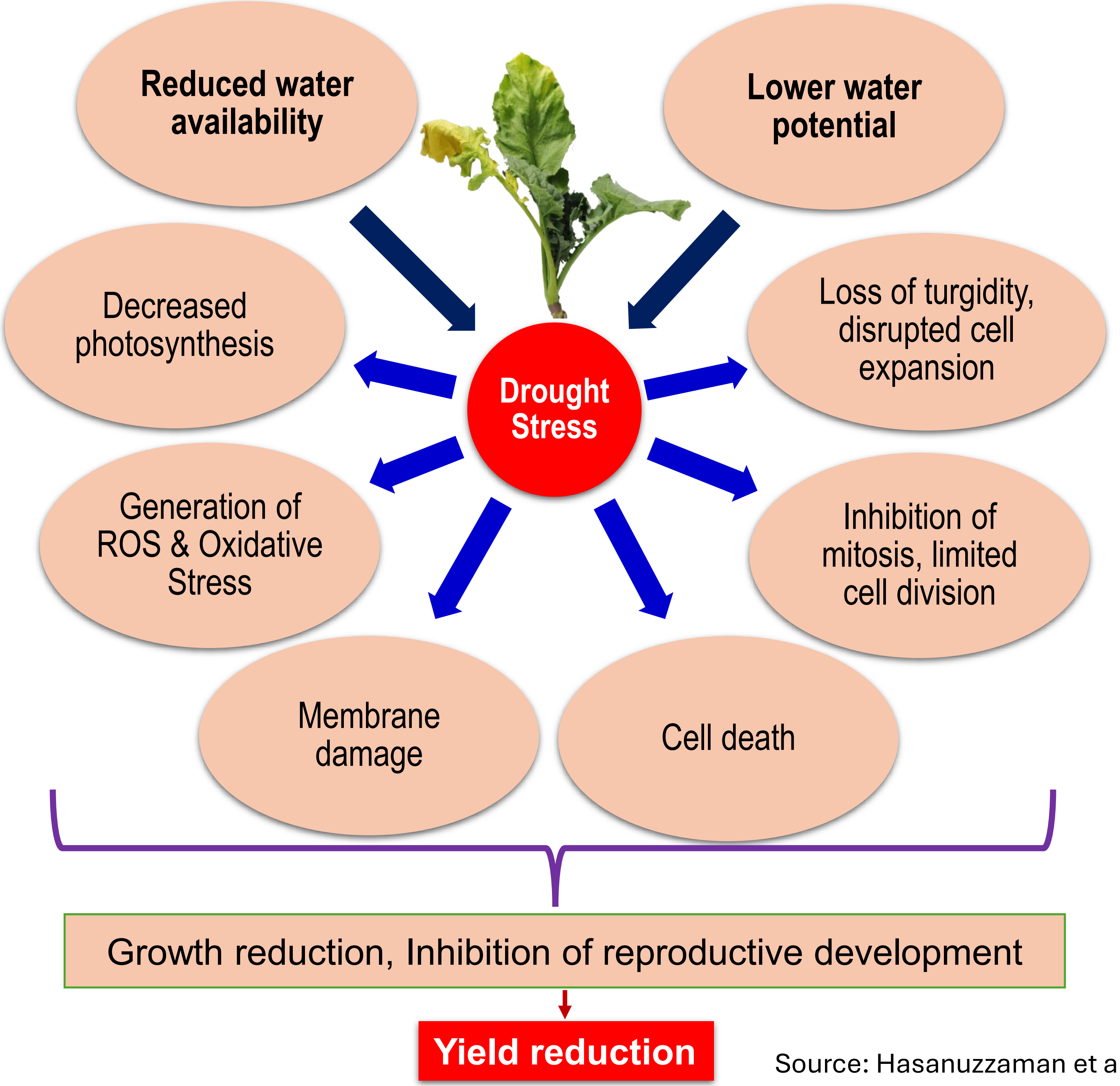

2017
1977
The percentage of our planet affected by drought has more than doubled in the last 40 years
Food and Agriculture Organization of the United Nations

Drought Prone Area in Bangladesh



Types of Drought

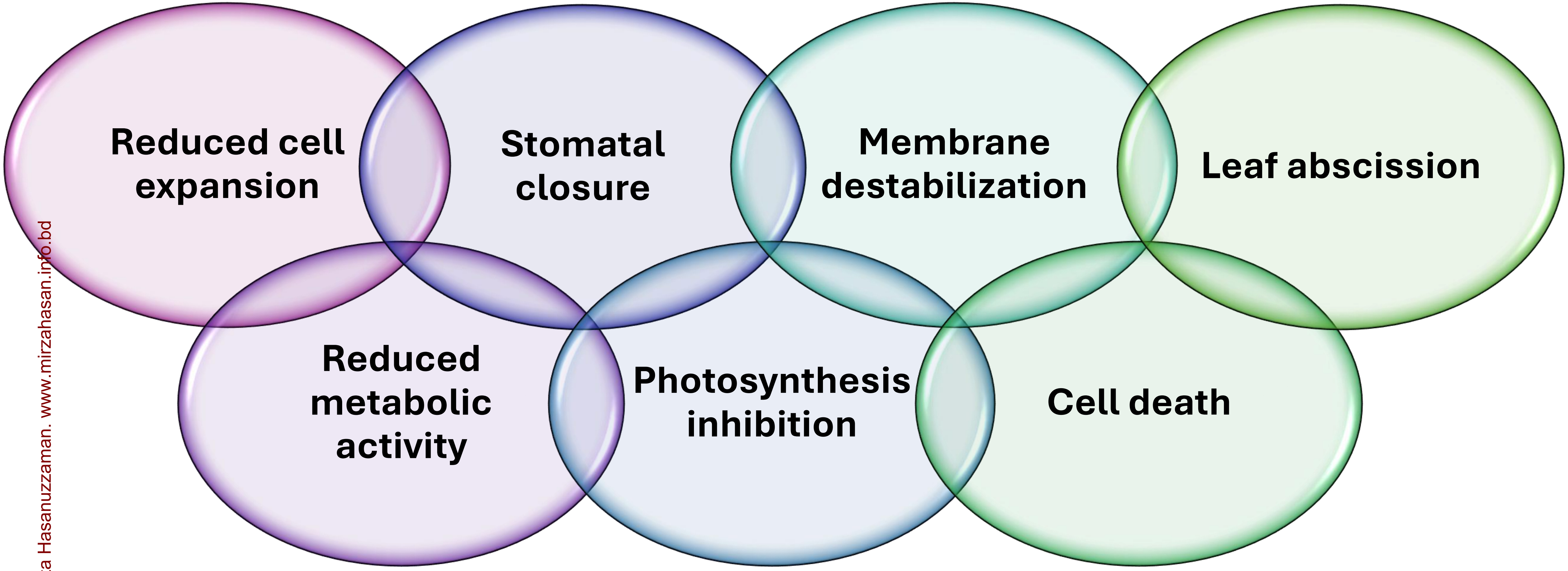




Source: Hasanuzzaman et al. (2014)

Effects of Drought in Plant

Physiological and Biochemical Responses :



Secondary effects of drought

Effects of Drought in Plant

Yield Responses

Reduced number of tillers or pods per plant.

Decreased number of grains per spike or cob.

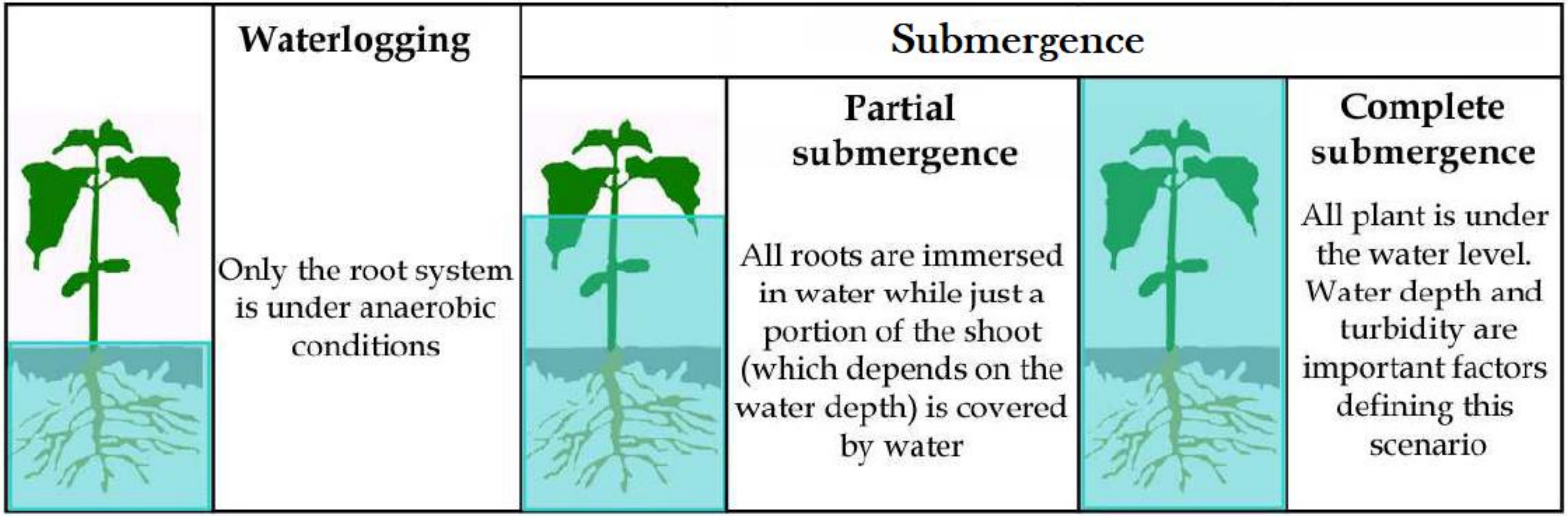
Increased unfilled grain.

Lower 1000-grain weight.

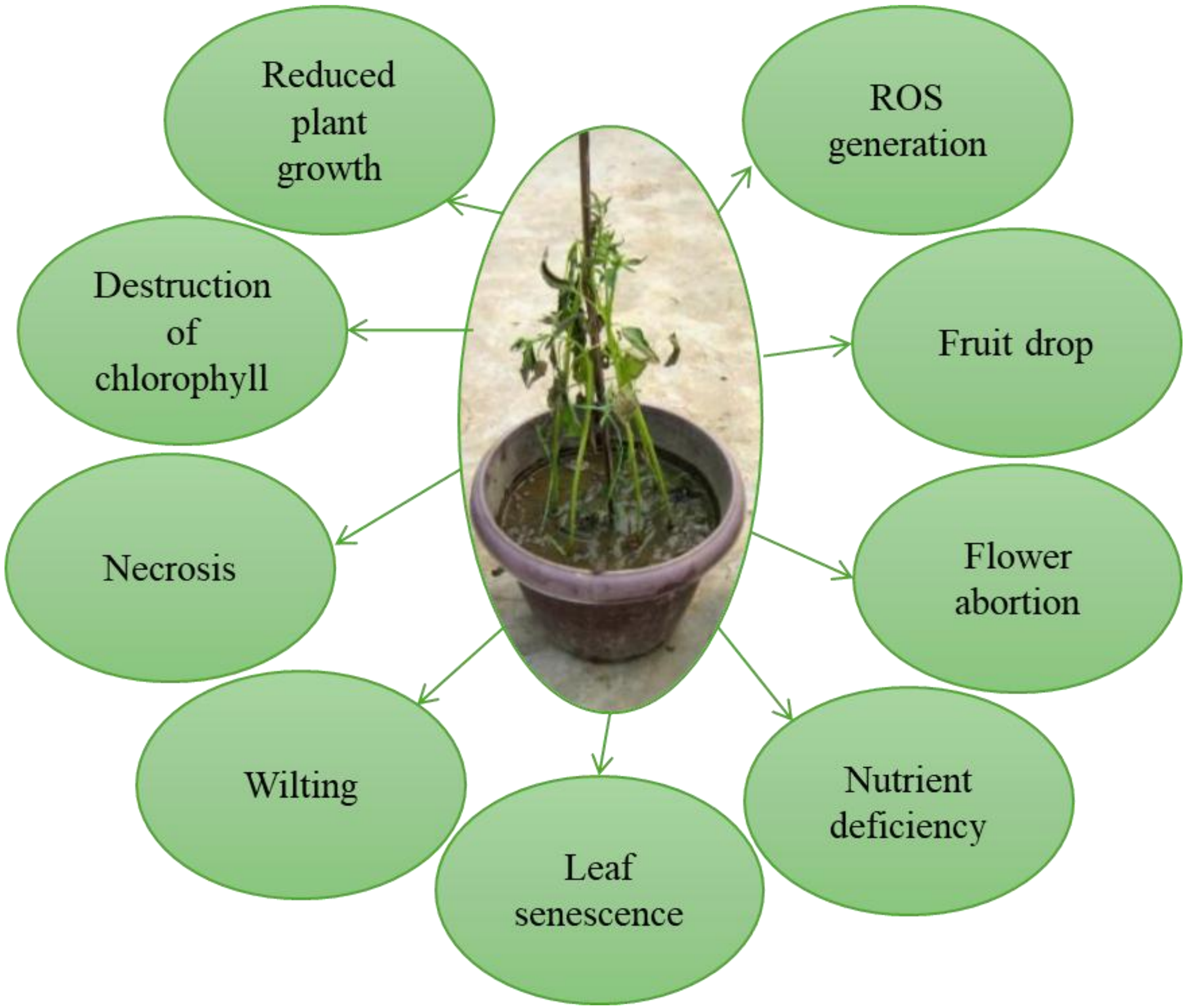
Fewer fertile florets and poor seed set.

Overall decline in harvest index and total yield.

Plant responses to flooding



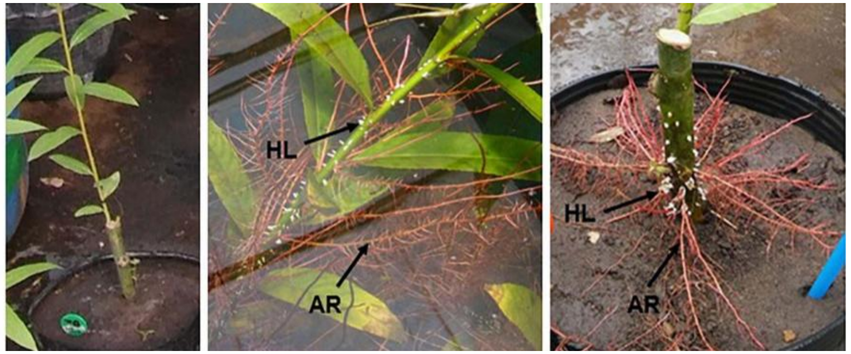
Effects of excess water stress



Source: Hasanuzzaman et al. (2017); Springer, New York

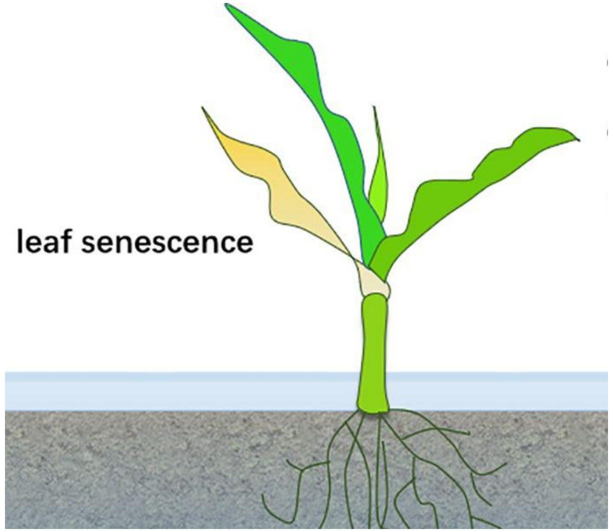
Effects of Flooding in Plant

Morphological effects of flooding in plants

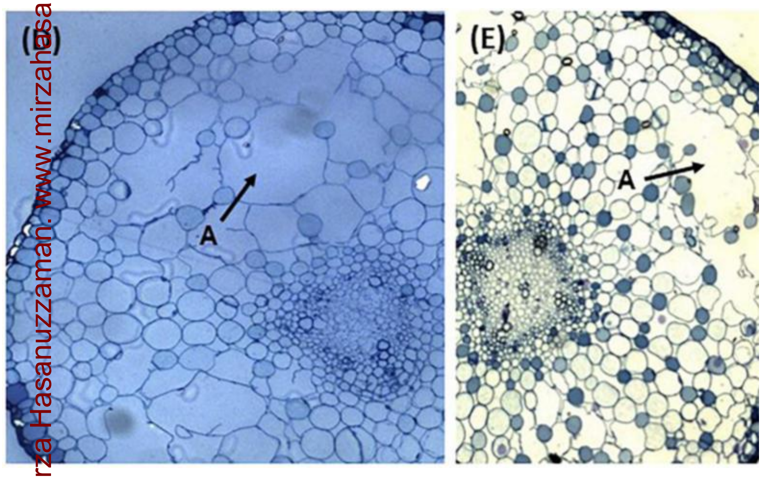


Reduced primary root growth; formation of adventitious roots

Root decay and browning

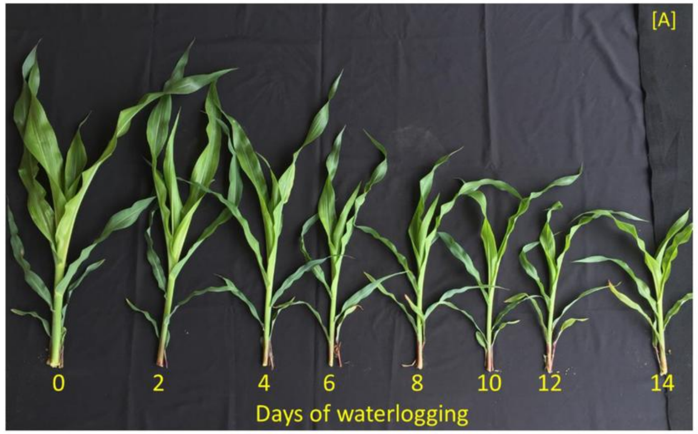


Leaf yellowing (chlorosis), wilting, and senescence



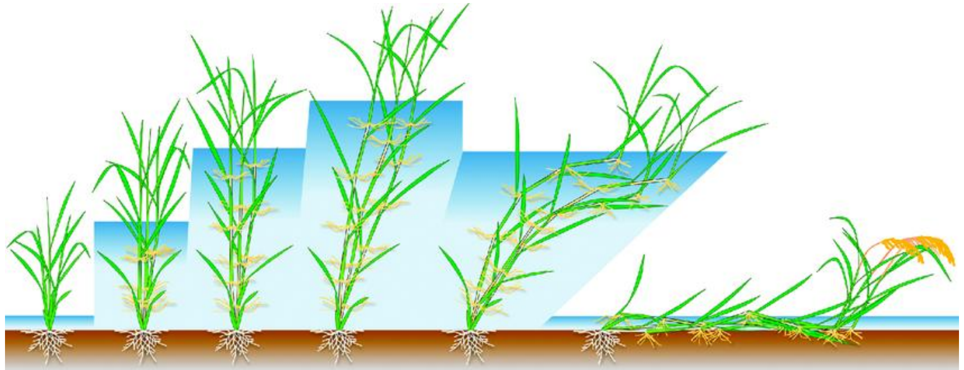
https://doi.org/10.3389/fpls.2021.575090

Development of aerenchyma tissue



DOI:10.3390/plants10102095

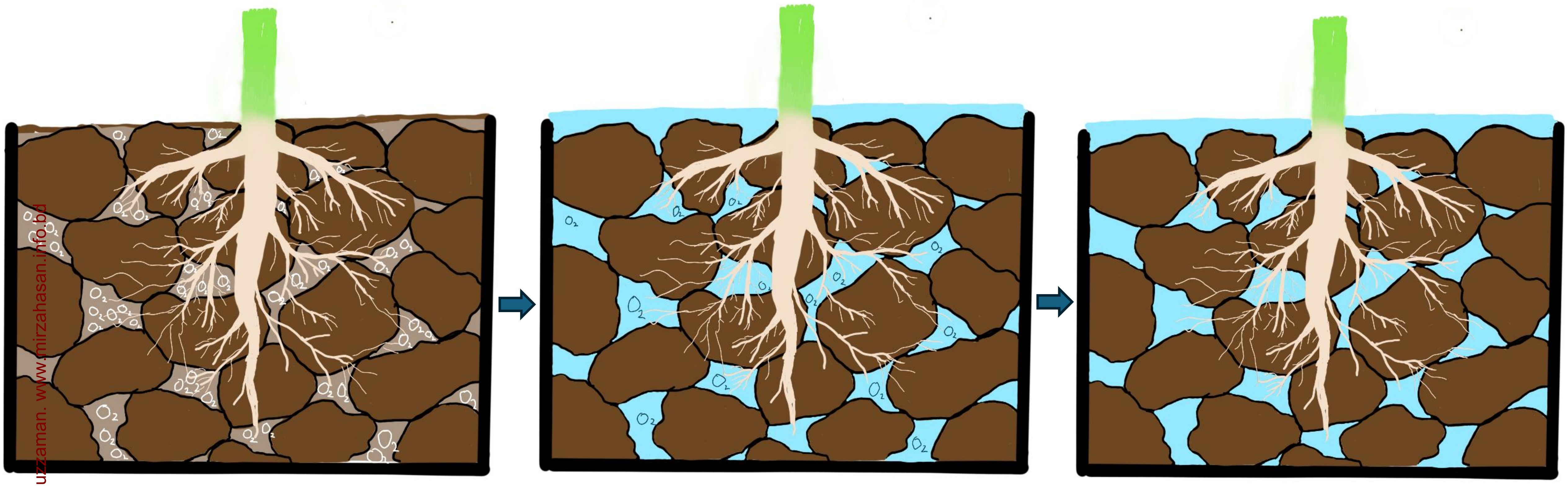
Reduced shoot height and biomass



Elongation in some flood-tolerant plants

Effects of Flooding in Plant

Physiological and Biochemical Responses :



Normal condition
Required amount of oxygen present in soil

Hypoxia
Insufficient oxygen

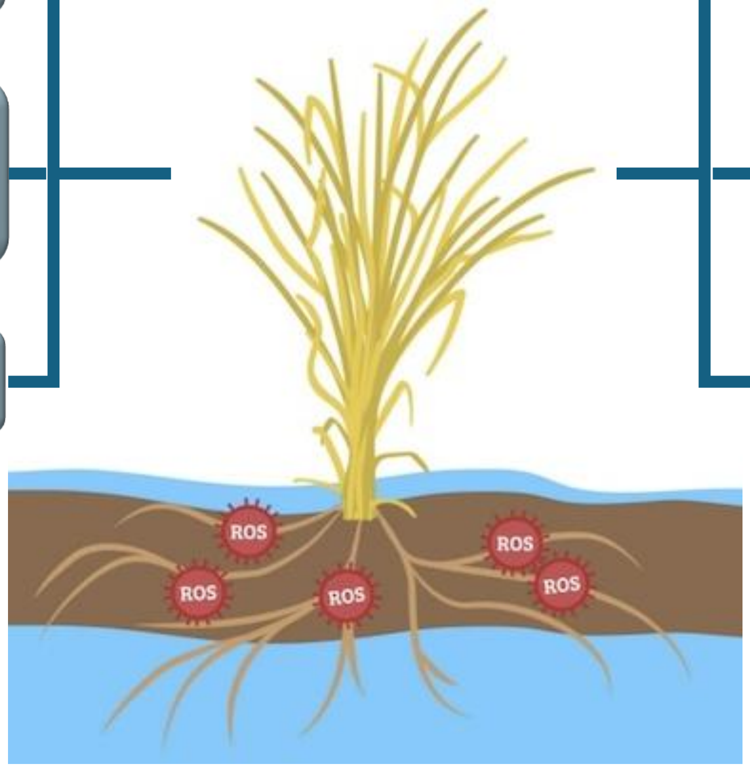
Anoxia
Complete absence of oxygen

Primary effects of flood stress

Effects of Flooding in Plant

Physiological and Biochemical Responses :

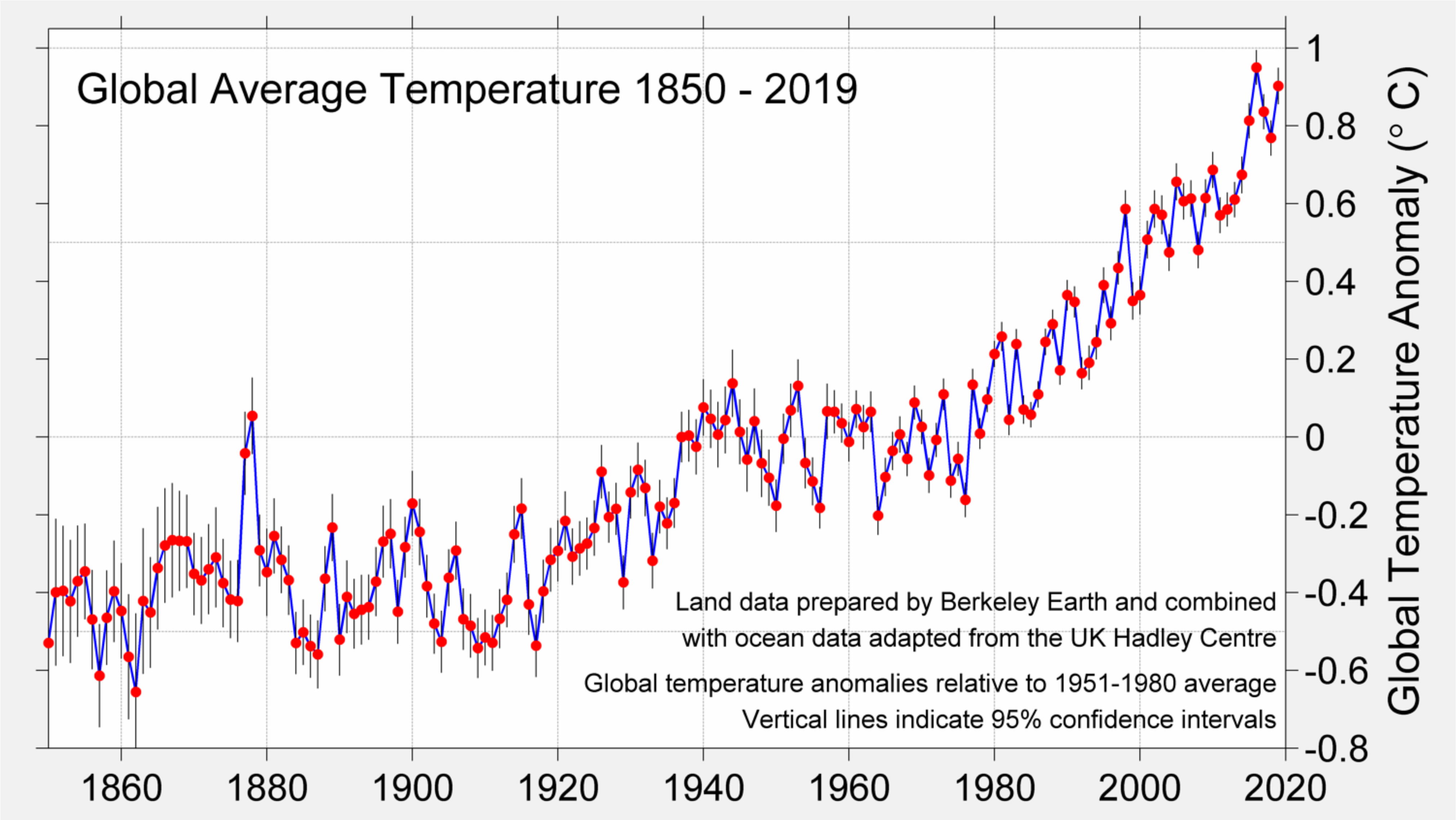
- Reduced cell respiration
- Increased ethylene and ABA levels
- Stomatal closure



- Fermentative metabolism
- Reactive oxygen species (ROS) production
- Inadequate ATP production

Secondary effects of flood stress

High temperature

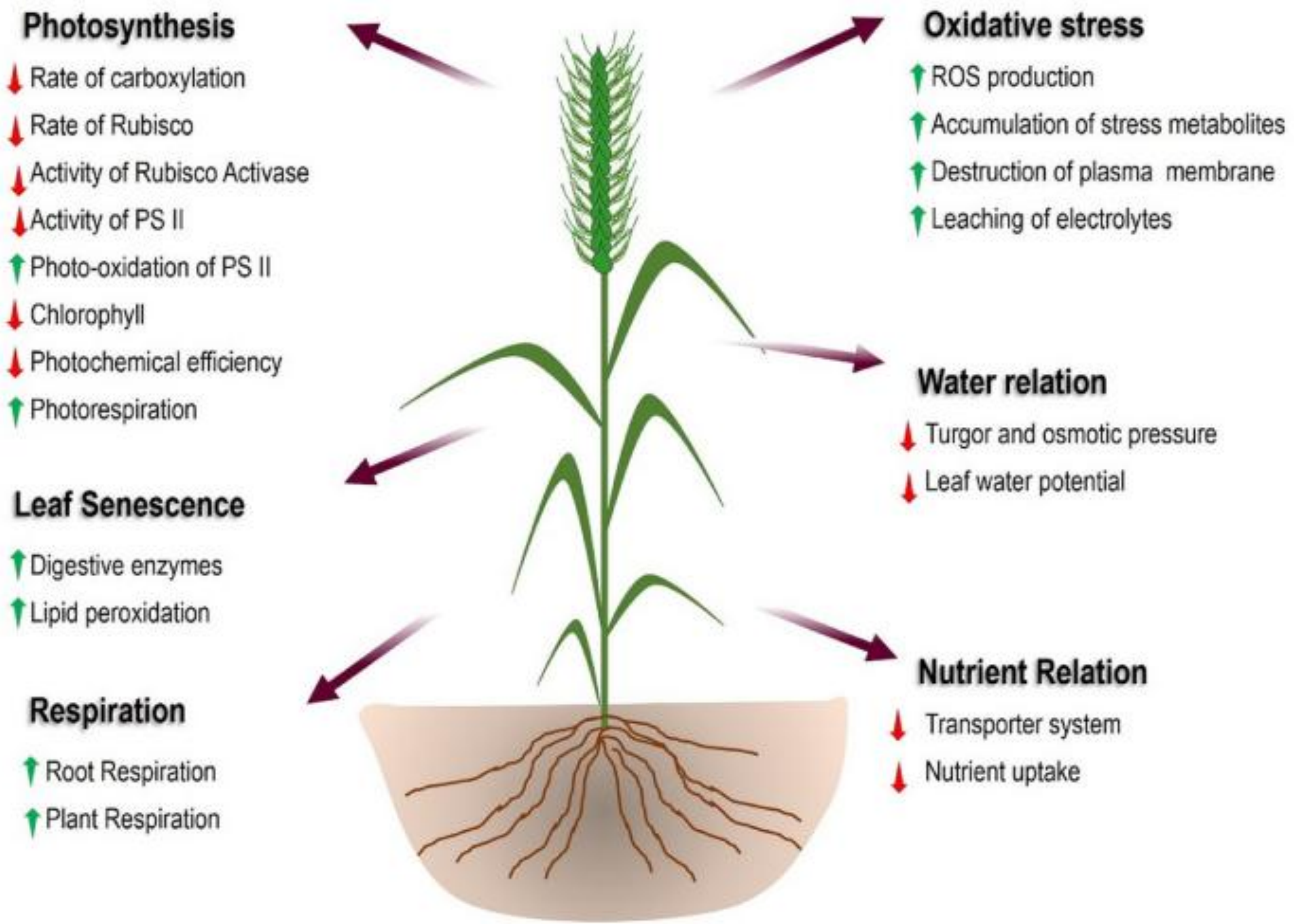


Source: Berkeley Earth (2021)

Heat Stress

- High temperature or heat stress results from temperatures high enough to damage plant tissues, substantially influencing the growth and metabolism of plants.
- Although variable for different plant species, temperatures in the range of 35–45°C produced heat stress effects on tropical plants (Hall 1992).
- However, the extent to which this occurs in specific climatic zones depends on the probability and period of high temperatures occurring during the day and/or at night.

Heat-induces damages



Lal et al. (2021). *Plant Cell Rep* doi:10.1007/s00299-021-02784-4

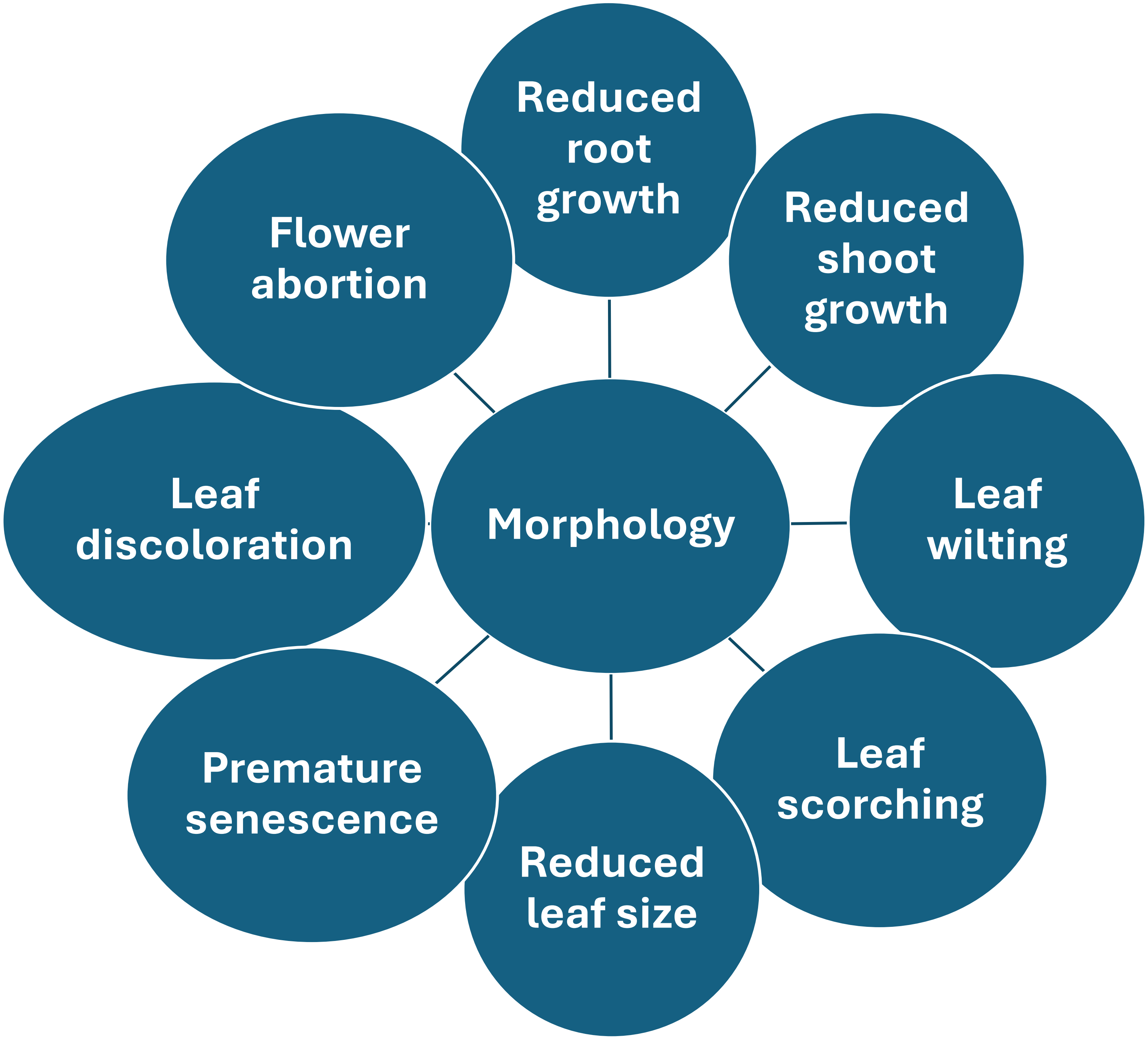
Effects of High Temperature on Seed germination and emergence

Seed germination is highly dependent on temperature as temperature is one of the basic prerequisites of this process.

Table: Ranges of temperatures for seed germination of different crop (Hasanuzzaman et al. 2013)

Crop species	Temperature (°C)		
	Minimum	Maximum	Optimum
Rice	10	45	20-35
Wheat	20	40	25-30
Maize	10	40	25-30
Soybean	10	35	25-30
Tomato	11	30	15-27
Cucumber	18	30	25-30
Egg plant	15	33	20-25
Peeper	15	35	20-30
Pumpkin	15	40	20-25
Water melon	15	35	25-30
Lettuce	4	25	15-20
Carrot	11	30	15-25
Cabbage	8	35	15-30
Spinach	5	30	15-20

Effects of high temperature stress on morphology of plants



Effects on Photosynthesis

- **Temperature** greatly influences the **rate and efficiency of photosynthesis** in plants.
- There is generally a **positive correlation** between temperature and photosynthetic rate within the optimal range.
- When temperature **exceeds the normal range (15°C–45°C)**, **heat injury** occurs, damaging photosynthetic enzymes.
- **High temperatures** cause **enzyme denaturation**, stopping **aerobic respiration** and reducing plant productivity.

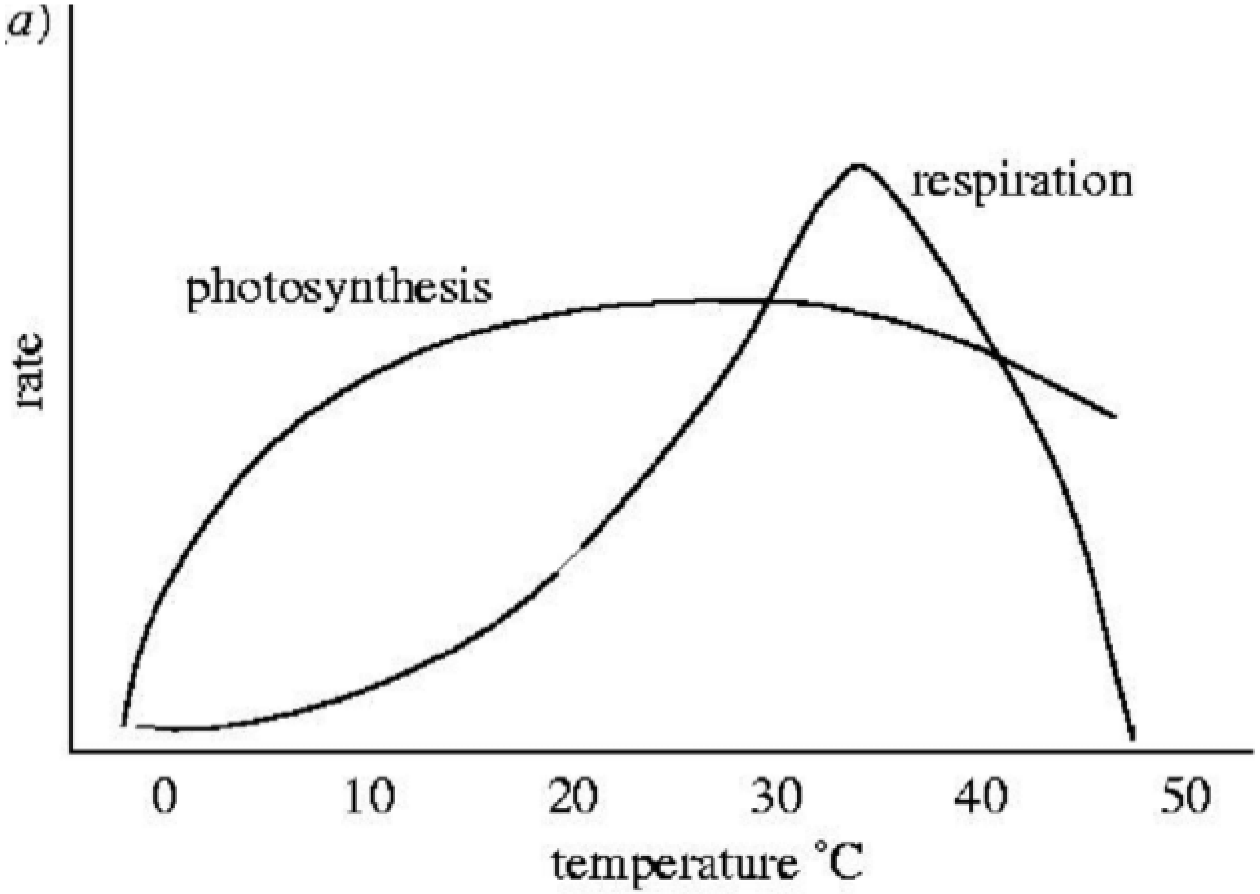
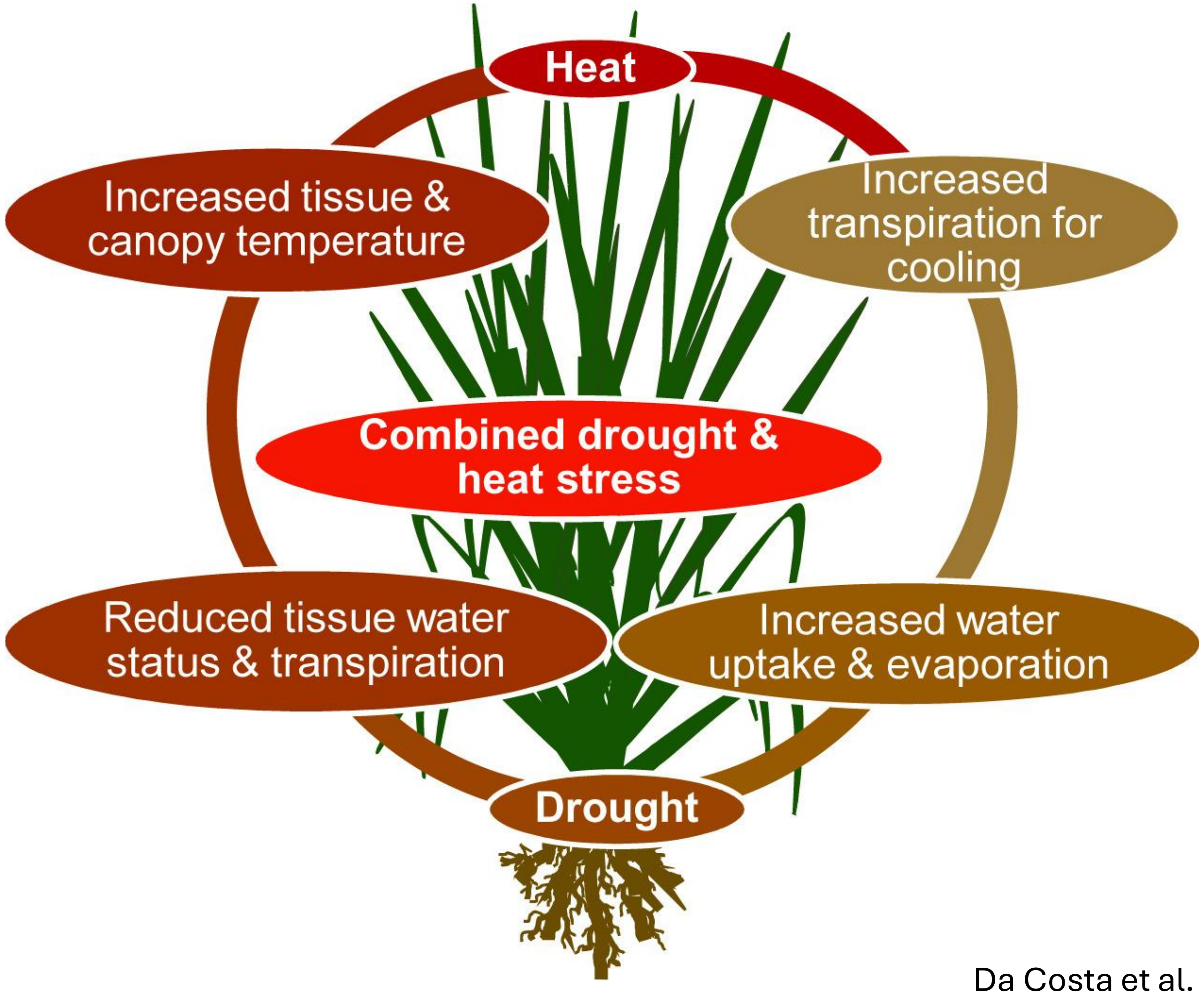


Fig: Changes in the rate of C3 photosynthesis and respiration as a function of temperature (Porter and Semenov 2005)

Heat and drought often prevail together



Da Costa et al. (2021). *Rice Science* 28:233-242

Heat stress action is very quick!

- Unlike other stresses, air temperature, can become stressful in just a few minutes
- Others, such as soil water content, may take days to weeks, and factors such as soil mineral deficiencies can take months to become stressful.

Effects of high temperature stress on yield

- Reduced flowering
- Poor seed development
- Delayed maturity
- Increased unfilled grain
- Reduction in seed weight

https://doi.org/10.3390/su13052972

Reproductive development

- It is well established that the reproductive development of many crop species is damaged by heat and in such cases they produce no flowers or if they produce flowers they may set no fruit or seeds.
- It is notable that reproductive development in plants is more sensitive to HT because plant fertility is considerably reduced as temperatures increase.

LOW TEMPERATURE STRESS

Low temperatures can damage plants both by a chilling effect, leading to physiological and developmental abnormalities, and by freezing, causing cellular damage directly or via cellular dehydration.

Generally, plants encounter two forms of low-temperature stress i.e., chilling and freezing.

- Chilling temperatures are low but positive temperatures (0–15 °C)
- Freezing temperature below 0 °C

Low Temperature Effects

Table: Physiological and biochemical perturbations in plants caused by fluctuation in the abiotic environment

Environmental factor	Primary effects	Secondary effects
Low temperature	• Membrane destabilization • Water potential reduction • Cellular dehydration • Ice crystal formation in cells	• Reduced cell/leaf expansion • Reduced cellular and metabolic activities • Stomatal closure • Photosynthesis inhibition • Leaf abscission • Membrane and protein destabilization • Ion cytotoxicity • Cell death • Physical destruction

Germination and emergence

- Chilling injury is a serious problem during germination and early seedling growth in many plant species.
- For instance, optimum temperature range for germination of rice seed lies between 20 and 35°C, and the temperature of 10°C is cited as the minimum critical value below which rice does not germinate.

Low Temperature Effects

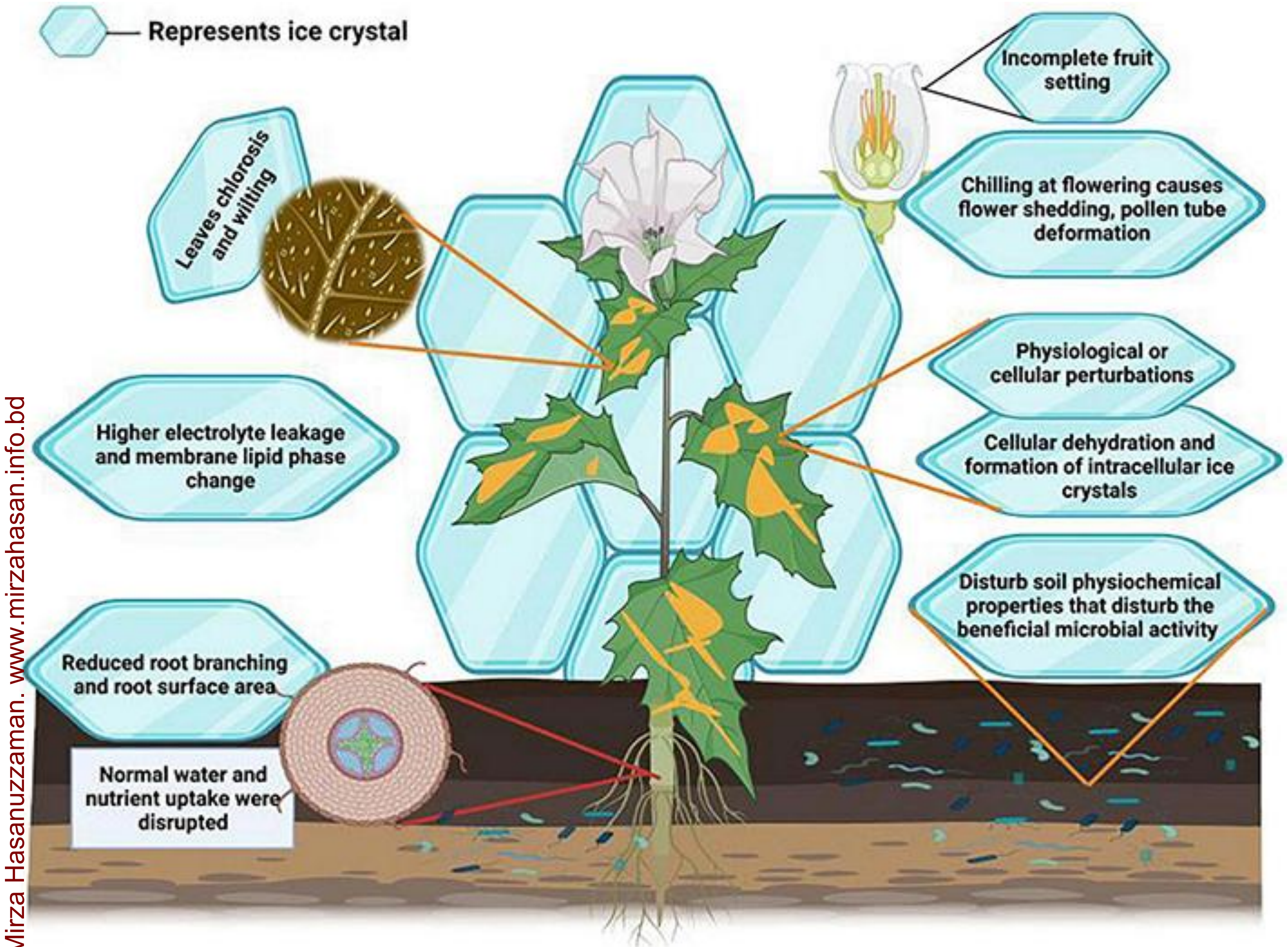


Figure: Effect of cold stress on plants.

H. Quari et al. (2022)

Cold stress induces the formation of crystal which reduces membrane integrity, causes electrolyte leakage and lipid saturation, reduces root growth which in turn decreases the water and nutrient uptake. Moreover, cold stress also causes leaf wilting and chlorosis and disturbs photosynthetic performance and microbial activities, and induces flowering shedding, deformation of pollen tube, incomplete fruit setting and results in significant growth and yield losses.

Metal/Metalloid Toxicity

Metals and metalloid ions are a natural part of our planet and are present in the diverse layers that compose it. However, many of its living forms (people, animals, plants, and microorganisms) may become hazardous when their levels are detected in high concentrations

Heavy Metals in Environment

- **Metals/metalloids** in the environment come from **two main sources**: **natural** and **anthropogenic**.
- **Natural sources** include **volcanic eruptions** and **weathering of metal-containing rocks**.
- **Anthropogenic sources** involve **mining, industrial activities, and agricultural practices**.
- These human-induced activities significantly **increase heavy metal contamination** in the environment.

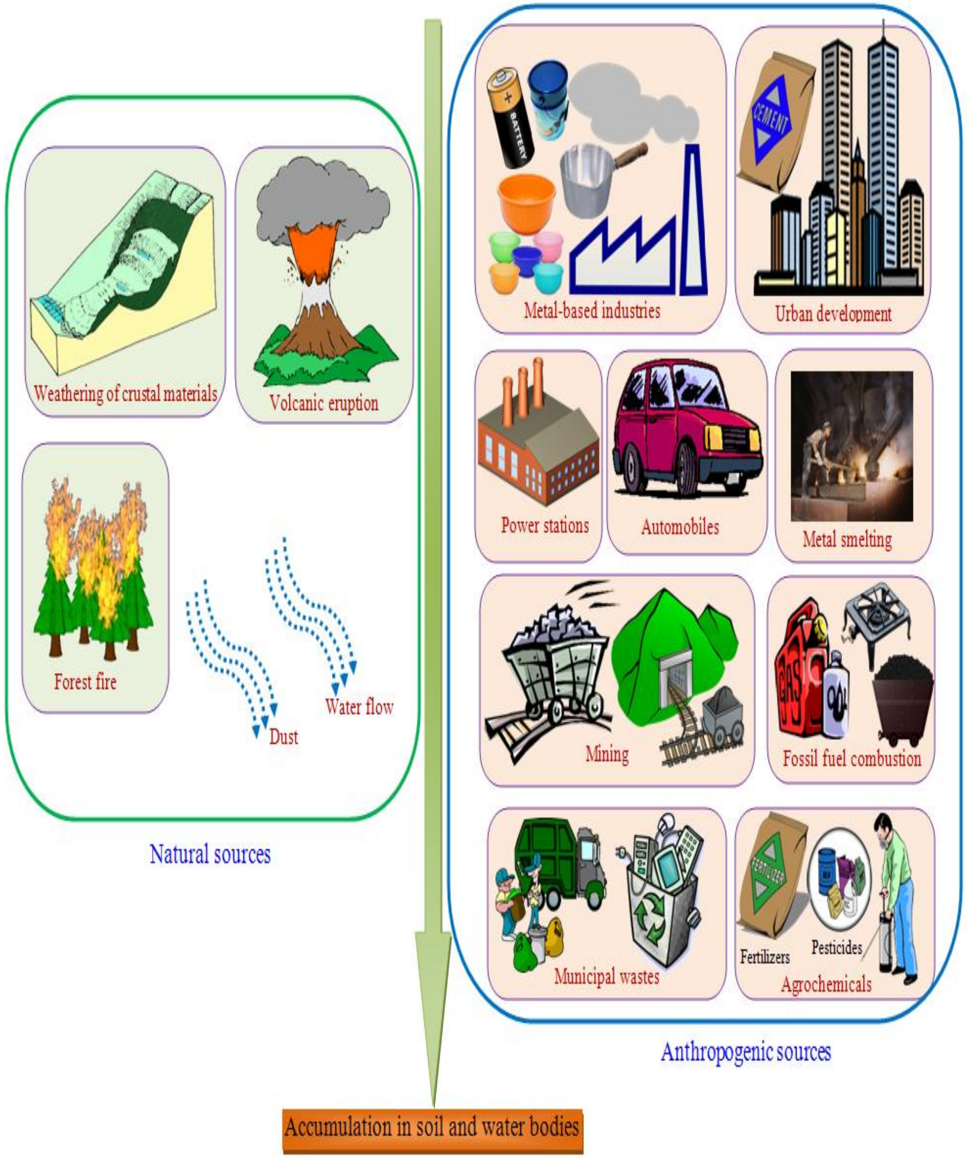


Fig: Sources of Heavy metal

Effects of Heavy Metal Toxicity in Plants

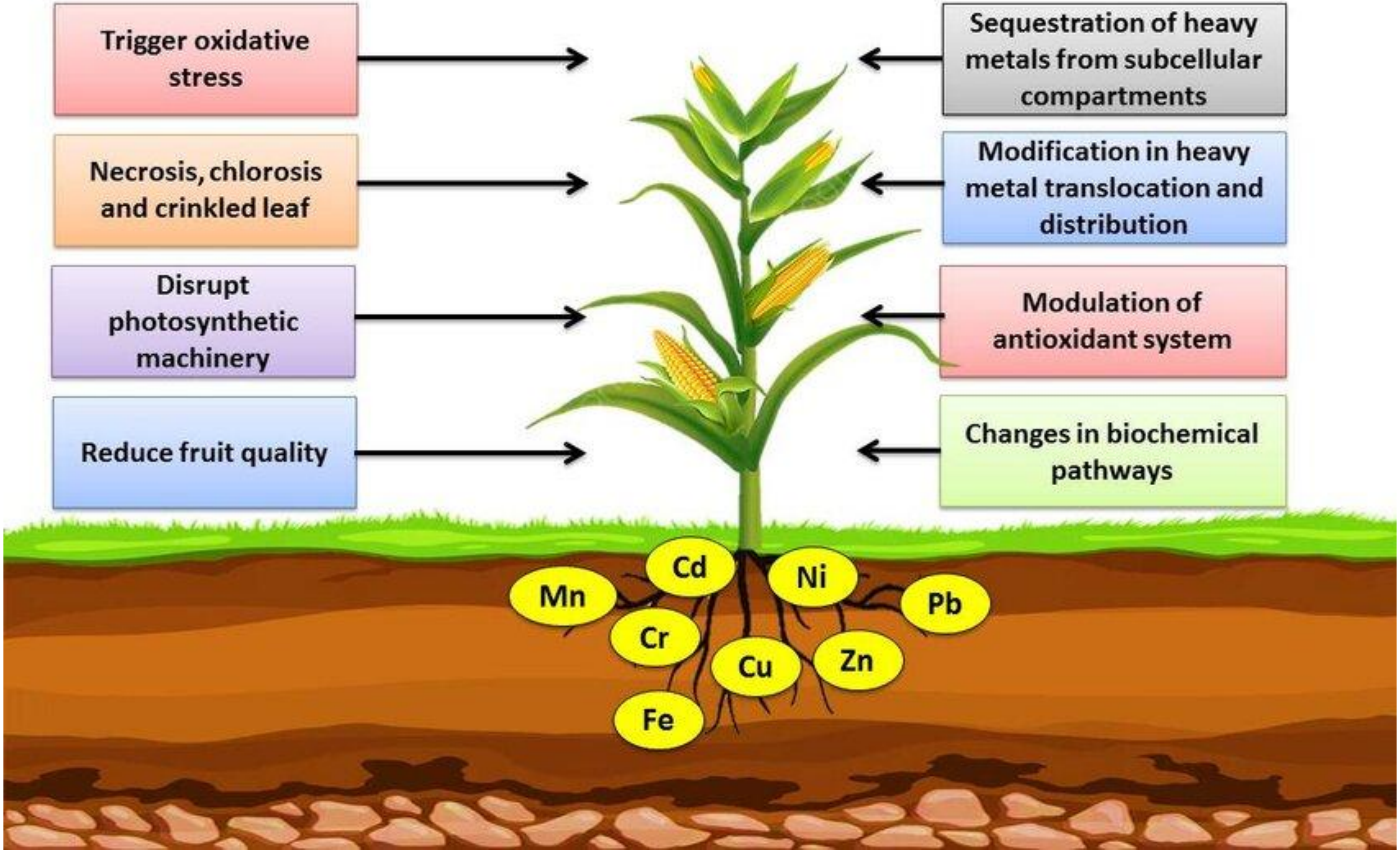
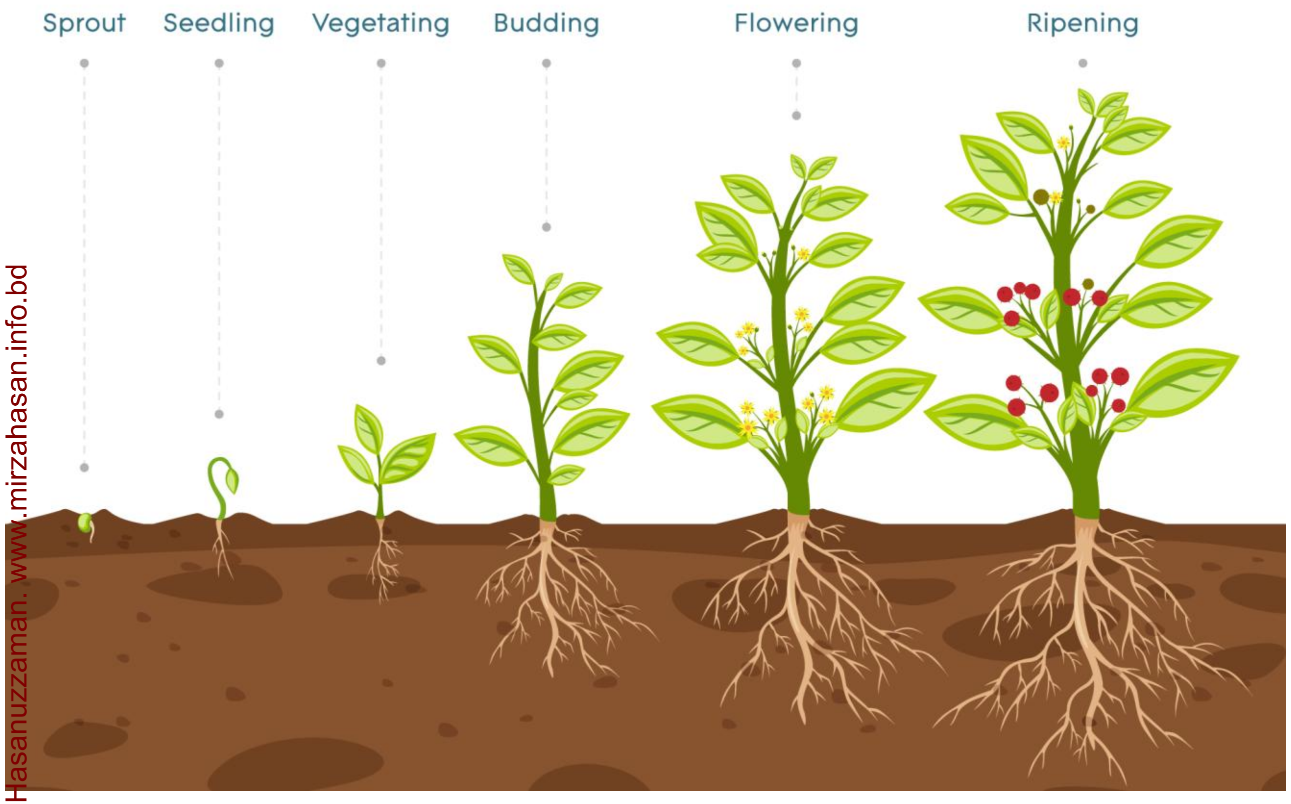


Fig: Effects of heavy metals on growth, physiological and biochemical responses of plants

Effects of Heavy Metal Toxicity in Plants

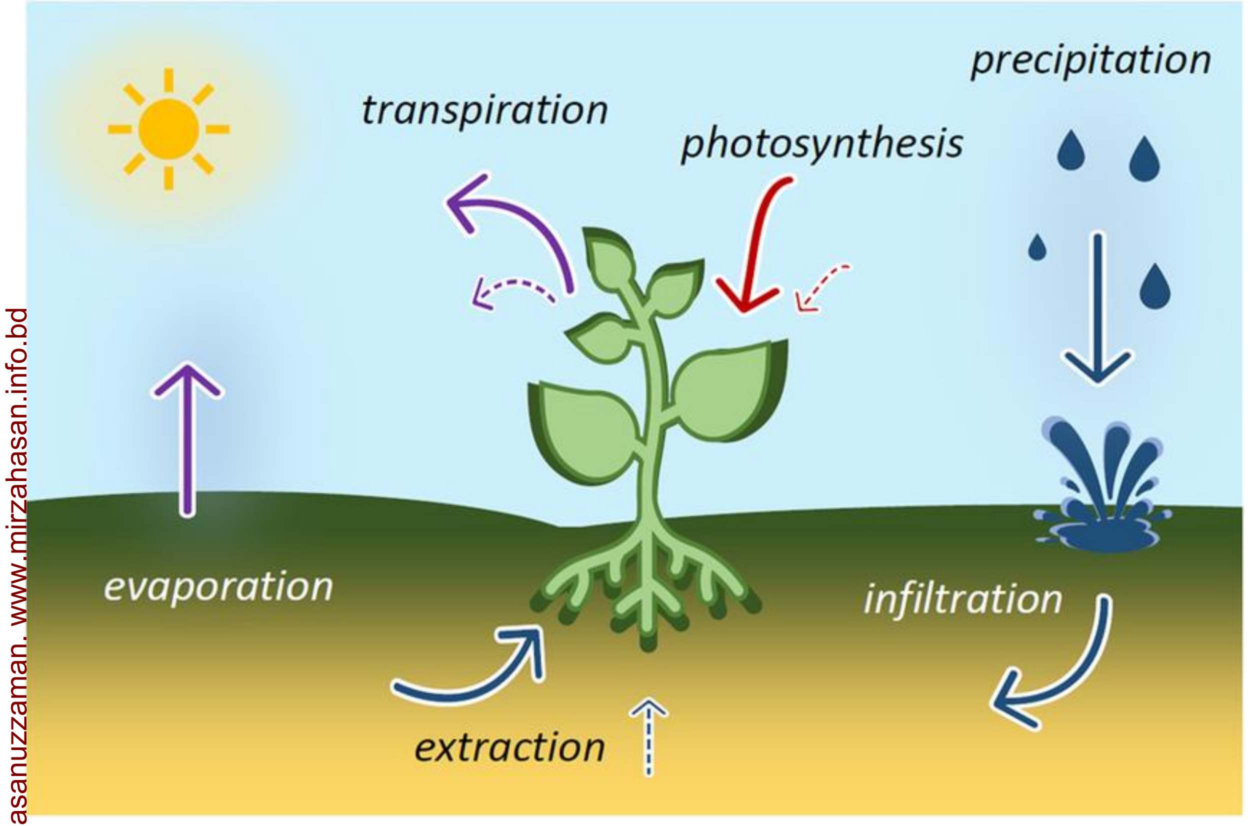
Growth



- Germination inhibition
- Growth reduction
- Premature senescence
- Reduction in productivity

Effects of Heavy Metal Toxicity in Plants

Physiology

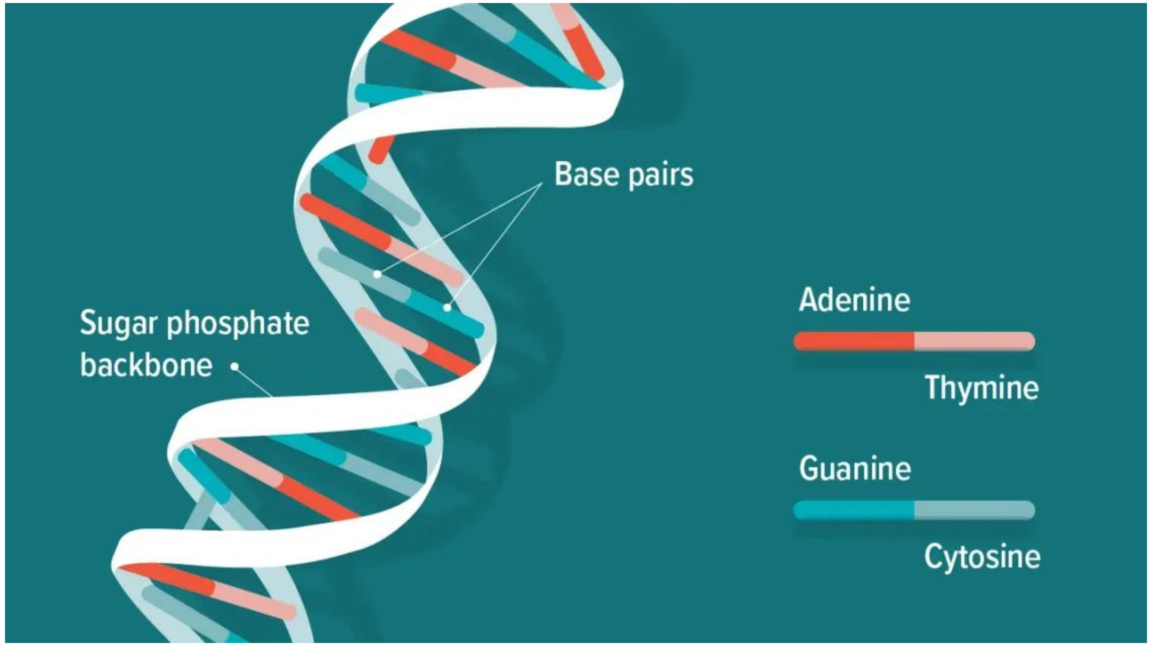


- Reduction in water uptake
- Altered transpiration rate
- Reduction in photosynthesis
- Altered respiration
- Metebolic toxicity
- Accumulation of growth inhibition

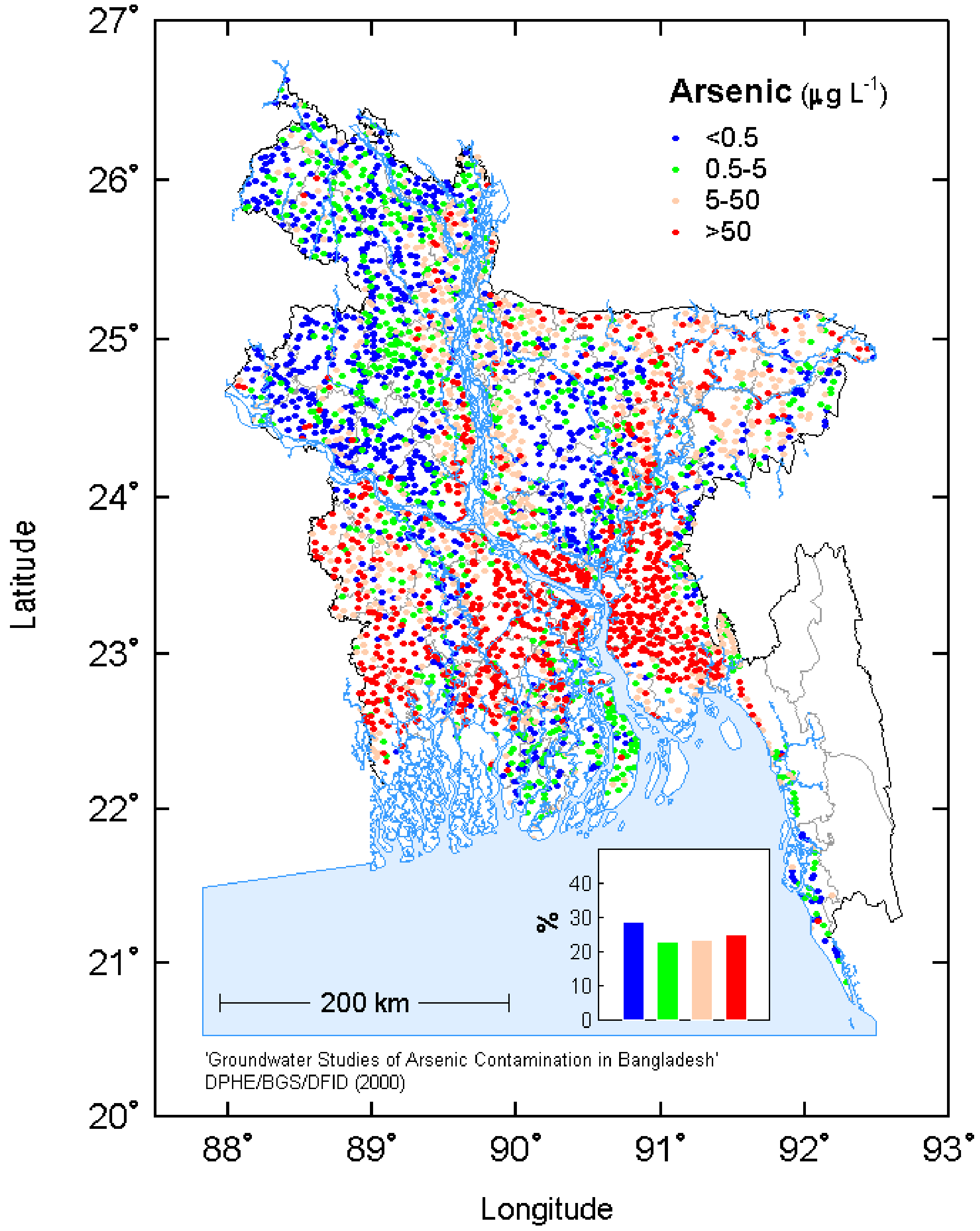
Effects of Heavy Metal Toxicity in Plants

Biochemistry

- Altered gene expression
- Breakdown of macromolecule
- Decreased protein synthesis
- Reduced activity of vital enzymes



It is estimated that nearly 80 million people of the country are affected by **arsenic** and one in ten has the probability of developing cancer from the poisoning.



Approaches in Mitigating Abiotic Stress in Crop Plants

Stress tolerant rice varieties

Drought	Tolerance level
BRRI dhan42	
BRRI dhan43	
BRRI dhan55	
BRRI dhan56	14-21 days without rain
BRRI dhan57	10-14 days without rain
BRRI dhan65	
BRRI dhan66	15-20 days without rain
BRRI dhan71	21-28 days without rain
BRRI dhan92	
BINA dhan19	

Salt	Tolerance level
BRRI dhan40	
BRRI dhan41	
BRRI dhan47	Up to 6 ds m^{-1}
BRRI dhan53	Medium salinity
BRRI dhan54	Medium salinity
BRRI dhan55	8-10 ds m^{-1} (3 weeks)
BRRI dhan61	12-14 ds m^{-1} (3 weeks)
BRRI dhan67	Up to 8 ds m^{-1}
BRRI dhan73	Up to 12 ds m^{-1} (3 weeks)
BRRI dhan78	6-9 ds m^{-1}
BINA dhan8	
BINA dhan10	

Submergence	Tolerance level
BR 21	
BR 24	
BRRI dhan27	
BRRI dhan42	
BRRI dhan43	
BRRI dhan51	12-14 days of submergence
BRRI dhan52	12-14 days of submergence
BRRI dhan65	
BRRI dhan76	
BRRI dhan77	
BRRI dhan78	12-14 days of submergence
BRRI dhan79	18-21 days of submergence
BRRI dhan85	
BRRI dhan91	
BINA dhan11	

Cold tolerant	Tolerance level
BRRI dhan36	<15 °C
BRRI dhan55	
BRRI dhan61	

Other cereals

Wheat

BARI gom-26 (Heat tolerant)

BARI gom-29 (Heat tolerant)

BARI gom-30 (Heat tolerant)

BARI gom-31 (Heat tolerant)

BARI gom-33 (Heat tolerant)

Maize

BARI hybrid bhutta-12 (Drought tolerant)

BARI hybrid bhutta-13 (Drought tolerant)

BARI hybrid bhutta-14 (Heat tolerant)

BARI hybrid bhutta-15 (Heat tolerant)

BARI hybrid bhutta-16 (Salt tolerant; 8-9 ds m^{-1})

Barley

BARI barley-8 (salt tolerant)

BARI barley-9 (Drought tolerant)

Pulses and oilseeds

Pulse crops:

Chickpea: BARI chhola-10 (Drought and Heat tolerant)

Oilseed:

Mustard

Rye-5 (Drought and Salt tolerant)

BARI sarisha-7 (short duration waterlogging tolerant)

BARI sarisha-8 (short duration waterlogging tolerant)

BARI sarisha-11 (Drought and Salt tolerant)

BARI sarisha-16 (Drought and Salt tolerant)

Groundnut

Jhinga badam (ACC-12) (Drought tolerant)

BARI chinabadam-19 (Drought tolerant)

Vegetables:

Potato

BARI alu-72 (Salt and Heat tolerant)

BARI alu-73 (Heat tolerant)

Sweet potato: BARI mishit alu-8 (Drought tolerant)

Cauliflower: BARI fulkopi-3 (Heat tolerant)

Tomato

BARI tomato-4 (Heat tolerant)

BARI hybrid tomato-10 (Heat tolerant)

Spices

Onion: BARI peyaj-6 (Cold tolerant)

Cinnamon: BARI daruchini-1 (Salt tolerant)

Agronomic Approaches

For Salt Stress:

- High water availability, with frequent irrigation if possible
- Selection of salt tolerate varieties
- Drip irrigation
- Fertilizers containing calcium and magnesium
- Application of plant growth-promoting bacteria (PGPB)
- Seed hardening with NaCl (10 mM concentration)
- Application of gypsum @ 50% Gypsum Requirement (GR)
- Incorporation of Dhaincha (6.25 t/ha) in soil before planting
- Foliar spray of 2% DAP + 1% KCl (MOP) during critical stages
- Extra dose of nitrogen (25%) in excess of the recommended
- Split application of N and K fertilizers

Agronomic Approaches

For Drought:

- **Crop and Variety Selection (**drought-tolerant or early-maturing varieties)
- **Soil Management (**mulching, conservation tillage, and addition of organic matter, balanced fertilizer)
- **Water Management** (drip or sprinkler systems)
- **Plant Growth Regulators (PGRs) and Osmoprotectants (**salicylic acid, proline, glycine betaine, and brassinosteroids)
- **Cropping System Management (**planting time, spacing, and population density, intercropping, crop rotation, and mixed cropping)
- **Residue and Mulch Management (**crop residues, straw, or plastic mulch)
- **Soil Conservation Practices**

Agronomic Approaches

For Flooding Stress

- Selection of flood-tolerant varieties
- Proper drainage and field leveling
- Fertilizer management
- Raised bed
- Sowing time alteration

High Temperature Stress

- Mulching and conservation tillage
- Irrigation scheduling, Overhead irrigation to avoid sunburn
- Seed hardening
- Use of biofertilizers
- Application of PGRs (Plant Growth Regulators)

Agronomic Approaches

For Low Temperature Stress

- Seed priming
- Sowing time management
- Fertilizer management
- Mulching with black polythene

For Heavy Metal Stress

- Soil amendments
- Microbial inoculation
- Mulching or cover crop
- Nutrient management
- Water management
- Organic matter management