

Lecture 3: Plant Stress

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Content

- Identify and understand the suite of environmental properties (e.g. light, heat, water, nutrients, etc.) that are able to induce plant stress.
- Contextualise this understanding within the broader field of planetary change (global change and planetary boundaries).
- Understand how climate change, specifically, is altering the environmental properties that induce plant stress.
- Link these environmental properties to the physiological and morphological responses of plants to stress.
- Understand the role of plant stress in shaping plant ecophysiological well being (e.g. the concept of resilience).
- Understand the notions of stress resistance, stress avoidance, and susceptibility to stress in the context of plant stress.

Aims

In this lecture, I will introduce you to the concept of plant stress and the environmental factors that induce stress responses in plants. You will explore the key environmental properties—such as light, temperature, water, and nutrients—that influence plant physiology and lead to stress under certain conditions. The lecture will place this understanding in the broader context of planetary change, particularly climate change, and its impact on the environmental properties that shape plant stress. Additionally, you will learn how plants respond to stress through physiological and morphological adaptations, and how these responses influence plant resilience and overall ecological health. The lecture will also cover the concepts of stress resistance, stress avoidance, and susceptibility to stress. As such, you will understand the diverse strategies plants use to survive in changing environments.

Learning Outcomes

By the end of this lecture, you will be able to:

1. Identify the suite of environmental properties (light, temperature, water, nutrients, etc.) that are capable of inducing stress in plants, and explain how these factors interact with plant physiology.
2. Contextualise plant stress within the broader framework of planetary change, particularly in relation to global environmental shifts and the concept of planetary boundaries.
3. Understand how climate change is altering environmental properties in ways that exacerbate plant stress, and recognise the long-term implications for plant ecophysiology and survival.
4. Link specific environmental stress factors to the physiological and morphological responses of plants, explaining how plants adapt or fail to adapt to stress conditions.
5. Explain the role of plant stress in shaping overall plant ecophysiological well-being, particularly through the concept of resilience, and how stress affects plant productivity and survival.
6. Understand the concepts of stress resistance, stress avoidance, and susceptibility to stress, and apply these notions to different plant species and ecosystems in the context of environmental stressors.

1 Introduction: Plant Stress

Climate change

Direct effects due to climate change:

- Photosynthesis (water, heat, CO₂ conc., O₃, other aerosols) [primarily aboveground]
- Rhizosphere processes (mediated by heat, moisture content, precipitation, OM content, N, P, other nutrients, thawing of permafrost, *etc.*) [belowground]

Stresses and positive stimuli:

- water: droughts or floods, changes in soil moisture content, water table, *etc.*
- heat: incl. change in length of growing season, metabolic rates of microbial communities, ...
- CO₂: ...
- aerosols: ...
- nutrients: ...

Today, we are going to talk about plant stresses. This will not be a very long lecture — just a brief overview of the various ways in which plants react to environmental stresses. This topic follows on from our previous work: at the end of last week, we explored planetary boundaries, and yesterday we delved deeply into climate change. Many of the environmental changes that plants respond to are being caused by climate change, but there are also several other stresses that have nothing to do with climate change, to which plants must also adapt. These will come up throughout the next few weeks.

So, why do we even need to worry about plant stresses? It is not as if plants have emotions or feelings, so we do not need to be concerned about their well-being... or do we? In fact, we do need to worry about how they behave and react, because the various ways in which climate change affects plants is often via the process of photosynthesis. Photosynthesis, as you know, is the foundational process that explains why plants are so productive and why they are able to support entire ecosystems. Fundamentally, all life on Earth depends on plants, and it is because of their ability to photosynthesise that they are so significant, both today and historically, even before people existed.

Now, photosynthesis is affected by many things: water availability, the amount of heat in the environment, carbon dioxide concentrations, ozone amount, varied aerosols, and more. Underground, the root systems also respond to heat, moisture, precipitation (in other words, rain), levels of organic matter, nutrients like nitrogen and phosphorus, as well as other macro and micronutrients, and even factors like thawing permafrost. The balance between above-ground processes (where photosynthesis happens) and below-ground processes (in the rhizosphere) ultimately affects the rate of plant productivity.

When we talk about photosynthesis, it is important to remember it does not only apply to terrestrial plants — it also occurs in oceanic or aquatic organisms. Many such organisms, like algae and all

seaweeds, do not have roots or a rhizosphere. Even though they may have structures resembling roots, they are anatomically different. Still, photosynthesis is the primary physiological process that underpins both plant and algae function in their environments.

Therefore, understanding how changes brought about by climate change — like water content, heat, CO₂ levels, etc.—affect both above- and below-ground processes, is crucial. A stress, by definition, is what happens when a plant's natural tolerance is exceeded. There can also be positive stimuli — where environmental conditions are “just right” and fall within the optimum range. What we are really interested in is how plants respond across a range of conditions — especially as we move toward extremes where stresses become important.

Climate change

Consequences:

- Invasive potential (due to change climatic envelopes, *i.e.*, heat, water)
- Phenological changes
- Change in strengths/directions of inter-species interactions (e.g. herbivory, parasitism, allelopathy, *etc.*)
- Increase/decrease in productivity
- Range expansions/reductions (due to change climatic envelopes)
- Change in phenotypes
- Changes to C pools
- Changes in N and P pools (interacting with N, P cycles)
- Change in resilience of plants and ecosystems
- Feedbacks (biosphere to/from atmosphere), indirect effects, interactions, trophic connections, ...
- Sea level rise and coastal squeeze
- Storms
- Droughts
- Extinction and extirpation

So, what is the practical significance of all of this? Why should we care? Well, plant stress affects many things relevant to people and ecosystems:

- **Invasive Potential:** Some plants become more invasive under stressed or adverse conditions. When natural biota are stressed, ecosystems become more susceptible to invasion by species previously absent — these are often “weeds.” A weed is, essentially, a plant growing rapidly in an environment where it is unwanted, not only in gardens but also in natural or disturbed environments.
- **Phenological Changes:** Stress can alter the timing of biological events. For instance, with warming climates, it may seem as if summers are beginning earlier — plants flower earlier, bees and other insects react earlier, and so on. This lengthening of the growing season influences the timing of various biological processes.
- **Interspecific Interactions:** Stress can change the strength and direction of interactions between species — such as herbivory, parasitism, or allelopathy. Stressed plants may be more vulnerable to herbivores, for example.

- **Productivity:** Plant stress can increase or decrease productivity, which directly impacts people, especially via agriculture. For instance, increased environmental stress can lead to incomplete or poorly developed crops — like underdeveloped corn cobs due to drought or heat stress.
- **Range Shifts:** Stress alters the zones where specific species can survive and thrive; as optimal envelopes shift, so do the ranges where species are comfortable.
- **Phenotype Changes:** The outward appearance or form of plants can evolve in response to environmental change.
- **Biogeochemical Cycles:** Environmental stress can alter carbon pools — as we discussed yesterday, with thawing permafrost releasing previously locked carbon and nitrogen into the atmosphere, leading to feedback loops that influence global warming further.
- **Resilience:** All these changes can reduce the resilience of ecosystems, create feedback loops, escalate vulnerability to storms and droughts, and in severe cases, drive species to local extinction (extirpation), or even outright extinction.

2 Productivity and People

This is where plant stress especially matters: humanity relies heavily on agriculture — developed over the last 10,000 or so years — and hence on productive plants. As plant stress increases, food productivity decreases, affecting not just people directly eating plants but also livestock and the broader organisation of society. The most vulnerable populations are those most directly reliant on agriculture: the poorest people will be most affected as food insecurity increases, and small-scale farmers can be driven into unsustainable debt.

Even in developed countries, while people might be insulated to a degree from direct food insecurity, increased costs and economic implications are inevitable. Stresses on crops do not always total crop failure, but can mean partial productivity loss. This leads to economic impacts — from local communities right up to affecting GDP, as we see in countries like South Africa, where agriculture is a significant part of the economy.

3 Broader Impacts

There are also broader socioeconomic and social aspects. California, for example, though typically Mediterranean in climate, has become increasingly dry and unable to meet its agricultural output reliably. Phenomena like severe hailstorms (which can directly damage plants) and societal reactions to climate extremes (such as the historical linkage between unseasonal weather and witch hunts — a point more anecdotal and possibly contentious—[attention]) show just how interconnected society and plant health truly are.

4 Plant Responses to Stress

Plant Stress

Stresses—conditions that prevent plants functioning optimally

- Plant can resist, adapt, or die
- *E.g.* too much or too little water, temperature extremes, salinity
- Plants have been adapting to survive a variety of different environmental conditions for a very long time—hence the adaptive radiation of angiosperms!
- Adapted to specific niches, including harsh environments, *e.g.* very dry
- These environments don't seem 'harsh' to them (a relative concept)...
- ...but any plant when taken out of its range of tolerance, these things become stresses
- *e.g.* Venus fly trap adapted to low nutrient soils, too much fertiliser (nutrients) is lethal
- *e.g.* alpine plants adapted for dry summers & cold winters die in poorly drained, waterlogged soil

Stress

Examples of stresses that might affect plants:

- Salinity (an osmotic stress)
- Too little or too much water (drought or flooding)
- Low or high heat
- Too little or too much light
- Too little or too much nutrients (*e.g.* N, P, Fe, Si, etc.)
- etc... (name some!)

Stresses affecting photosynthesis

The main physiological process that sets plants apart from animals (*et al.*)

Affected by global warming (and global change generally) through:

- change in *light intensity*
- change in *temperature*
- change in *CO₂ concentrations*
- *water availability*
- many other indirect effects

These environmental variables are strongly coupled to the major stresses that plants (*et al.*) experience, *e.g.*,

- light stress
- thermal stress
- CO₂ stress
- water stress
- *etc.*

Three stress response strategies

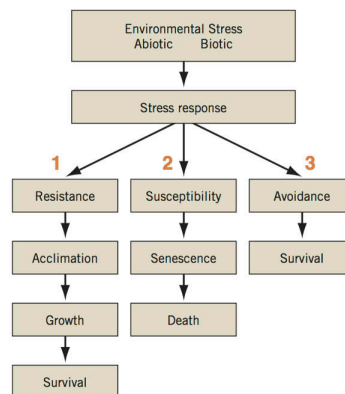


FIGURE 13.3 The effect of environmental stress on plant survival.

So, what do plants do when confronted by stress? There are three general strategies:

1. **Resist the stress:** Acclimatise or otherwise develop responses that allow survival and growth.
2. **Adapt and thrive:** Use evolutionary adaptations that confer long-term tolerance.
3. **Die:** Simply be unable to cope, leading to death — a fate for species with narrow environmental tolerance (“stenothermal” for temperature tolerance, for example).

Plant stresses include:

- **Abiotic:** Salinity, drought, heat extremes, light extremes, nutrients, etc.
- **Biotic:** Pathogens, herbivores, competing species, etc.

1. Stress avoidance

Avoidance through life history traits, *e.g.*:

- Ephemeral plants: avoid the stress altogether by growing and reproducing when environmental conditions are favourable. Seeds or other propagules survive the unfavourable conditions (*e.g.* over winter; during a drought; too low light; *etc.*)
- Deciduous plants lose leaves during winter, as this would cause susceptibility to cold stress
- In seaweeds: a heteromorphic life history, where one phase, for example, grows during winter and the other during summer

1. Stress avoidance

Avoidance through seasonal adaptation: seaweeds and other plants: may also avoid stress by seasonally adapting to the conditions prevalent at the time

1. Stress avoidance

Avoidance can also involve some morphological adaptations acquired through evolution

- Often these plants and seaweeds have phenotypic properties that predispose them to certain environments, *e.g.*
 - deep-rooted plants may avoid drought by having a root system that can access water during dry times when shallow-rooted cannot
 - fleshy-leaved plants (succulents) or those with thick cuticles, *etc.*, can also avoid drought-related stresses

Avoidance refers to plants preventing stress from impacting them, often via life-history strategies or adaptations:

- **Ephemerals:** Grow and reproduce rapidly only when conditions are optimal (e.g., spring flowers after seasonal rains).
- **Deciduousness:** Drop leaves to avoid freeze damage (common in boreal forests).
- **Seaweeds with Alternation of Generations:** Present as large fleshy organisms during favourable seasons and tough, small forms during stressful periods.
- **Deep-rooted plants:** Access deep water during droughts.
- **Succulents:** Store water during dry seasons, use CAM metabolism to reduce water loss.

2. Stress resistance

These plants and/or algae tolerate stressful conditions; this means that they can acclimatise to unfavourable abiotic situations
Acclimatisation means that it is a short term response (or a gradual onset response) and the plant, when it encounters environmental stressors, acquire through targeted physiological pathways and gene expression the properties that allow it to tolerate the adverse conditions
When the adverse conditions are not present, these traits also do not exist

Resistance is a short-term response — plants acclimatise through physiological changes, often triggered by gene expression changes that allow short-term survival under stress. Once conditions normalise, the plant resumes normal function.

3. Stress susceptibility

These plants and algae simply senesce and die

Susceptibility occurs in plants with very narrow tolerance ranges. These “specialist” species often reside in environments that are stable, but when stress exceeds their adaptation, they senesce and die.

Plants may evolve a wide (“eurythermal”) vs. narrow (“stenothermal”) tolerance range, depending on their resistance or avoidance mechanisms.

5 Conclusion

That is a broad overview of how plants cope with environmental stresses. Nothing too difficult here, but much of this content will recur throughout the rest of the BDC223 course and beyond. In our next set of lectures, we will look at one of the most critical environmental influences for plant life... light. We will discuss what light is, how plants harvest it, and the physiological process of photosynthesis in detail.

Bibliography