**Chapter # 1**

Environmental Stress

Plant environmental (abiotic) stress constitutes a major limitation to agricultural production and the farmer's livelihood. Crop production is hardly ever free of environmental stress. The major plant environmental stresses of contemporary economical importance worldwide are drought, cold (chilling and freezing), heat, salinity, soil mineral deficiency and soil mineral toxicity.   
While the "[green revolution](http://en.wikipedia.org/wiki/Green_revolution)" indeed had an immense impact on agriculture since the 1960's, its benefits were limited mainly to farming under non-stress or moderately stressed conditions. For the farmers in stress prone agriculture that seriously lack in water, soil fertility, nutrient supply, and favorable weather, the "green revolution" had only a moderate impact and in some region no impact at all. A major challenge in agriculture practice and research today is how to cope with plant environmental stress in an economical and an environmentally sustainable approach.

In recent years '[global warming](http://en.wikipedia.org/wiki/Global_warming)' and its effect on crop plant production has become a very 'hot' issue. Solving this problem at the plant science level is almost exclusively a question of coping with plant stress. International agricultural and environmental research institutions now re-discover plant stress as a major component of the effect of global warming on local and global food production.

Research to meet these challenges is complex as it involves learning in widely different disciplines such as atmospheric sciences, soil science, plant physiology, biochemistry, genetics, plant breeding, molecular biology and agricultural engineering. The most successful cases of solution development by research in this area involved close interdisciplinary collaboration and integration. Such collaboration requires extensive exchange of knowledge and ideas pertaining to plants under stress. Regretfully the contemporary trend in agricultural and biological research is increased specialization and reduced wide interdisciplinary collaboration.

**Definitions**

The term *stress* had none of its contemporary connotations before the 1920s. It is a form of the [Middle English](http://en.wikipedia.org/wiki/Middle_English) *destresse*, derived via [Old French](http://en.wikipedia.org/wiki/Old_French) from the [Latin](http://en.wikipedia.org/wiki/Latin) *stringere*, "to draw tight."

The stress of plants is defined in various ways; however, scientists agree that stress should be defined according to physiological and ecological requirements of an organism throughout its life-cycle. Stress is generally understood as the reaction of a biologica system to extreme environmental factors that, depending on their intensity and duration, may cause significant changes in the system.

In addition to the term “stress” Levitt (1980, 1982) used the term “strain”, which might be used in the cases when the physiological changes caused by extreme environmental conditions do not bring about significant inhibition of plant growth or reproduction. Larcher (1980) calls the responses of plants to stressors of protective or adapting character “alarm reactions”.

An environmental factor that reduces the growth rate of a plant below the maximum level for its age and genotype may be regarded as a stress upon the plant, which is itself said to be under stain. If the strain disappears on removal of the stress it may be said as elastic, and if remains is called as plastic.

The most of the plants require a similar balance of the resources---energy, water, light, nutrients—to main optimal growth. Natural environment however usually differ from the ideal conditions required by plants. Plants have a limited range to cope with such environmental changes (stresses).

“Stress is an unavoidable part of life” and is one of the most frequently researched issues within environmental psychology. Thus, this article evaluates the effect of environmental stressors on individuals. Part of the analysis is the definition of the concept of stress and an explanation of the physiology and psychology of stress provides the necessary information to understand the construct of stress. I selected three environmental stressors and evaluate the affect of those stressors on the individual. Those stressors are: temperature, chemical pollution, and noise. At last, the discussion of strategies to manage those three environmental stressors provides some examples to minimize the impact of environmental stressors on humans.

**The Concept of Stress:**From an environmental point of view, “stress has been defined as a state that occurs when people are faced with demands from the environment that require them to change in some way”. The changes in which people have to adapt to is due to natural and technical catastrophes such as tornados, major personal life events like the death of a loved one, or daily hassles like routine rituals that affect human’s daily functioning. This interrelationship between the individual and its environment is of focus and environmental psychologists are not yet sure if stress is the threat itself or the person’s perception and response to such a threat.

In sum, stress can be thought off as …“both something that is happening to a person and the person’s response to what’s happening”. Many components like psychological and environmental events, the perception of such, and the physiological and behavioral response of the individual are involved when stress occurs and explains the following description of the physiology and psychology of stress.

Any ecosystem is always in a state of flux. Change can be initiated by various factors - physical, chemical, climatic, evolutionary, man-made, etc. Some of these changes tend to enhance the quality, productivity and evolution of the ecosystem, while others tend to degrade the ecosystem.

In simpler terms, any influence that causes a measurable biological change is called environmental stress. The agent of stress could be a pesticide, a toxic chemical, an exotic species or even too much amount of any nutrient. The accentuation of any biological condition, not quite alien to the ecosystem, can also lead to a biological change.

Stress, when it exceeds certain thresholds, has the capability to even alter the basic structure of any ecosystem. A 'naturally and chronically stressed' ecosystem is one in which there is reduced species richness and structural complexity, has long-lived species, with a small crop of biomass, has low rate of productivity, decomposition and nutrient cycling.

Periodic fires have a beneficial effect on some ecosystems. Fires burn the undergrowth and dry organic matter like leaves and turn them into ash, which is rich in minerals. The onset of rains helps in infusing new and luxuriant growth. But in some ecosystems, fires may wreak havoc causing the ecosystem years of repair to be restored to its original form.

**Sources of Environmental Stresses**

Plants are subject to many types of environmental stressors that fall into one of two general categories: biotic and abiotic.

The majority of phytopathogenic fungi belong to the Ascomycetes and the Basidiomycetes. The fungi reproduce both sexually and asexually via the production of spores and other structures. Spores may be spread long distances by air or water, or they may be soil borne.

Bacterial diseases are much more prevalent in sub-tropical and tropical regions of the world. Most plant pathogenic bacteria are rod-shaped (bacilli).

Nematodes are small, multicellular wormlike creatures. Many live freely in the soil, but some species parasitize plant roots. They are a problem in tropical and subtropical regions of the world, where they may infect crops.

Abiotic stress is the negative impact of non-living factors on the living organisms in a specific environment. The non-living variable must influence the environment beyond its normal range of variation to adversely affect the population performance or individual physiology of the organism.

Abiotic stress is the most harmful factor concerning the growth and productivity of crops worldwide.



1. **Biotic Stressors:**

Biotic Stress occurs as a result of damage to plants by other living organisms. Fungi, [bacteria](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_bacteria), parasites, insects (beneficial and harmful), weeds, and native or cultivated plants are examples of [biotic](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_biotic) stressors.

**FUNGI:**

The majority of phytopathogenic fungi belong to the Ascomycetes and the Basidiomycetes.The fungi reproduce both sexually and asexually via the production of spores and other structures. Spores may be spread long distances by air or water, or they may be soil borne. Many soil inhabiting fungi are capable of living saprotrophically, carrying out part of their lifecycle in the soil. These are known as facultative saprotrophs. Fungal diseases may be controlled through the use of fungicides and other [agriculture](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_agriculture) practices, however new races of fungi often evolve that are resistant to various fungicides. Biotrophic fungal pathogens colonize living plant [tissue](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_tissue) and obtain nutrients from living host cells. Necrotrophic fungal pathogens infect and kill host [tissue](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_tissue) and extract nutrients from the dead host cells.

**BACTERIA:**

Most [bacteria](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_bacteria) that are associated with plants are saprotrophic, causing no harm to the plant itself. However, a small number (around 100 known [species](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_species)) do cause disease. Bacterial diseases are much more prevalent in sub-tropical and tropical regions. Most plant [pathogenic](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_pathogenic) [bacteria](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_bacteria) are rod-shaped (bacilli) and have specific pathogenicity factors allowing them to colonize the plant. Five main types of bacterial pathogenicity factors are known: [cell](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_cell) wall-degrading enzymes, toxins, [effector](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_effector) proteins, phytohormones, and exopolysaccharides pathogens (such as Erwinia) that use [cell](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_cell) wall-degrading enzymes to cause soft rot. Agrobacterium changes the level of auxins causing tumours with phytohormones. Exopolysaccharides are produced by [bacteria](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_bacteria) and block [xylem](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_xylem) vessels, often leading to the death of the plant.

**PARASITES:**

Nematodes are small, multicellular wormlike creatures. Many live freely in the soil, but there are some [species](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_species) that parasitize plant roots. They infect crops mainly in tropical and subtropical regions of the world. Potato cyst nematodes (Globodera pallida and G. rostochiensis) are widely distributed in Europe and North and South America, causing $300 million worth of damage in Europe every year. Root knot nematodes have quite a large [host range](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_hostrange), whereas cyst nematodes tend to infect only a few [species](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_species). Nematodes can cause radical changes in [root](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_root) cells in order to facilitate their lifestyle.

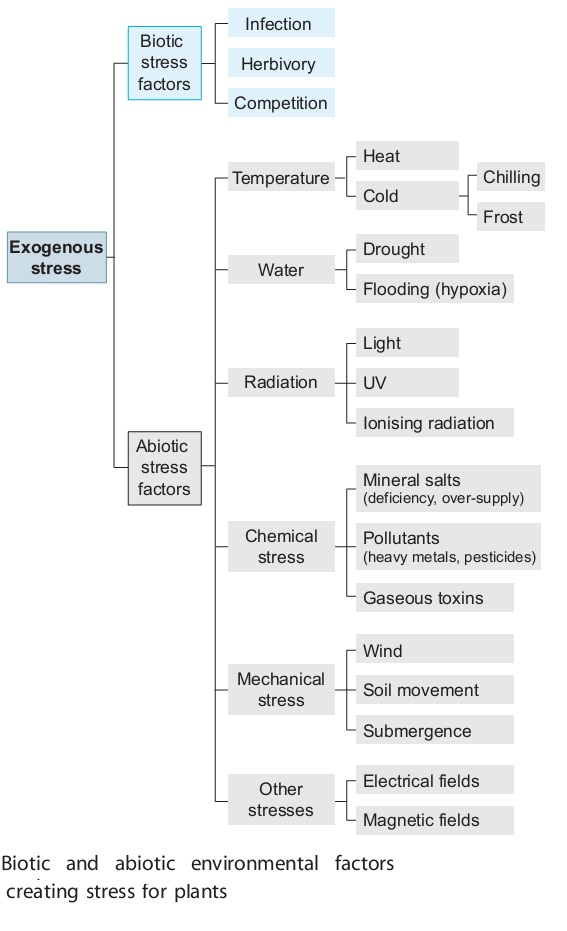
**PARASITIC PLANTS:**

Parasitic plants such as mistletoe and dodder are included in the study of phytopathology. Dodder, for example, is used as a conduit for the [transmission](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_transmission) of viruses (or virus-like agents) from a host plant to a plant that is atypically a host for a non graft-transmissible agent.

1. **Abiotic Stressors:**

Abiotic stress is defined as the negative impact of non-living factors on a living organisms in a specific environment. The non-living variable must influence the environment beyond its normal range of [variation](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_variation) to adversely (and significantly) affect the [population](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_population) performance or individual [physiology](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_physiology) of the organism. Whereas a [biotic](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_biotic) stress would include such living disturbances as fungi or harmful insects, [abiotic](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_abiotic) stress is essentially unavoidable. Abiotic stress affects both animals and plants, but plants are especially dependent on and sensitive to environmental factors, so their environment is particularly constraining. Abiotic stress is the most harmful factor concerning the [growth](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_growth) and productivity of crops worldwide. Research shows that [abiotic](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_abiotic) stressors are at their most harmful when they occur in combination. The most [basic](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_basic) stressors include: high winds, extreme temperatures, drought, flood, and other natural disasters such as tornados and wildfires (Figure 0). The lesser-known stressors generally occur on a smaller scale and are less noticeable, but they include: poor [edaphic](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_edaphic) conditions like rock content and pH, high radiation, compaction, contamination, and other highly specific conditions like rapid rehydration during [seed](https://www.boundless.com/biology/response-to-external-stimuli-in-plants/plant-responses-to-environmental-stresses/examples-environmental-stressors-to-plants/#key_term_glossary_seed) germination.

**Types of Environmental Stresses in Plants:**



1. **Biotic Stresses:**

Biotic Stress is [stress](http://en.wikipedia.org/wiki/Stress_%28biological%29) that occurs as a result of damage done to plants by other living organisms, such as bacteria, viruses, fungi, parasites, beneficial and harmful insects, weeds, and cultivated or [native plants](http://en.wikipedia.org/wiki/Native_plant)., the damage caused by these various living and nonliving agents can appear very similar. Even with close observation, accurate [diagnosis](http://en.wikipedia.org/wiki/Diagnosis) can be difficult. For example, [browning](http://en.wikipedia.org/wiki/Browning) of leaves on an [oak tree](http://en.wikipedia.org/wiki/Oak_tree) caused by drought stress may appear similar to leaf browning caused by oak wilt, a serious vascular disease, or the browning cause by [anthracnose](http://en.wikipedia.org/wiki/Anthracnose), a fairly minor leaf disease.

Biotic stresses cause damage to plants via living organisms, including fungi, bacteria, [insects](http://biology.about.com/od/insects/Insects.htm), and weeds. [Viruses](http://biology.about.com/od/virology/ss/viruses.htm), although they are not considered to be living organisms, also cause biotic stress to plants.

Fungi cause more diseases in plants than any other biotic stress factor. Over [8,000 fungal species](http://ohioline.osu.edu/hyg-fact/3000/pdf/PP401_07.pdf) are known to cause plant disease. On the other hand, only about [14 bacterial genera](http://ohioline.osu.edu/hyg-fact/3000/pdf/PP401_06.pdf) cause economically important diseases in plants, according to an Ohio State University Extension publication. Not many plant pathogenic viruses exist, but they are serious enough to cause [nearly as much crop damage worldwide as fungi](http://www.biologynews.net/archives/2008/10/02/research_about_plant_viruses_could_lead_to_new_ways_to_improve_crop_yields.html), according to published estimates. Microorganisms can cause plant wilt, leaf spots, root rot, or seed damage. [Insects](http://insects.about.com/) can cause severe physical damage to plants, including to the leaves, stem, bark, and flowers. Insects can also act as a vector of viruses and bacteria from infected plants to healthy plants.

The method by which weeds, considered as unwanted and unprofitable plants, inhibit the growth of desirable plants such as crops or flowers is not by direct damage, but by competing with the desirable plants for space and nutrients. Because weeds grow quickly and produce an abundance of viable seed, they are often able to dominate environments more quickly than some desirable plants.

It is a major focus of agricultural research, due to the vast economic losses caused by biotic stress to cash crops. The relationship between biotic stress and plant yield affects economic decisions as well as practical development. The impact of biotic injury on [crop yield](http://en.wikipedia.org/wiki/Crop_yield) impacts [population dynamics](http://en.wikipedia.org/wiki/Population_dynamics), plant-stressor [coevolution](http://en.wikipedia.org/wiki/Coevolution), and ecosystem nutrient cycling. Biotic stress also impacts horticultural plant health and natural [habitats](http://en.wikipedia.org/wiki/Habitat) ecology. It also has dramatic changes in the host recipient. Plants are exposed to many stress factors, such as drought, high salinity or pathogens, which reduce the yield of the cultivated plants or affect the quality of the [harvested products](http://en.wikipedia.org/w/index.php?title=Harvested_products&action=edit&redlink=1). [Arabidopsis thaliana](http://en.wikipedia.org/wiki/Arabidopsis_thaliana) was used as a model plant to study the responses of plants to different sources of stress.

1. **Water Stress:**

One of the most important abiotic stresses affecting plants is water stress. A plant requires a certain amount of water for its optimal survival; too much water (flooding stress) can cause plant cells to swell and burst; whereas drought stress (too little water) can cause the plant to dry up, a condition called desiccation. Either condition can be deadly to the plant.

Scarcity of water is a severe environmental constraint to plant productivity. Drought-induced loss in crop yield probably exceeds losses from all other causes, since both the severity and duration of the stress are critical. Here, we have reviewed the effects of drought stress on the growth, phenology, water and nutrient relations, photosynthesis, assimilate partitioning, and respiration in plants. This article also describes the mechanism of drought resistance in plants on a morphological, physiological and molecular basis. Various management strategies have been proposed to cope with drought stress. Drought stress reduces leaf size, stem extension and root proliferation, disturbs plant water relations and reduces water-use efficiency. Plants display a variety of physiological and biochemical responses at cellular and whole-organism levels towards prevailing drought stress, thus making it a complex phenomenon. CO2 assimilation by leaves is reduced mainly by stomatal closure, membrane damage and disturbed activity of various enzymes, especially those of CO2 fixation and adenosine triphosphate synthesis. Enhanced metabolite flux through the photorespiratory pathway increases the oxidative load on the tissues as both processes generate reactive oxygen species. Injury caused by reactive oxygen species to biological macromolecules under drought stress is among the major deterrents to growth. Plants display a range of mechanisms to withstand drought stress. The major mechanisms include curtailed water loss by increased diffusive resistance, enhanced water uptake with prolific and deep root systems and its efficient use, and smaller and succulent leaves to reduce the transpirational loss. Among the nutrients, potassium ions help in osmotic adjustment; silicon increases root endodermal silicification and improves the cell water balance. Low-molecular-weight osmolytes, including glycinebetaine, proline and other amino acids, organic acids, and polyols, are crucial to sustain cellular functions under drought. Plant growth substances such as salicylic acid, auxins, gibberrellins, cytokinin and abscisic acid modulate the plant responses towards drought. Polyamines, citrulline and several enzymes act as antioxidants and reduce the adverse effects of water deficit. At molecular levels several drought-responsive genes and transcription factors have been identified, such as the dehydration-responsive element-binding gene, aquaporin, late embryogenesis abundant proteins and dehydrins. Plant drought tolerance can be managed by adopting strategies such as mass screening and breeding, marker-assisted selection and exogenous application of hormones and osmoprotectants to seed or growing plants, as well as engineering for drought resistance.

In waterlogged soil, diffusion of gases through soil pores is so strongly inhibited by their water content that it fails to match the needs of growing roots. A slowing of oxygen influx is the principal cause of injury to roots, and the shoots they support (Vartapetian and Jackson, 1997). The maximum amount of oxygen dissolved in the floodwater in equilibrium with the air is a little over 3 % of that in a similar volume of air itself. This small amount is quickly consumed during the early stages of flooding by aerobic micro-organisms and roots. In addition to imposing oxygen shortage, flooding also impedes the diffusive escape and/or oxidative breakdown of gases such as ethylene or carbon dioxide that are produced by roots and soil micro-organisms. This leads to accumulations that can influence root growth and function. For example, accumulated ethylene may slow root extension, while carbon dioxide in the soil can severely damage roots of certain species.

1. **Temperature Stress:**

Temperature stresses can also wreak havoc on a plant. As with any living organism, a plant has an optimal temperature range at which is grows and performs best. If the temperature is too cold for the plant, it can lead to cold stress, also called chilling stress. Extreme forms of cold stress can lead to freezing stress. Cold temperatures can affect the amount and rate of uptake of water and nutrients, leading to cell desiccation and starvation. Under extremely cold conditions, the cell liquids can freeze outright, causing plant death.

Hot weather can affect plants adversely, too. Intense heat can cause plant cell proteins to break down, a process called denaturation. Cell walls and membranes can also "melt" under extremely high temperatures, and the permeability of the membranes is affected.

[Heat](http://en.wikipedia.org/wiki/Heat) stress has been shown to cause problems in [mitochondrial](http://en.wikipedia.org/wiki/Mitochondrial) functions and can result in [oxidative](http://en.wikipedia.org/wiki/Oxidative) damage. Activators of heat stress receptors and defenses are thought to be related to ROS. Heat is another thing that plants can deal with if they have the proper pretreatment. This means that if the temperature gradually warms up the plants are going to be better able to cope with the change. A sudden long temperature increase could cause damage to the plant because their cells and receptors haven’t had enough time to prepare for a major temperature change.

Heat stress can also have a detrimental effect on plant reproduction. Temperatures 10 degrees Celsius or more above normal growing temperatures can have a bad effect on several plant reproductive functions. Pollen [meiosis](http://en.wikipedia.org/wiki/Meiosis), pollen germination, [ovule](http://en.wikipedia.org/wiki/Ovule) development, ovule viability, development of the embryo, and seedling growth are all aspects of plant reproduction that are affected by heat. There have been many studies on the effects of heat on plant reproduction. One study on plants was conducted on [Canola](http://en.wikipedia.org/wiki/Canola) plants at 28 degrees Celsius, the result was decreased plant size, but the plants were still fertile. Another experiment was conducted on Canola plants at 32 degrees Celsius, this resulted in the production of sterile plants. Plants seem to be more easily damaged by extreme temperatures during the late flower to early seed development stage (Cross, McKay, McHughen, & Bonham-Smith, 2003).

The effect of high temperature on higher plants is primarily on photosynthetic functions. The heat tolerance limit of leaves of higher plants coincides with (and appears to be determined by) the thermal sensitivity of primary photochemical reactions occurring in the thylakoid membrane system. Tolerance limits vary between genotypes, but are also subject to acclimation. Long-term acclimations can be superimposed upon fast adaptive adjustment of the thermal stability, occurring in the time range of a few hours. Light causes an increase in tolerance to heat, and this stabilization is related to the light-induced proton gradient. In addition to irreversible effects, high temperature may also cause large, reversible effects on the rate of photosynthesis. We report here some studies of photosynthetic gas exchange and chlorophyll fluorescence, designed to examine the energetic balance between photosynthetic carbon metabolism and light reactions during steady state photosynthesis with leaves of cotton plants at different temperatures. At temperatures exceeding the optimum for assimilation, but well below the tolerance limit, the feedback control of light reactions by carbon metabolism declines, as additional dissipative processes become important. Energy dissipated by photorespiration can exceed that consumed by CO2 assimilation, and a reversible, temperature-induced non-photochemical 'quenching' process, related to 'spillover' of excitation energy to photosystem 1, decreases the efficiency of photosystem 2 with increasing temperature. However, despite the overall decline in the 'potential quantum efficiency', our analysis indicates that CO2 assimilation may be limited, in part, at high temperature by an imbalance in the regulation of the carbon metabolism, which is reflected in a 'down-regulation' of the ribulose-1,5-bisphosphate carboxylase/oxygenase.

The heat stress response is characterized by inhibition of normal transcription and translation, higher expression of heat shock proteins (hsps) and induction of thermotolerance. If stress is too severe, signaling pathways leading to apoptotic cell death are also activated. As molecular chaperones, hsps provide protection to cells against the damaging effects of heat stress and enhance survival. The enhanced expression of hsps is regulated by heat shock transcription factors (HSFs). Recent advances in molecular genetic approaches have provided new insights into the plant heat stress response. A striking characteristic of plants is that they contain highly complex multigene families encoding HSFs and hsps. This review outlines our current knowledge of the functions of plant hsps and the regulation of HSFs, and offers a comparative view of heat stress responses in plants and other organisms. Recent observations indicating that heat stress response overlaps with other stress responses are also discussed.

One of the types of Abiotic Stress is [cold](http://en.wikipedia.org/wiki/Cold). This has a huge impact on farmers. Cold impacts crop growers all over the world in every single country. Yields suffer and farmers also suffer huge losses because the weather is just too cold to produce crops. In the U.S. one of the largest industries is agriculture. Humans have planned the planting of our crops around the seasons. Even though the seasons are fairly predictable, there are always unexpected storms, heat waves, or cold snaps that can ruin our growing seasons. ROS stands for reactive oxygen species. ROS plays a large role in mediating events through transduction. Cold stress was shown to enhance the transcript, protein, and activity of different ROS-scavenging enzymes. Low temperature stress has also been shown to increase the H2 O2 accumulation in cells. Plants can be acclimated to low or even freezing temperatures. If a plant can go through a mild cold spell this activates the cold-responsive genes in the plant. Then if the temperature drops again, the genes will have conditioned the plant to cope with the low temperature. Even below freezing temperatures can be survived if the proper genes are activated.

1. **Radiation Stress:**

Light intensity and quality are integral part of the environment that affect the physiology of cells and growth and development of the whole plant. Excessive, deficient and inappropriate spectral distributions of light can be defined as stress to the integrated plant system, having deleterious effects. More than required quantities of photosynthetically active radiations i.e. PAR (400-700 nal) and increased absorption of UV-radiations produce radiation stress in plants. The biosphere receives solar radiations at wavelength ranging from 290 nm - 3000 nm. Ultraviolet spectrum can be divided into three regions UV-A (320-400 nm), UV-B (280-320 nm) and UV-C (200-280 nm). Studies of ultraviolet radiations on plants mainly focus on UV-B radiations because UV-C is completely absorbed by the atmosphere and UV-A has no detrimental impact on plant architecture and functions. Leaves are the perception sites for incoming radiations. UV stress is a complex oxidative stress inducing the production of various Reactive Oxygen Species (ROS) in plants, these generated ROS serve to modify metabolism and gene expression so that plant may evolve mechanisms to respond to adverse environmental conditions.

1. **Air Pollutants:**

Air pollutants affect plants worldwide; these effects may be severe or subtle. Various air pollutants have been identified as phytotoxic agents. Phytotoxicity of sulfur dioxide (SO2) has been recognized for about a century, effects of ozone (O3) for more than 30 years, acidic precipitation for almost 20 years, and effects of elevated levels of nitrogen compounds (nitrogen oxides [NOX] and ammonia [NH3]) in the last decade. Importance of other pollutants such as peroxyacetyl nitrate (PAN), fluorides or heavy metals has also been recognized.

1. **Other Abiotic Stresses:**

Other abiotic stresses are less obvious, but can be equally as lethal. In the end, most abiotic stresses affect the plant cells in the same manner as do water stress and temperature stress. Wind stress can either directly damage the plant through sheer force; or, the wind can affect the [transpiration](http://forestry.about.com/od/foresttermsandglossary/g/transpire.htm) of water through the leaf [stomata](http://forestry.about.com/od/foresttermsandglossary/g/stomata.htm) and cause desiccation. Direct burning of plants through wildfires will cause the cell structure to break down through melting or denaturation.

In farming systems, the addition of agrochemicals such as fertilizers and pesticides, either in excess or in deficit, can also cause abiotic stress to the plant. The plant is affected through an imbalance of nutrition, or via toxicity. High amounts of salt taken up by a plant can lead to cell desiccation, as elevated levels of salt outside a plant cell will cause water to leave the cell, a process called [osmosis](http://biology.about.com/od/cellularprocesses/ss/diffusion_3.htm). Plant uptake of heavy metals can occur when plants grow in soils fertilized with improperly composted sewage sludge. High heavy metal content in plants can lead to complications with basic physiological and biochemical activities such as photosynthesis.

**Interactions and Effects of E.S on Plant Growth Stages**

**Seed Germination**

In the germination process, the seed’s role is that of a reproductive unit; it is the thread of life that assures the survival of all plant species. Furthermore, because of its role in stand establishment, seed germination remains a key to modern agriculture. Thus, especially in a world acutely aware of the delicate balance between food production and world population, a fundamental understanding of germination is essential for maximum crop production.

Seed germination depends on both internal and external conditions. The most important external factors include [temperature](http://en.wikipedia.org/wiki/Temperature), [water](http://en.wikipedia.org/wiki/Water), [oxygen](http://en.wikipedia.org/wiki/Oxygen) and sometimes [light](http://en.wikipedia.org/wiki/Light) or ts require different variables for successful seed germination. Often this depends on the individual seed variety and is closely linked to the [ecological conditions](http://en.wikipedia.org/wiki/Ecology) of a plant's [natural habitat](http://en.wikipedia.org/wiki/Natural_habitat). For some seeds, their future germination response is affected by environmental conditions during seed formation; most often these responses are types of [seed dormancy](http://en.wikipedia.org/wiki/Seed_dormancy).

Germination and emergence are the two most important stages in the life cycle of plants that determine the efficient use of the nutrients and water resources available to plants (Gan et al., 1996) and can compete for an ecological niche (Forcella et al., 2000). Environmental factors such as temperature, light, pH, and soil moisture are known to affect seed germination (Martins et al., 2000; Canossa et al., 2008; Ikeda et al., 2008; Rizzardi et al., 2009). Temperature plays a major role in determining the periodicity of seed germination and the distribution of species (Guan et al., 2009). Germination rate usually increases linearly with temperature, at least within a well-defined range, and declines sharply at higher temperatures (Alvarado & Bradford, 2002). Other major factors that affect seed germination are water potential and salinity. Researches showed that osmotic and salt stress can delay, reduce or prevent germination (Zhou et al., 2005). In addition to these factors, germination is also affected by pH and planting depth (Lu et al., 2006; Norsworthy & Oliveira, 2006)

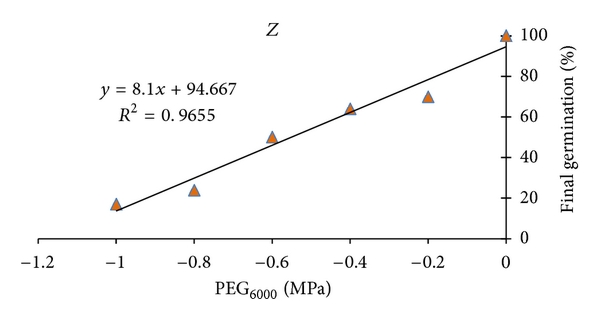
Few researches have been coated here for further understanding.

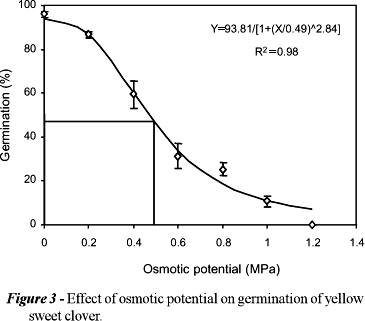
1. **Water:**

**Water** is required for germination. Mature seeds are often extremely dry and need to take in significant amounts of water, relative to the dry weight of the seed, before cellular [metabolism](http://en.wikipedia.org/wiki/Metabolism) and growth can resume. Most seeds need enough water to moisten the seeds but not enough to soak them. The uptake of water by seeds is called [imbibition](http://en.wikipedia.org/wiki/Imbibition), which leads to the swelling and the breaking of the seed coat. When seeds are formed, most plants store a food reserve with the seed, such as [starch](http://en.wikipedia.org/wiki/Starch), [proteins](http://en.wikipedia.org/wiki/Protein), or [oils](http://en.wikipedia.org/wiki/Oil). This food reserve provides nourishment to the growing embryo. When the seed imbibes water, [hydrolytic enzymes](http://en.wikipedia.org/wiki/Hydrolytic_enzyme) are activated which break down these stored food resources into metabolically useful [chemicals](http://en.wikipedia.org/wiki/Chemical).

1. **Effects of Water Deficiency Stress during Seed Growth on Yield and its Components, Germination and Seedling Growth Parameters of Some Wheat Cultivars (Majid Abdoli and Mohsen Saeidi, 2012).**

Little information is available in the literature about the effect of terminal drought stress on seed germination and vigor of wheat. The objectives of this experiment were to study the effect of terminal water deficiency stress on yield and its components, seed germination and vigor of nine wheat cultivars (Bahar, Parsi, Pishtaz, Pishgam, Chamran, Zarin, Sivand, Marvdasht and DN-11). To this end, an experiment was caried out in a split–plot experiment based on randomized completed blocks design with three replications during 2010-2011 season in research farm of Razi University in Iran. The results showed that post anthesis water deficency significantly decreased grain yield, biomass, 1000 grain weight and grain number spick-1 in cultivars. Under post-anthesis water deficiency, cultivars in terms of all under-study traits had significant differences. In the second experiment, influence of water deficiency stress infarm on germination percentage and seedling growth parameters have been measured. Based on laboratory results, water deficiency stress in farm caused reduction in all germination characteristics, except plumule to radicle ratio and mean germination time. According to farm and laboratory results, it can be said that Sivand cultivar with the highest yield and grain weight had the best germination characteristics and less affected by water deficiency stress. Also Pishgam and DN-11 were the next cultivars based on germination characteristics.

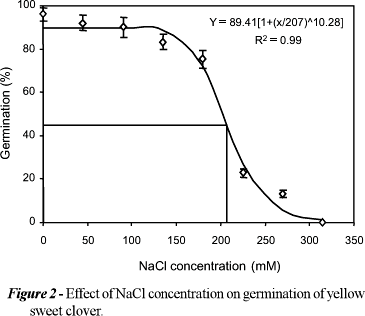




1. **Salt:**
2. **Salt Stress Effects on Respiration and Growth of Germinated Seeds of Different Wheat (Triticum aestivum L.) Cultivars (Moud A. M. and K. Maghsoudi, 2008).**

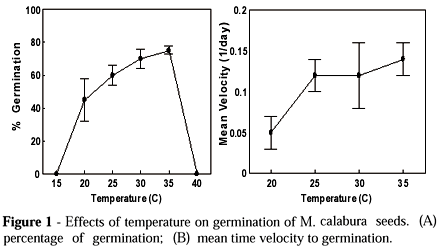
Establishment of seedlings at early growth stages of crop plants as one of the most important determinants of high yield is severely affected by soil salinity. Therefore, high germination rate and vigorous early growth under salty soils is preferred. In this study salt tolerance of wheat cultivars were examined at germination and seedling growth stages. Seeds were germinated and grown in long dark cups using distilled water as control and two levels of salt stress imposed by 9 and 15 ds/m NaCl solution for 48 hours. Coleoptile and root growth was measured as the response of cultivars to salinity. Seedling respiration was expressed as the difference between initial seed weight and seedling dry weight after 48 hours. Significant differences were found among cultivars in terms of coleoptile and root growth under salt stress condition. Differences among cultivars in terms of respiration rate were also significant indicating that genetic variation exists among wheat cultivars. It was also found that seedling respiration was decreased as salinity level was increased. Significant correlation coefficients were found between coleoptile growth and respiration under all condition. Salt stress inhibited coleoptile growth more than root growth. It was concluded that wheat seedling maintenance respiration is higher than what is estimated for C plants.

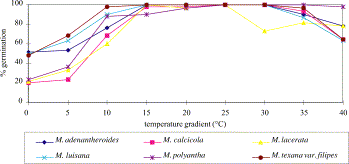
1. To investigate the effect of salt stress on seed germination of yellow sweet clover, three replicates of 50 seeds were incubated in moist paper towels with sodium chloride solutions of 0, 45, 90, 135, 180, 225, 270 and 315 mM. The seeds were incubated at 18 ºC in darkness. Seed germination did not decrease significantly from 0 to 100 mM, but beyond this point declined with increasing salinity following a sigmoid trend and was completely inhibited at 300 mM salinity ([Figure 2](http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-83582010000300002#f2)). The concentration required for 50% inhibition was 100 mM NaCl. (**Ghaderi-Far et al., 2010**).



1. **Temperature:**

**Temperature** affects cellular metabolic and growth rates. Seeds from different species and even seeds from the same plant germinate over a wide range of temperatures. Seeds often have a temperature range within which they will germinate, and they will not do so above or below this range. Many seeds germinate at temperatures slightly above 60-75 F (16-24 C) [room-temperature if you live in a centrally heated house], while others germinate just above freezing and others germinate only in response to alternations in temperature between warm and cool. Some seeds germinate when the soil is cool 28-40 F (-2 - 4 C), and some when the soil is warm 76-90 F (24-32 C). Some seeds require exposure to cold temperatures ([vernalization](http://en.wikipedia.org/wiki/Vernalization)) to break dormancy. Seeds in a dormant state will not germinate even if conditions are favorable. Seeds that are dependent on temperature to end dormancy have a type of physiological dormancy. For example, seeds requiring the cold of winter are inhibited from germinating until they take in water in the fall and experience cooler temperatures. Four degrees Celsius is cool enough to end dormancy for most cool dormant seeds, but some groups, especially within the family [Ranunculaceae](http://en.wikipedia.org/wiki/Ranunculaceae) and others, need conditions cooler than -5 C. Some seeds will only germinate after hot temperatures during a [forest fire](http://en.wikipedia.org/wiki/Forest_fire) which cracks their seed coats; this is a type of physical dormancy.





Ricalde et al., 2004.

1. **Light:**

**Light or darkness** can be an environmental trigger for germination and is a type of physiological dormancy. Most seeds are not affected by light or darkness, but many seeds, including species found in forest settings, will not germinate until an opening in the canopy allows sufficient light for growth of the seedling. Scarification mimics natural processes that weaken the seed coat before germination. In nature, some seeds require particular conditions to germinate, such as the heat of a fire (e.g., many Australian native plants), or soaking in a body of water for a long period of time. Others need to be passed through an animal's [digestive tract](http://en.wikipedia.org/wiki/Digestive_tract) to weaken the seed coat enough to allow the seedling to emerge.

**Vegetative Growth**

The period of growth between germination and flowering is known as the vegetative phase of plant development. During the vegetative phase, plants are busy carrying out photosynthesis and accumulating resources that will be needed for flowering and reproduction. Different types of plants show different growth habits. The movies in this section will document various growth processes that occur during the vegetative phase of development.

Growth is the process by which a plant increases in the number and size of leaves and stems. The result of plant growth is forage production and the amount harvested by animal or machine is forage yield. The growth of both plants and animals requires energy. Animals get their energy by digesting the plants they eat. Plants get their energy from the sun through photosynthesis. Photosynthesis is the process where the green pigment in the plant's leaf (chlorophyll) absorbs energy from sunlight and, using this energy, water, and carbon dioxide, produces oxygen and simple sugars. The plant then uses these sugars to make more complex sugars and starches for storage as energy reserves, to make cellulose and hemicellulose for cell walls or with nitrogen, to make proteins. How the plant uses its energy depends on the developmental stage of the plant and on environmental conditions.

Plant growth is limited by the environment. Many plant problems are caused by environmental stress. Therefore, it is important to understand the environmental aspects that affect plant growth. Five important environmental factors are light, temperature, water, air and nutrients.

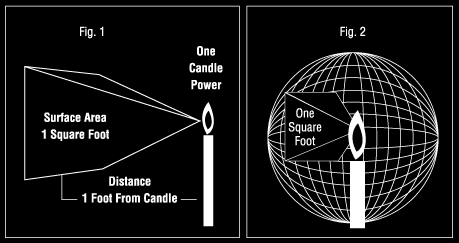
1. **Light:**

Light has three principal characteristics affecting plant growth: quantity, quality, and duration.

***A. Quantity***refers to the intensity or concentration of sunlight and varies with the season of the year. The maximum is present in the summer and the minimum in winter. The more sunlight a plant receives, up to a point, the greater capacity it has to produce plant food through photosynthesis. The brightness of light is measured in foot-candles

1. Light quantity can be decreased in a garden or greenhouse by using shadecloth above the plants or growing plants in the shade of a tree.

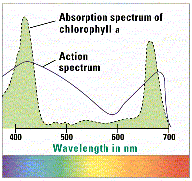
2. It can be increased by surrounding plants with reflective material, white backgrounds, or supplemental lights.

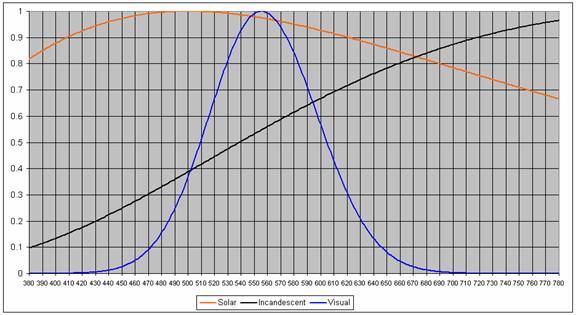
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***B. Quality***refers to the color or wavelength reaching the plant surface. Sunlight can be broken up by a prism into red, orange, yellow, green, blue, indigo, and violet. Red and blue light have the greatest effect on plant growth. Red light, when combined with blue light, encourages flowering in plants. Green light is least effective to plants as they absorb less of it.

Blue light is primarily responsible for vegetative growth or leaf growth.

1. Fluorescent or cool white light is high in the blue and red range of light quality and is used to encourage leafy growth and short plants.
2. Incandescent light is high in the red or orange range, but generally produces too much heat and too much stem elongation in plants to be a valuable light source.
3. A combination of fluorescent and incandescent comes close to natural sunlight.

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***C. Duration***refers to the amount of time a plant is exposed to sunlight or the lack of it’s designated photoperiod. It is not the length of the light period but the length of uninterrupted dark periods that is critical to floral development. The ability of many plants to flower is controlled by photoperiod. Plants can be classified into three categories, depending upon their flowering response to the duration of light or darkness.

*1.* ***Short-day plants***form flowers only when the day length is less than about 12 hours in duration (long nights). Short-day plants include many fall flowering plants such as chrysanthemum and poinsettia.

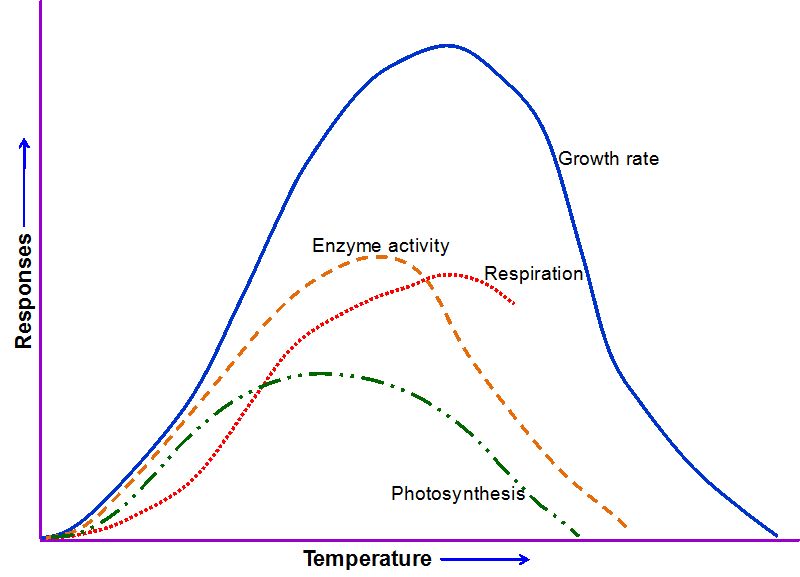
*2****. Long-day plants***form flowers only at day lengths exceeding about 12 hours (short nights). They include almost all of the summer flowering plants, as well as many vegetables including beet, radish, lettuce, spinach, and potato.

*3.* ***Day-neutral plants***form flowers regardless of day length. Some plants do not really fit into any category but may be responsive to combinations of day lengths. The petunia will flower regardless of day length, but flowers earlier and more profusely under long daylight.

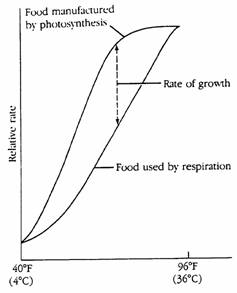
1. **Temperature:**

Temperature effects various plant processes including:

* Photosynthesis: increases with temperature to a point
* Respiration: increases with temperature
* Transpiration: increases with temperature
* Flowering: triggered in some plants by low temperature
* Sugar storage: low temperatures reduce energy use and increase sugar storage



Temperature affects the productivity and growth of a plant, depending upon whether the plant is a warm- or cool-season crop. If temperatures are high and day length is long, cool-season crops such as spinach will flower. Temperatures that are too low for a warm-season crop such as tomato will prevent fruit set. Adverse temperatures also cause stunted growth and poor quality vegetable production; for example, bitterness in lettuce is caused by high temperatures.**19b**



**Thermoperiod** refers to a daily temperature change. Plants respond to and produce maximum growth when exposed to a day temperature that is about 10º to 15º F higher than a night temperature. This allows the plant to photosynthesize (build up) and respire (break down) during an optimum daytime temperature and to curtail the rate of respiration during a cooler night. Higher temperatures cause increased respiration, sometimes above the rate of photosynthesis. This means that the products of photosynthesis are being used more rapidly than they are being produced.

**Degree–days** are used to predict crop maturity. The hours of each day that the temp rises above a base temp (usually 50 F) are added and when the proper number for the crop is reached it should be ripe. This is mathematically similar to calculating chilling periods for breaking dormancy in temperate perennial plants.

**For growth to occur, photosynthesis must be greater than respiration**.

**Too low temperatures** can also produce poor growth. Photosynthesis is slowed down at low temperatures. Since photosynthesis is slowed, growth is slowed, and this results in lower yields.

**Not all plants** grow best under the same temperature range.

1. Snapdragons grow best at nighttime temperatures of 55º F and the poinsettia at 62º F.

2. Florist cyclamen does very well under very cool conditions while many summer annual bedding plants prefer a higher temperature.

However, in many temperate perennials, a certain number of days of low temperature are needed by plants in order to break dormancy and grow properly this is called a chilling requirement, or chilling period.

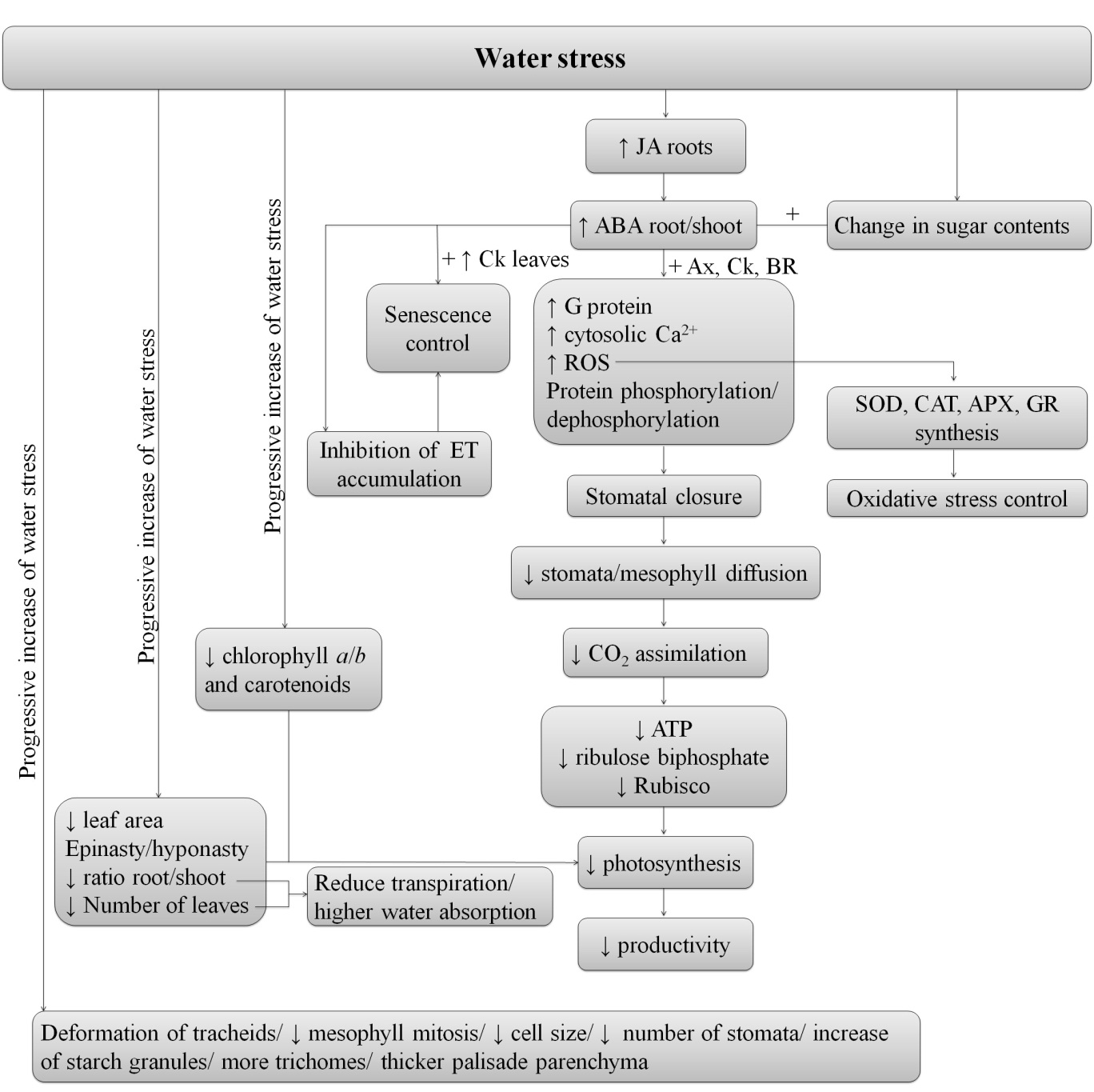
This is true of crops originating in cold regions.

1. Apples are a prime example: most varieties require (1,000 to 1,200 hours below 45º F but above 32º F before they break their rest period and begin growth).

2. Lilies and daffodils need 6 weeks of temperatures at 33º F before blooming.

**Plants** can be classified as either hardy or nonhardy depending upon their ability to withstand cold temperatures.

1. Winter injury can occur to nonhardy plants if midwinter temperatures are too low or if unseasonably low temperatures occur early in the fall or late in the spring.
2. Winter injury may also occur because of desiccation or drying out. Plants need water during the winter. When the soil is frozen, the movement of water into the plant is severely restricted. On a windy winter day, evergreens can become water-deficient in a few minutes and the leaves or needles then turn brown.
3. Unseasonably high winter temperatures can cause premature bud break in some plants and consequent fruit bud freezing damage.
4. Late spring frosts can ruin entire crops. Flowers freeze more easily than leaf buds.
5. If temperatures drop too low during the winter, entire trees of some species are killed by freezing and desiccating plant cells and tissue.
6. **Water:**

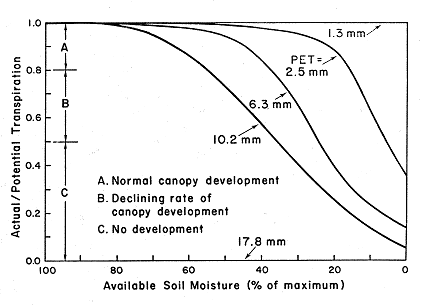


Most growing plants contain about 90% water. Water is the medium for transfer within the plant and is the solvent system of the cell. Water is one of the raw materials for photosynthesis required for the production of new compounds. In soft tissues water pressure provides support and as plants lose water from their leaves they are cooled. A net loss of water will cause growth to stop and continued deficiency results in death. A growing plant absorbs water from the soil and gives it off in transpiration. CO2 enters the plant through a film of water that surrounds the leaf and as the film evaporates it is replenished by the plant. The transpirational loss of water in exchange for CO2 is necessary for plant growth. Rapidly growing plants require large quantities of water, far in excess of that found in the plant for synthesis of new materials.

Moisture stress is generally detrimental to plant growth reducing both yield and quality of the crop. The degree and duration of the stress will determine how severely growth is reduced, however, growth rate may never return to the level it was before the stress. The stage of growth when moisture stress occurs is also important. Moisture stress at the time of flower initiation may significantly reduce yield. Severe stress leads to premature flower, leaf and fruit drop.



Transpiration leads to moisture stress if moisture is not readily available to the roots. As moisture stress increases, stomates close and photosynthesis is reduced. Warm dry air has a high evaporative capacity, increasing the rate of transpiration. As we ll, the increase in leaf temperature resulting from high light intensity raises the rate of transpirational loss.



Water stress effects on canopy growth and crop greenness cause reductions from the entered canopy and greenness values which represent non-stress conditions. The stress was classified into three different zones as depicted in Figure. For canopy development, stress zone A (where AT/PT is high) assumes normal growth conditions, Zone B computes a linear decline of growth from full normal daily growth to no growth, and no growth occurs if the AT/PT ratio falls in zone C. The ranges and number of zones have been fixed to default values. The increment of expected daily growth is computed from the entered canopy curve, then this amount is reduced by multiplying the factor for the stress zone encountered.

Poor water quality can be a major problem for growers, particulary those with hydroponic systems, due to contamination from organic and inorganic substances. Even the best domestic water supplies may contain substances that affect plant growth. Therefore, a complete water analysis is recommended for greenhouse growers. Hydroponic systems require detailed elemental analysis of irrigation waters. In order to develop an appropriate recommendation for nutrient levels in solution the concentration of existing elements in the water must be known. Adjustments can then be made in the solution for the crop to be grown. Depending on the result of the water analysis, some form of water treatment may be necessary. Water treatment may simply involve the use of a filtering system for particulate debris, or may require more sophisticated methods of ion exchange or reverse osmosis in addition to filtration. In some cases all that may be necessary is the adjustment of nutrient solution, as in hard water areas where the majority of calcium and magnesium is already provided by the water source.

Excess of water (waterlogging) at the same time adversity effect the root man and plant growth rate usually results in plants death especially fruit trees and crop plants.



**Flowering and Reproduction**

A flower, sometimes known as a bloom or [blossom](http://en.wikipedia.org/wiki/Blossom), is the [reproductive](http://en.wikipedia.org/wiki/Reproduction) structure found in [flowering plants](http://en.wikipedia.org/wiki/Flowering_plant) (plants of the division [Magnoliophyta](http://en.wikipedia.org/wiki/Magnoliophyta), also called angiosperms). The biological function of a flower is to effect reproduction, usually by providing a mechanism for the union of sperm with eggs. Flowers may facilitate outcrossing (fusion of sperm and eggs from different individuals in a population) or allow selfing (fusion of sperm and egg from the same flower). Some flowers produce [diaspores](http://en.wikipedia.org/wiki/Diaspore_%28botany%29) without fertilization ([parthenocarpy](http://en.wikipedia.org/wiki/Parthenocarpy" \o "Parthenocarpy)). Flowers contain sporangia and are the site where gametophytes develop. Flowers give rise to fruit and seeds. Many flowers have evolved to be attractive to animals, so as to cause them to be vectors for the transfer of pollen.

1. **Temperature:**

The adverse effects of high temperature stress (HTS) on plant reproduction have implications on worldwide crop production systems as well as contributing to the geographical distribution of natural plant species. The sensitivity of reproductive development to HTS is not well understood. However, with a predicted temperature increase of +1.4 °C to +5.8 °C between the years 1990 and 2010 ([IPCC Working Group I, 2001](http://jxb.oxfordjournals.org/content/55/396/485.full#ref-19)), a good understanding of the phenomenon will be required if the impact of these higher temperatures is to be limited and the current crop germplasm improved.

HTS during flowering results in reduced seed yield in both monocotyledon and dicotyledon plants, for example, Brassica napus (L.) ([Nuttal et al., 1992](http://jxb.oxfordjournals.org/content/55/396/485.full" \l "ref-28); [Morrison, 1993](http://jxb.oxfordjournals.org/content/55/396/485.full#ref-25); [Angadi et al., 2000](http://jxb.oxfordjournals.org/content/55/396/485.full#ref-1)), Linum usitatissimum (L.) ([Gusta et al., 1997](http://jxb.oxfordjournals.org/content/55/396/485.full" \l "ref-9)), Lycopersicon esculentum (Mill.) ([Peet et al., 1998](http://jxb.oxfordjournals.org/content/55/396/485.full" \l "ref-31); [Sato et al., 2002](http://jxb.oxfordjournals.org/content/55/396/485.full#ref-41)), Phaseolus vulgaris (L.) ([Shonnard and Gepts, 1994](http://jxb.oxfordjournals.org/content/55/396/485.full" \l "ref-43)), Triticum aestivum (L.) ([Saini et al., 1983](http://jxb.oxfordjournals.org/content/55/396/485.full#ref-39)), and Zea mays (L.) ([Herrero and Johnson, 1980](http://jxb.oxfordjournals.org/content/55/396/485.full" \l "ref-11); [Carlson, 1990](http://jxb.oxfordjournals.org/content/55/396/485.full#ref-2)). The range of species adversely affected by HTS during the reproductive stage suggests that some common mechanisms may be involved in HTS‐induced reduction of seed production.

**Thermoperiod** refers to daily temperature change. Plants produce maximum growth when exposed to a day temperature that is about 10 to 15°F higher than the night temperature. This allows the plant to photosynthesize (build up) and respire (break down) during an optimum daytime temperature, and to curtail the rate of respiration during a cooler night. High temperatures cause increased respiration, sometimes above the rate of photosynthesis. This means that the products of photosynthesis are being used more rapidly than they are being produced. For growth to occur, photosynthesis must be greater than respiration.

Low temperatures can result in poor growth. Photosynthesis is slowed down at low temperatures. Since photosynthesis is slowed, growth is slowed, and this results in lower yields. Not all plants grow best in the same temperature range. For example, snapdragons grow best when night time temperatures are 55°F, while the poinsettia grows best at 62°F. Florist cyclamen does well under very cool conditions, while many bedding plants grow best at a higher temperature.

Buds of many plants require exposure to a certain number of days below a critical temperature (chilling hours) before they will resume growth in the spring. Peaches are a prime example; most cultivars require 700 to 1,000 hours below 45°F and above 32°F before they break their rest period and begin growth. This time period varies for different plants. The flower buds of forsythia require a relatively short rest period and will grow at the first sign of warm weather. During dormancy, buds can withstand very low temperatures, but after the rest period is satisfied, buds become more susceptible to weather conditions, and can be damaged easily by cold temperatures or frost.

Few researches have been presented below for understanding to the effect of environmental stress on different crops.

1. **High temperature stress of Brassica napus during flowering reduces micro‐ and megagametophyte fertility, induces fruit abortion, and disrupts seed production (Young et al., 2004)**

High temperature stress (HTS), during flowering, decreases seed production in many plants. To determine the effect of a moderate HTS on flowering, fruit and seed set in Brassica napus, plants were exposed to a HTS (8/16 h dark/light, 18 °C night, ramped at 2 °C h–1, over 6 h, to 35 °C for 4 h, ramped at 2 °C h–1 back to 23 °C for 6 h) for 1 or 2 weeks after the initiation of flowering. Although flowering on the HTS‐treated plants, during both the 1 week and 2 week HTS treatments, was equal to that of control‐grown plants, fruit and seed development, as well as seed weight, were significantly reduced. Under HTS, flowers either developed into seedless, parthenocarpic fruit or aborted on the stem. At the cessation of the HTS, plants compensated for the lack of fruit and seed production by increasing the number of lateral inflorescences produced. During the HTS, pollen viability and germinability were slightly reduced. In vitro pollen tube growth at 35 °C, from both control pollen and pollen developed under a HTS, appeared abnormal, however, in vivo tube growth to the micropyle appeared normal. Reciprocal pollination of HTS or control pistils with HTS or control pollen indicated that the combined effects of HTS on both micro‐ and megagametophytes was required to knock out fruit and seed development. Expression profiles for a subset of HEAT SHOCK PROTEINs (HSP101, HSP70, HSP17.6) showed that both micro‐ and megagametophytes were thermosensitive despite HTS‐induced expression from these genes.

1. **Temperature stress and plant sexual reproduction: uncovering the weakest links (Zinn et al., 2010).**

The reproductive (gametophytic) phase in flowering plants is often highly sensitive to hot or cold temperature stresses, with even a single hot day or cold night sometimes being fatal to reproductive success. This review describes studies of temperature stress on several crop plants, which suggest that pollen development and fertilization may often be the most sensitive reproductive stage. Transcriptome and proteomic studies on several plant species are beginning to identify stress response pathways that function during pollen development. An example is provided here of genotypic differences in the reproductive stress tolerance between two ecotypes of Arabidopsis thaliana Columbia (Col) and Hilversum (Hi-0), when reproducing under conditions of hot days and cold nights. Hi-0 exhibited a more severe reduction in seed set, correlated with a reduction in pollen tube growth potential and tropism defects. Hi-0 thus provides an Arabidopsis model to investigate strategies for improved stress tolerance in pollen. Understanding how different plants cope with stress during reproductive development offers the potential to identify genetic traits that could be manipulated to improve temperature tolerance in selected crop species being cultivated in marginal climates.

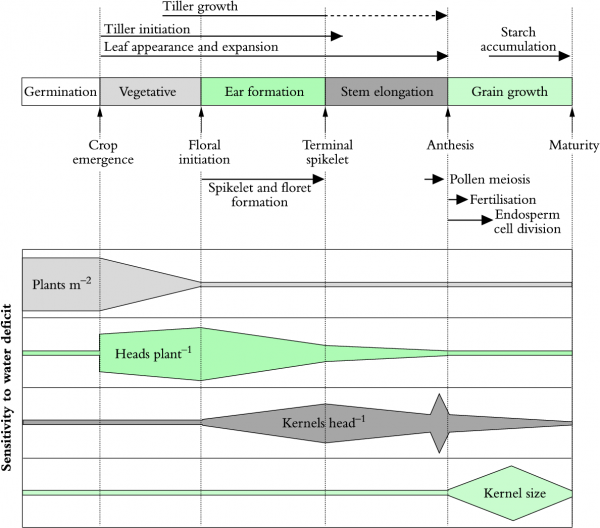
1. **Effects of low temperature stress during flowering period on pollen characters and flag leaf physiological and biochemical characteristics of rice (Beng et al., 2011)**

Taking cold-tolerant rice cultivar 996 and cold-sensitive rice cultivar 4628 as test materials, a growth chamber experiment was conducted to investigate their pollen characters and flag leaf physiological and biochemical characteristics under the effects of low temperature stress. The plants were respectively treated with low temperature [ 19 degrees C (06:00-8:00; 19:00-23:00 )/21 degrees C (08:00-10:00; 16:00-19:00)/23 degrees C (10:00-16:00)/17 degrees C (23:00-06:00)] and optimal temperature [24 degrees C (06:00-8:00; 19:00-23:00)/26 degrees C (08:00-10:00; 16:00-19:00)/30 degrees C (10:00-16:00)/22 degrees C (23:00-06:00)] for seven days after heading. Low temperature stress decreased the anther dehiscence coefficient and pollen germination rate, as well as the sterile pollen rate of spikelets on middle and lower parts of panicles, with the anther dehiscence coefficient and pollen germination rate of cultivar 996 being significantly higher than those of cultivar 4628, indicating that cold-tolerant cultivar 996 had the capability to keep better pollination and pollen germination. Under low temperature stress, the flag leaf soluble protein and free proline contents and their increments of cultivar 996 were significantly higher than those of cultivar 4628, while the MDA content and relative conductivity and their increment were in adverse, indicating that cold-tolerant cultivar 996 had more quick and strong protective responses, and was able to keep stable membrane structure and function.

1. **Water:**

The study of different growth and developmental events in crop plants with respect to time is called crop phenology. Drought strongly affects crop phenology by shortening the crop growth cycle with a few exceptions. Limited water supply triggers a signal to cause an early switching of plant development from the veg-etative to reproductive phase. For instance, total growth duration of both bread wheat (Triticum aestivumL.) and barley (Hordeum vulgareL.) decreased under drought, which gen-erally results in substantial yield reductions. The effect of drought is phase specific in most cases. For example, drought at pre-anthesis delayed flowering in quinoa (Chenopodium quinoaWild.) and bread wheat plants. Likewise, drought at anthesis commonly delays flowering in rice (Oryza sativaL.); interestingly, the longer the delay, the higher the yield penalty. In soybean (Glycine maxL.), drought during grain filling hastened maturity but yield was down due to smaller grains. Different crops respond to drought differently. For instance, upon exposure to drought flowering is delayed in maize, quinoa, and rice, whereas in soybean, wheat, and barleydrought hastened flowering and physiological maturity.

A generalised sequence for vegetative growth and reproductive development in a cereal plant (Figure 15.16) can be used to highlight key physiological phases (i.e. crop phenol-ogy) and their comparative sensitivity to water deﬁcit. Overall, the earlier a water deﬁcit occurs, the less effect it has on ﬁnal yield. However, cereals are particularly sensitive to water deﬁcit at or just before anthesis.



A schematic representation of phenology for a cereal plant, showing major developmental phases, from germination to grain maturity. Band widths represent relative sensitivity to water deficit. (Notional values compiled by D.G. Abrecht and R.J. French)

Water deﬁcit at anthesis affects yield by reducing the number of grains per ear rather than ear number or grain size. This suggests that water deﬁcit interferes with fertilisation. In wheat, male fertility is more strongly affected than female fertility since droughted plants fertilised with pollen taken from well-watered plants produce normal numbers of grain, but well-watered plants fertilised with pollen from droughted plants produce few grains. Saini and Aspinall also found that the period when grain set was most sensitive to water deﬁcit coincided with pollen meiosis and microspore release from the tetrads.

By contrast, water deﬁcit impedes embryo development after fertilisation in maize rather than pollen fertility *per se*. Drought stress can also delay silking so that pollen is shed before plants have receptive stigmas (Herrero and Johnson 1981).

Water deﬁcit during the vegetative phase of a cereal crop affects grain yield via vegetative growth and tillering. Water deﬁcit reduces leaf expansion rates. In wheat and maize, drought stress can also reduce the rate of leaf appearance (Abrecht and Carberry 1993; Armstrong *et al*. 1996). Therefore stressed crops have lower leaf area indices and intercept less radiation. This is the major cause of reduced crop growth caused by water deﬁcit during vegetative growth. Robertson and Giunta (1994) have shown that water deﬁcit prior to anthesis did not affect radiation use efﬁciency in wheat.

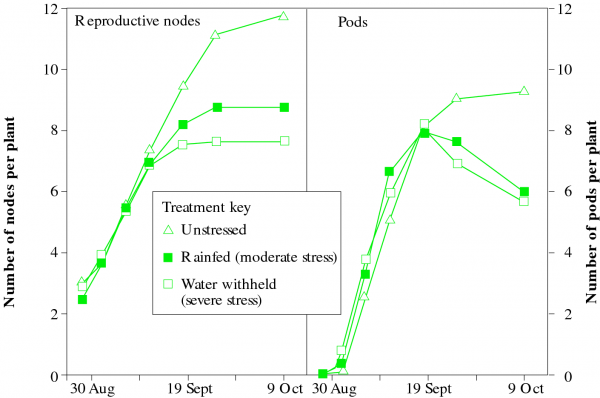
Water deﬁcit experienced during vegetative growth also reduces the rate of tiller appearance, but compensatory responses do occur. For example, Aspinall *et al*. (1964) found that barley stressed during vegetative growth grew more tiller buds after rewatering, so plants stressed early produced more tillers although many of these tillers bore no heads. There is no compensation for water-deﬁcit-induced reductions in tiller number in wheat following rewatering, and wheat sub-jected to water deﬁcit during vegetative growth consequently carries fewer fertile tillers per plant (Armstrong *et al*. 1996).

Water deﬁcit after anthesis influences grain size, although grain number per ear is also reduced if the deﬁcit occurs in the ﬁrst two weeks after anthesis. Later deﬁcits reduce grain size by shortening the duration of grain ﬁlling (Brookes *et al*. 1982).

The balance between vegetative growth and reproductive development is crucial to ﬁnal yield. Vegetative growth establishes a carbon source in leaves, roots and support struc-tures which is used by reproductive sinks. This balance is largely achieved by developmental partitioning, especially in determinate plants such as wheat. Growth and developmental phases correspond to phenological events, and consequently the timing of photoassimilate partitioning is largely determined by phenology.

Indeterminate plants, including most grain legumes, express a complicated phenology because flowering is followed by a phase of mixed vegetative and reproductive growth. This is usually followed by a period of purely reproductive growth. The previous mixed phase enables grain legumes to set enough reproductive sinks to yield satisfactorily. In species such as ﬁeld pea, lentil, chickpea and faba bean new pods are set sequentially. Moreover, each pod or pair of pods is formed together with supporting stem and a subtending source leaf (French 1990). Other grain legumes, such as narrow-leafed lupin, carry additional groups of pods on late-formed racemes. This pattern of prolonged reproductive development in grain legumes becomes compressed in response to water deﬁcit, resembling drought stress effects on node formation and pod set in ﬁeld peas.

Reproductive growth is less sensitive to water deﬁcit than vegetative growth, and increased partitioning to reproductive structures is one consequence. Ong (1984) provided a very clear example of this in groundnut. Once seed is set, growth rates are often maintained under water deﬁcit. Soybean and wheat behave similarly. In general, mild water deﬁcit can even accelerate seed growth (French and Turner 1991) because vegetative growth is severely constrained and photoassimilate is diverted to reproductive structures. If drought stress intensiﬁes, carbon assimilation diminishes and stored reserves are then mobilised for seed growth. Seed growth rate is thus sustained, but duration of ﬁlling can be shortened, resulting in smaller seeds. In groundnut, mild water deﬁcit prior to or just after flowering increases pod set in a selective way. Development of small pods is reduced and fewer of them become mature pods. Water deﬁcit in cotton also reduces the proportion of flowers setting bolls.



In field pea, water deficit curtains duration of flowering which results in fewer pods per plant. Reproductive nodes formed on each plant are not as severely reduced, but their effectiveness in forming pods is diminished by drought stress.

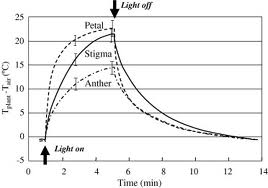
Such contrasting effects of water deﬁcit on reproductive structures are commonplace. By and large, small structures suffer in favour of large structures. In the tropical pasture legume *Macroptilium atropurpureum* water deﬁcit retards small bud development prior to floral initiation. Later develop-mental stages are not affected but survival of floral buds is reduced. Again, in soybean, water deﬁcit at anthesis reduces pod set at high floral positions while improving basal pod set (Westgate and Peterson 1993). In cotton, small fruiting buds and bolls are shed in response to water deﬁcit, while pods formed later are also shed in groundnut in response to water deﬁcit. A decrease in pod numbers in ﬁeld peas again results from a loss of young pods.

Such patterns of crisis reaction to drought stress where small structures are shed preferentially ensure that repro-ductive structures nearing maturity are retained and thus enhance prospects for successful completion of a life cycle, a feature of plant development with obvious selection advantage.

1. **Light:**

Although there is a natural growth cycle for every plant, the vegetative and flowering stages of growth are directly influenced by light. Artificial lights allow for year-round growth and quick production, but the intensity and nutrients that natural sunlight offers can never truly be duplicated. Without light, we would not have green plant life, vegetable gardens would not produce and flowers would not bloom. Light gives food and energy to plants through photosynthesis and makes everything flourish. It is an essential part of all life on Earth.

The flowering stage of plant growth requires light from the red and orange part of the spectrum. By limiting the amount of light and the number of hours exposed, you can induce the flowering stage artificially. The plant knows to start reproducing and begins its flowering stage, laying seed for another season and finally reaching dormancy.



What exactly causes a plant to flower? We do not yet have a complete answer to that question, but we do know a great deal about the mechanisms that trigger the response. There is no single phenomenon that causes flowering, nor is there one magical hormone that is responsible for it. Plants flower in response to several triggers that lead to a fairly complex chain of physiological and genetic responses, which ultimately cause a change in the morphological characteristics of the flowering apical shoots. Chief among these triggers are an effect of the light known as Photoperiodism.

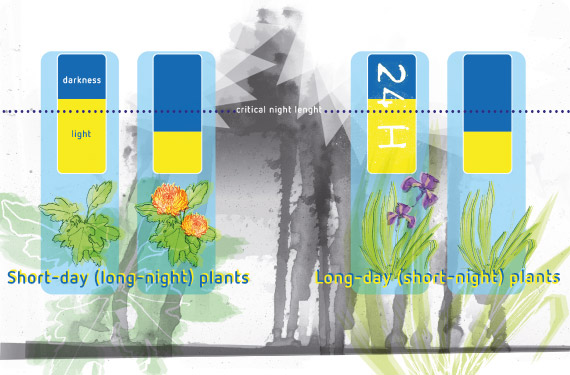
**Photoperiodism** means the plant’s response to certain light signals, including both the duration and the quality of the light it receives. Plants do not sense light in the same manner as people or animals sense light. In plants, the part of the electromagnetic spectrum which we perceive as light acts by providing energy for specific photo-chemical reactions in both control and energy production pathways. Animals also use light energy to ‘see’ the world around them. Light is a duality, existing both as a discrete particle (a photon) and as a wave. The higher the frequency (shorter wavelength), the higher the energy state of the quantum bundle known as a photon (see figure 1). The photo-chemical systems within plants are designed to capture specific frequencies of light and harness its energy to perform chemical reactions.

Plants capture light energy for two basic reasons: to make carbohydrates, and to control some of the thousands of processes that occur in plant cells. Here, we are only interested in process control, but the wavelengths used to make carbohydrates are roughly similar. There are basically four colours of the spectrum that plants work with: UV (ultraviolet) from 340 – 400 nanometre, blue from 400 – 500 nm, red from 600 – 700 nm, and far red (the start of infra-red) from 700 – 800 nm. These figures are not absolute because actually the colours overlap and a plant will use some of the energy from 500 – 600 nm too, although not much. The plant makes use of different pigments to capture different wavelengths of energy. Broadly speaking, the four bands of electromagnetic energy control the activities of the plant through three collection points, or light absorbing pigments; cryptochromes (blue and UV), phytochromes (red and far red), and phototropins (blue and UV).

Light controls the natural rhythms of the plant (as it controls – for example – the sleep patterns of animals too!). These natural rhythms, or Circadian Rhythms, are inherent in all life forms. Life has a series of events it goes through during the course of each day. There are periods of activity and periods of rest. There are times when fuel is consumed and other times when certain activities or tasks are performed. All of these activities become programmed into a more-or-less 24 hour period. It is inefficient to produce the chemicals used for capturing photons when it is dark (although some are). Just like a factory, components need to arrive when needed, stock taking must be done and a minimum level should be kept available, and assembly lines should roll when all the right parts are there. Light determines these rhythms, and not only through its presence but its quality as well.

A plant senses both the quality and the quantity of the light it receives. Based on environmental factors such as air quality or the time of year, the plant will sense a different ratio of colours. This difference is basically measured by the pigments which, when coupled with other triggers and processes, control what the plant ‘does’, and when. It sets the biological clock in the plant so that all the plant’s processes continue to run in harmony. Cryptochromes sense the direction of the light and its quantity. Responses governed by cryptochromes include stomatal function, gene transcription and activation, the inhibition of stem elongation, pigment synthesis, and the tracking of the sun by the leaves. Phototropins, the other blue light receptors, are responsible for phototropism or plant movement, and the movement of the chloroplasts inside the cell in response to the quantity of light as a damage avoidance system. There is also some evidence that they activate the guard cells at the opening of the stomates.

Phytochrome is a complex of pigments that occurs in two basic kinds: one that responds to red light (Pr), and another that responds to far red light (Pfr), depending on the light frequencies that they absorb the most (even though the other frequency will also activate it and blue light too). The two pigments generally convert back and forth, with Pr converting to Pfr with red light and vice versa (although some forms of Pr/Pfr lose the ability to reconvert depending on the amount of light, the intensity, or the quality of the light received). The active form, which triggers responses such as flowering, is Pfr. Red light exerts the biggest influence on photomorphogenesis (the effect of light on plant development) and far red light can sometimes reverse Pfr responses. Phytochrome controls many functions such as gene expression and repression, gene transcription, the elongation of seedlings and stems, germination, photoperiodism (the flowering response), shade avoidance and adjustment to differing light levels, and chlorophyll synthesis.



If we take two plants, one which is set to flower at a day length of 10 hours light/14 hours darkness (a short-day plant) and the other set to flower at 14 hours light/10 hours darkness (a long-day plant), the period that determines flowering is actually the night. This process is illustrated in figure 3. In effect, the short-day plant needs 14 hours of darkness to accumulate Pr and convert enough Pfr to Pr for the level of Pfr to be suppressed for long enough overnight for a morphological change to begin. This change becomes irreversible after a certain number of days. In a long-day plant, this process is basically the same but reversed. They respond to the presence of higher levels of Pfr.

The length of time for which Pfr is the predominant phytochrome is what causes the plant to begin flowering. However, if the Circadian Rhythms are not right, and initially they will not be, the components needed to effect change may not be present at the beginning and the rhythms will have to ‘catch up’ before the change begins. Pfr ceases the repression of Florigen, the flowering signal, or it stimulates expression, and the signal makes the plant flower. Basically, the levels of Pfr tell the plant how long the night is.

**Short Day Plants:** A plant that requires a long period of darkness Short day plants only form flowers when the length of the day is less than about 12 hours Most spring and fall flowering plants are short day plants Chrysanthemums, poinsettias, and goldenrods are examples of short day plants. The chrysanthemum is in demand all year, which is why florist have to regulate their flowering using artificial lighting.

**Long Day Plants:** Ever notice all the roadside vegetable stands in the early summer months? A plant that requires a short night to flower. These flowers only bloom when they receive more than 12 hours of light each day. The best time of the year for long day plants to flower is late spring or early summer, when the days are longer (this is opposite in the southern hemisphere) Many garden vegetables are long day plants such as potatoes, lettuce, and barley. After the summer solstice days become shorter, and long day plants are harvested shortly after.

**Day Neutral Plants:** Do not initiate flowering based on photoperiodism. They flower regardless of day length, but flower earlier and more often with longer days. More often, the age of the plant, and temperature around it effect flowering. Beans, tomatoes, and roses fall into the category of day neutral plants. Roses are the most popular day neutral flowers.

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