Plant-plant interactions

Photo courtesy of Ronald Pierik
Plants sense and respond to other plants

Often, but not always, plants compete with each other for limiting resources, such as light and nutrients.

How do they perceive competitors?

Are all of their interactions competitive?

How do interactions between plants affect higher organizational levels (e.g., communities)?

Photo credit: Tom Donald
Outline

Key definitions and concepts

Competition
• Competition for light
• Competition belowground
• Do plants perceive “self” or “kin”?

Cooperation / Facilitation
• Environmental modulation
• Enhanced nutrient availability
• Stress cues

Putting knowledge to work

Photo credit: Mary Williams
Key definitions and concepts

Phenotypic plasticity

The capacity of an individual (or a genotype) to exhibit a range of phenotypes in response to variation in the environment

Phenotypic plasticity in animals

Predator-induced helmet formation in *Daphnia cucullata*

Temperature-dependent sex determination in reptiles and fish

Phenotypic plasticity in plants

Root plasticity in response to localized nutrient availability

Shoot plasticity in response to light

Plant morphology is highly modular

Each module behaves quasi-independently, although integration between them allows elaborate coordinated responses of the entire plant to changing growth conditions.

In the shoot, each module is a **phytomer** that includes a node, internode, axillary bud and leaf.

Phenotypic plasticity involves alternative outcomes

Not every developmental change is considered phenotypic plasticity. Plastic development is all about alternatives.

Phenotypic plasticity: Can be observed

Adaptive phenotypic plasticity: Initially, only a hypothesis. Whether observed plasticity is adaptive cannot be assumed and has to be demonstrated

Not all plants display the same range of phenotypic plasticities

Phenotypic outcomes vary with conditions, and different genotypes respond differently.

The extent of phenotypic plasticity is variable.

The type (morphology, architecture, physiology etc.) and hierarchy of phenotypic plasticity are variable...
Some traits are more plastic than others

<table>
<thead>
<tr>
<th>More plastic</th>
<th>Less plastic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of vegetative parts</td>
<td>Pinnate leaf shape</td>
</tr>
<tr>
<td>Architecture</td>
<td>Seed size</td>
</tr>
<tr>
<td>Number of shoots, leaves and flowers</td>
<td>Leaf margin serration</td>
</tr>
<tr>
<td>Elongation of stems</td>
<td>Shape of inflorescence</td>
</tr>
<tr>
<td>Hairiness</td>
<td>Floral characters</td>
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Fruits and flowers are not very plastic – possibly because they convey information to animals. These bonsais show the full-sized fruits and flowers, which look huge on tiny trees.

Allometry

The study of the relative size, scale or growth rate of parts, and the consequences of allometric scaling

Some proportions change during development

Male *Dynastes* beetles: horns grow faster than bodies

Humans: Proportional size of head decreases with developmental age

Allometry can be plastic: Environmental conditions or genetic change can cause a deviation from standard allometry

- Allometric constraint
- Evolutionary variation
- Ecological variation

Total plant biomass (kg)

Shoot: root ratio

0.1  10  1000

Shade

Signals and cues convey information

Signals are generally considered to be an intended information broadcast and can include: hormones, bacterial metabolites, electrical signals, light quality, stress signals.

Cues are considered to be without intent and can include: Nutrient resources, water, light.

Semaphores are signals

Odors and light can be cues

Signals and cues affecting plants

**Internal Signaling**
- Primary metabolites
- Hormones
- Electrical pulses

**External Cueing**
- Abiotic: Physical and chemical environment, atmospheric, edaphic.
- Biotic: Secretions, exudates, volatiles etc

**External Signaling**
- Biotic only

Some hormones, such as ethylene and strigolactones, serve as communication vectors both internally and externally.

External cueing:
*Can be observed*

External signaling:
*Initially, only a hypothesis. Whether it is adaptive for the emitter as well as the receiver must be determined*
Cues inform decisions about when and how to allocate finite resources.

Like a poker player, plants have limited resources. Gambling on a bad hand, or expending resources at the wrong place or time can be a big mistake.

Signals and cues indicate the “best bet.”

Cues that indicate future conditions and circumstances are particularly important. Plants grow slowly, and can’t run away, so they have to live with the consequences of their behaviors.

Plant behavior

What a plant does in the course of its lifetime, in response to an event or change in the environment

Example: Phototropic curvature towards a light source

Images: Wisconsin fast plants, Tangopaso
Plant behavior affects morphological and biochemical phenotypes

One of the most studied plastic responses is shade-induced stem elongation.

The induction of defense responses to herbivory or pathogens is another type of phenotypic plasticity. For example, herbivore attack can induce the synthesis of an anti-nutritive such as a protease-inhibitor.

Plant behavior is affected by many environmental parameters

Abiotic factors: Light, moisture, nutrients, etc.

Biotic factors: competitors, symbionts, pathogens, herbivores, etc.

Genome and epigenome

Phenotypic outcomes:
• Number and length of root and shoot
• Number, size and architecture of leaves, branches and lateral roots
• Production of metabolites
• Etc.

Plant behavior is mediated through phenotypic plasticity
Case study: Plasticity of leaf morphology in aquatic plants

Many species prone to periodic submergence show phenotypic plasticity of their leaf forms. Submerged leaves are often thinner and without stomata or cuticle.

Summary: Behavior is the variable response to the environment

The mechanisms by which plants perceive their environment and integrate information into a behavioral response are not well understood, but under intense investigation.

Plant interactions involve perception through cues and signals, and plastic behavioral responses.

Photo credit: Tom Donald
Plants are affected by each other positively and negatively

Negative effect:
Competition for light

Negative allelopathic effect:
Here, the invasive species *Alliaria petiolata* (garlic mustard) suppresses all others

Positive effect:
Nutrient sharing and suppression of parasitism

Positive effect:
Stress cues

With similar needs, competition between plants can be intense

“We can dimly see why the competition should be most severe between allied forms, which fill nearly the same place in the economy of nature...”

Charles Darwin, 1859, On the Origin of Species, Ch 3  Struggle for Existence
Light information governs shoot phenotype, but also affects root development and interactions.

Nutrient and water distribution and various signals and cues govern root phenotype.

Plants compete with themselves and others.

Self-shading

Self-competition & signalling

Shading by non-self

Competition and cues from non-self
Light can be a limiting resource in many environments

Trees growing in forests can grow more than 100 meters high, shading plants below them, including their own offspring

Photos courtesy Ariel Novoplansky
Responses to shading: confrontation, avoidance, tolerance

- **Confront**
  - Elongation response, increased apical dominance
  - Growing away from competitors
- **Avoid**
  - Light- or fire-dependent germination
- **Tolerate**
  - Shade tolerant morphology and physiology

Plants perceive light levels and color (or light quantity and quality)
Detection of light levels and quality

Plants perceive light through photoreceptors that are sensitive to light of various wavelengths.

- Ultraviolet: Short wavelength, High energy
- Blue light receptors
- Red / far-red receptors
- Infrared: Long wavelength, Low energy

UV receptor | Blue light receptors | Red / far-red receptors
Phytochrome detects the boundary of photosynthetically active radiance

Photosynthetically active radiance (PAR)

Far-Red light – too little energy for photosynthesis

Phytochrome detects both photosynthetically active red light (660 nm) and photosynthetically inactive far-red (730 nm) light

Cryptochrome detects blue (450 nm) light

Absorption spectra for chlorophyll and accessory pigments
A low ratio of red to far-red light is indicative of vegetative shading.

Green and red light are not absorbed by the photosynthetic pigments – they reflect and pass through leaves.

Phytochrome identifies the ratio of Red to Far-red light (R:FR), an indicator of vegetative shading.

Red light is depleted as light passes through the canopy.

PAR

Daylight Spectra

Open

Canopy

400 500 600 700 nm

Shaded

Full sun

R  FR

R  FR

Phytochrome’s conformation and absorption spectra “switch”

Phytochrome changes conformation when it absorbs light:
Red light converts it to the $P_{fr}$ form, which mainly absorbs far-red light;
Far-red light converts it to the $P_r$ form, which mainly absorbs red light

Transduction of light information downstream of photoreceptors

Many of the molecular events that contribute to shade avoidance have been elucidated, and include effects on transcription factor activity and hormone levels and responses.
Shade avoidance is a collection of responses to vegetative shading

- Light
- Vegetative shading
- Delayed or suppressed germination
- Stem and hypocotyl elongation
- Petiole elongation, leaf hyponasty, narrow leaves
- Early flowering

Plants can also *anticipate* and respond to probable future shade


**Plants elongate less when wearing a collar that filters out far-red light reflected from adjacent leaves.**

**Touch is another cue that signals future competition and stimulates elongation.**
Case study: *Portulaca oleracea*, light responses in recumbent plant

*Portulaca oleracea* grows and branches in a way that minimizes self shading

When lower red/far-red ratios are provided from one direction, the plant grows away, suggesting that phytochrome controls the growth directionality.

Future shade can be more important than present shade

Filters were set up on opposite sides of *Portulaca* seedlings

- Little red
- Little far-red

One side (grey) transmitted very little photosynthetic light, equally low in R and FR

The other side transmitted and reflected more photosynthetic light but much more far-red than red light

Do the plants grow towards the side with more light now (green) or more light later (grey)? The low R / FR ratio on the “green” side implies the presence of potential competitor...

*Portulaca* grows away from far-red light, even when it means that they are growing towards less light

Low R:FR cues indicate the presence of a competitor, so growing away from the direction of such cues might improve the plant’s fitness

Some plants have evolved to tolerate shade – life in the dim lane

Shade-tolerant species are adapted to low light environments

Photos courtesy Tom Donald and Ariel Novoplansky
Shade tolerance takes many forms

**Adaptations to maximize light interception:**
- Increased leaf area
- Leaves oriented to intercept light
- Leaves positioned to minimize overlap
- High chlorophyll $b$ to $a$ content

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Long-lived shade-tolerant plants invest relatively more resources into **defenses** against herbivores and pathogens.

Reduced stem-elongation response

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Energetics of shade tolerance: max. assimilation, min. expenditure

Typically, shade tolerant plants have a lower rate of respiration in the dark, lower light compensation point, and lower light saturation point.
Light information: Angle, gradients, quality, and time of day

Light information is MORE than just quantity and spectrum. It is likely that plants respond to a richer gamut of light cues.

Vertical, mid-day shade (possibly low R:FR) might indicate a very tall neighbor – don’t bother trying to catch up!

Horizontal and late-day low R:FR cues might indicate similarly-sized neighbors – go for it!

Germination plasticity: light and other cues for seed germination

One of the most important decisions a plant makes is when to germinate.

Many seeds germinate in response to white or red light, but far-red light is inhibitory.
Fire (heat and smoke) can promote seed germination

Fire stimulates seed release or germination in some plants.

Some cones and seed pods are fire-serotinous, opening in response to fire.

Image sources: pfern, Hesperian, © Kurt Stueber, 2003
Karrikkins are germination-promoting compounds found in smoke

Fire-induced germination lets seedlings become established with less competition from taller plants.

Karrikkins are cues from smoke that promote germination.

However, following a fire, there can be increased competition between similarly-sized seedlings....
Plants produce many redundant organs that compete with each other.

Somatic competition can increase plant performance by putting resources into more successful organs.

Are these branches shedding as a direct result of them growing in low light? Or is it a result of competition with other, more successful branches on the same tree?

Branch autonomy may vary according to circumstances

Case study: Two-shoot peas and correlative inhibition

Two shoot peas
Removing the shoot from a pea seedling causes two shoots to regenerate – a good system to study somatic competition!

5-day old pea

Shoot removal

5 days

“Two-shoot pea”

Two equal shoots can co-exist, but very often one becomes dominant and the other dies

Why does the smaller shoot die?

Case study: Two-shoot peas and correlative inhibition

A shoot in the dark can survive 10 days (using nutrient reserves), but in competition with a more successful shoot in the light, the darkened shoot dies. The plant selectively allocates reserves to the stronger shoot.

Model: Resources are allocated to the best option. In A, the best (only) option is the shoot in the dark. In B, resources are allocated to the shoot in the light, at the expense of the other shoot.

Within and between trees, branches in the best conditions prevail

Less successful branches, e.g. shaded by neighbors or self are discriminated against and shed

Photo credit: Tom Donald
Summary: Perception of and response to vegetative shading

Light is a resource and also a source of information that affects plant behavior.

Adaptive responses to competition for light can be architectural (shoot position, size and number), morphological (stem elongation, increased leaf area), physiological (amount of chlorophyll or Rubisco), etc.

When soil resources are abundant, plants allocate less biomass to their roots

When nutrient distribution is patchy, roots proliferate in the nutrient rich patches

Competition belowground: Root growth is extremely plastic

Many studies have found that roots have a tendency to grow away from each other.
Belowground competition: Cues, signals and responses

- Resource limitation
- Root-exuded chemicals
- Other

Perception

Response
- Confront (overproliferate)
- Avoid (underproliferate)
- Tolerate

Belowground competition: Cues, signals and responses

Resource limitation
Root-exuded chemicals
Other

Perception

Response
- Confront (overproliferate)
- Avoid (underproliferate)
- Tolerate
Plants compete for nutrients, which are frequently limiting for growth.

This map shows the difference between actual vegetation productivity and maximum theoretical productivity based on availability of water and sunlight; the difference is attributed to nutrient limitation.

Most plants enhance nutrient uptake through associations with mycorrhizal fungi or nitrogen-fixing bacteria

Some plants
Nitrogen-fixing bacteria

Most plants
Mycorrhizal fungi

Bacteria in nodules produce reduce atmospheric nitrogen

Extensive fungal surface area facilitates nutrient and water uptake

Fungus inside plant root

Photo credits: Gerald Holmes, Valent USA Corporation, Ulrike Mathesius, Bugwood.org, Sara Wright, USDA; Kristine Nichols, USDA
In some cases, roots avoid contact or proximity to other roots

Plants exposed to the chemical exudates of another root system decreased their rate of root growth.

How do roots respond to the roots of another plant? Plexiglass boxes were set up to record root responses...

Control roots without contact or with a physical barrier

Plants exposed to the chemical exudates of another root system decreased their rate of root growth.

Plants integrate information about nutrients and neighbors

Plants were planted alone or with a neighbor, in uniform soil or soil with nutrient rich patches (shaded bar), and root distribution analyzed.

In uniform soil, roots avoided each other.

But they proliferate in a nutrient-rich patch, in spite of their neighbor.

Many plants make allelochemicals that deter competitors

Allelopathic chemicals (allelochemicals) interfere with growth of nearby plants

Juglone is an allelochemical produced by black walnut (*Juglans nigra*)

Sorgoleone is produced in *Sorghum bicolor* root hairs and exuded as oily drops. It accumulates in the soil and acts as a pre-emergence herbicide affecting photosynthesis in very young seedlings

Allelochemicals can suppress plant growth directly or indirectly

*m*-tyrosine is a nonprotein amino acid from fescue (*Festuca* spp) roots, that inhibits plant growth directly. 

*Alliaria petiolata* (garlic mustard) is an invasive plant in the US that indirectly suppresses plant growth through the inhibition of their mycorrhizal fungal symbionts.
Summary: Plants compete belowground

The Monterey manzanita (*Arctostaphylos montereyensis*) suppresses competitors through allelopathy

Besides resource competition, the best understood form of belowground competition is the production of toxic or inhibitory allelochemicals.

Additional cues likely contribute to belowground interactions.
Plants can respond differently to self, kin and alien

Is that me?

You seem familiar…

Photo credits: Tom Donald
Do plants respond differently to relatives and unrelated plants?

YES- This study showed that roots tend to avoid roots of plants that are not related

Same genotype: More overlap

Different genotype: Less overlap - avoidance

Do roots discriminate self from non-self?

Yes, plants discriminate self from non-self. Plant B, competing with non-self, makes ~50% more root mass than plant A, competing only with self.

Yes, When cuttings that originate from the very same node are separated, they become progressively alienated from each other and relate to each other as genetically alien plants.

These studies showed more root growth in the presence of “other” than “self”. What cues and signals are involved?

S/NS may rely on self recognition, rather than on NS discrimination

“Double plants” were produced with two shoots and two roots. Some double plants were split, to make “twins”. Some of the split plants were paired up with an unrelated alien. Does a plant recognize self without a physiological connection?

Split pea “Twins” and alien make more roots than intact peas, indicating that physiological connections are important for recognizing “self”

Spatially, intact peas produced more roots toward nonself than toward self roots. Pairs of severed plants developed similarly towards their neighbors, regardless of whether these neighbors were their own twins or alien.

Case study: Parasitic plants are extreme competitors

• Parasitic plants cost approximately 10 billion USD in crop losses annually

• They infest major cereal crops including corn, sorghum, millet and rice, in over 70 million hectares

• Food production for 300 million people is affected

• No effective control measure has been developed

Parasitic plants perceive their hosts through chemical cues

*Cuscuta pentagona* (dodder) uses tropisms, touch and volatile cues, to locate its hosts

Host-exuded strigolactones and flavonoids promote germination and attachment of *Striga* and other parasitic plants

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Facilitative behaviors: Plants benefitting from their neighbors

Tempering of harsh abiotic environments

Stress cues can induce anticipatory responses

Enhancing nutrient uptake

Benefit from others is commonly higher in harsher environments

In harsher, high-elevation environment, plants whose neighbors were removed fared relatively poorly, indicating that they benefited from their neighbors.
Plants can protect others from harsh abiotic and biotic environments

High Andes
Buffered substrate and air temperature, enhanced soil moisture and nutrient content

Southern France
Protection from browsing

Semi-arid plains of Spain
Protection from drought

Semi-arid environment, Jordan
Protection from browsing and drought

Plants can benefit from amelioration of abiotic stresses by their neighbors

- Wind breaking
- Increased retention of soil moisture
- Improved physical characteristics of soil
- Increased soil oxygenation in waterlogged environments
- Increased nutrients
- Decreased evaporation and soil salinity

Palo verde (*Parkinsonia* spp) can act as a “nurse plant” for saguaro cactus (*Carnegiea gigantean*). Tiny cactus seedlings need shade to get established. Often, though, the cactus later outcompetes its nurse plant.

Photo credits: Tom Donald, Joy Viola, Northeastern University, Bugwood.org
Intercropping and crop rotation confer many benefits

The total yields of fields grown with two or more species at the time or in alternating years can be higher than the most productive monocultures.
A common mycorrhizal network can facilitate resource sharing

Intercropping with sorghum drastically enhanced flax’s growth (+46% increase). Nutrient uptake was facilitated via the common mycorrhizal network (CMN)

Case study: Community-level effects of phenotypic plasticity

How does phenotypic plasticity and facilitation affect other community members?

Variation in root architecture affects the plant communities associated with *Quercus douglasii*; only shallow-rooted trees compete with grasses.

**Diagram:**
- **High water potential:**
  - Trees facilitate herbs; bunchgrass rare
  - High biomass of shallow roots

- **Low water potential:**
  - Trees compete with herbs; bunchgrass common
  - Low biomass of shallow roots

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Cues from other plants can prime plants for defense or tolerance

Alarm signals are well described in social animals. Stressed plants may emit cues to which other plants respond.

Perception of and responses to stress and stress cues

**Perception**
- Mechanical damage
- Herbivore-derived chemicals
- Pathogens
- Drought or UV light

**Volatile compounds**
- Root exudates
- Other?

**Responses**
- Induction and priming of defense responses
- Volatile emission
- Stomatal closure
- Genomic instability
Volatile compounds from damaged plants can initiate defenses in others

When nearby sagebrush was mechanically damaged, wild tobacco increased production of defense compounds (PPO) and suffered less herbivore damage.

What are the active compounds and how far do they spread?

Why do plants emit volatile signals?

- Volatile signals may have evolved for intra-plant communication
- Having defensive neighbors can enhance the emitter’s fitness
- Some volatiles are also inhibitory allelochemicals that reduce competition
- Some volatiles promote indirect defenses by acting as signals to attract predatory arthropods

Case study: Plants may also communicate drought stress

Can other stresses be communicated between plants? Can unstressed plants respond to stress cues emitted from their stressed neighbors?

Testing for root-to-root and relay communication

Stress cue moves from the stressed plant via the roots

Stomatal aperture was measured in plants without a soil connection and plants whose roots share soil with the induced (IND) plant.

Before treatment all the plants had the same stomatal width.

After treatment, stomatal aperture was reduced in plants whose roots were in contact (directly or indirectly) with the stressed plant.

No response in plants that did not share their rooting volume.

Summary: Cooperative and facilitative behaviors

Plants can benefit from other plants, which can
• Modulate the abiotic environment,
• Facilitate nutrient uptake, \textit{and}
• Emit cues that prime for stress

Like competition, facilitative encounters occur between and within species

Photo credit: Tom Donald
Putting knowledge to work

Understanding plant behavioral responses can contribute to combatting highly competitive invasive species…

Water hyacinth (*Eichhornia crassipes*)

Leafy spurge (*Euphorbia esula*)

Kudzu (*Pueraria montana var. lobata*)

And to developing novel crop combinations, such as the intercropping of dry beans, coffee and papaya near Palmira, Colombia.

Photo credits: Ted Center, USDA; William M. Ciesla, Forest Health Management International; John D. Byrd, Mississippi State University; Howard F. Schwartz, Colorado State University.
Reproductive success

Condition

Are invasive plants more plastic, and so more able to succeed in diverse environments?

Some invasive plants show greater than average phenotypic plasticity, but many do not.

Some invasive plants succeed by making lots of small seeds, growing very quickly, producing allelochemicals, or competing effectively for water or nutrients.

Kudzu (Pueraria lobata), also known as “The vine that ate the South”

Case study: Knotweed, “from prize-winners to pariahs”

Prize-winners
In 1847, the Society of Agriculture & Horticulture awarded a gold medal to *Fallopia japonica*, “for the most interesting new ornamental plant of the year”

Pariahs
Now they are one of the most aggressive plant invaders, and cause considerable economic and ecological damage.

Allelochemical production and rapid growth rate contribute to their ecosystem dominance

Knotweed shows a highly plastic response to salt, which allows it to succeed in salty environments

Case study: Backfiring biocontrol of invasive knapweed?

Spotted knapweed (*Centaurea stobe* ssp. *micranthos / Centaurea maculosa*) was introduced into North America in the 1890s. It is a “noxious weed” that competes very effectively with native plants. Starting in the 1980s, the specific herbivore knapweed root moth has been introduced as a biocontrol agent, with mixed results.

Herbivory may induce allelochemical production, further harming native plants – a case of biocontrol backfiring!

Case study: Maize, bean, squash – the three sisters

Archeological records show that Native Americans have grown corn, beans and squash together for millennia.

The corn provides a structure for the climbing bean vines, and the ground-covering squash maintains soil moisture and suppress weeds.

A recent study found that the root systems of the three plants are complementary, minimizing belowground competition.

Case study: Push-pull planting systems to enhance productivity

Pests are a particular problem in tropical agriculture. An agronomic system called push-pull was developed to protect corn crops from stem borer caterpillars.

This involves intercropping maize with a legume Desmodium, in a field surrounded by Napier grass (Pennisetum purpureum).

Case study: Push-pull planting systems to enhance productivity

*Desmodium* PUSHES away the insects by producing repellent volatile chemicals

Napier grass PULLS away the insects by producing attractive volatile chemicals

*Desmodium* also produces allelochemicals that interfere with *Striga* parasitism, protecting the crop from yet another pest

**ALLELOPATHY:** chemicals exuded by *Desmodium* roots inhibit attachment of *Striga* to maize roots and cause suicidal germination of *Striga*

Case study: Allelopathic rice plants

Momilactone B

Momilactones are allelopathic compounds produced by rice that interfere with the growth of a common paddy weed, barnyard grass (*Echinochloa crus-galli*).

Efforts are underway to increase momilactone production in cultivated rice varieties, to reduce the need for herbicide use and mechanical weed removal.

Case study: Exploiting light-response plasticity for increased productivity

Greenhouse covers, including a fluorescent pigment that absorbs some of the blue and green sunlight and emits additional red light, increases the ratio between RED and FAR-RED light.

In response to such spectral cues, some plants reduce their allocation to competitive organs and increase allocation to agriculturally-important organs such as flowers and fruits. LEDs can produce similar effects.

Summary of plant-plant interactions

A plant’s phenotype depends on its genotype and environment, and relies on its plasticity. The environment includes cues from and interactions with other plants, many of which we are just beginning to understand, and which continue to be very active research areas.
Summary of plant-plant interactions

Plants *perceive* other plants through changes in the light spectrum, volatile and root-exuded chemicals, effects on nutrients, water and soil microbes, and other unknown signals. Their *responses* depend on their age, genotype and other endogenous and exogenous factors, and may include confrontation, avoidance or tolerance.
Future directions (1)

Can fragile ecosystems and biological diversity be protected by better understanding plant–plant interactions?

Aggressive aliens, moved by human actions, damage ecosystems

Japanese knotweed (*Fallopia japonica*)

Giant hogweed (*Heracleum mantegazzianum*)

Can food yields be increased by suppressing competition and competitive responses, enhancing facilitation and increasing production of desired organs?

- Human population growth demands more food production, and higher crop yields
- Plant-plant interactions can decrease yields, but these effects can be ameliorated
Future directions (3)

Can crop yields be increased, especially in marginal agricultural land, by inducing and priming plants to better fit their particular expected growth conditions, forthcoming opportunities and stresses?