Plant and Microbial Sciences

TABLE OF

CONTENTS

Course Material

Part IB Plant and Microbial Sciences Course Overview

To ensure supplies of food, fibre, pharmaceuticals, fuel and other plant and microbe-derived products and to do so sustainably, requires a new generation of scientists who are able to integrate and apply knowledge ranging across multiple scales - from the molecular to the ecological.

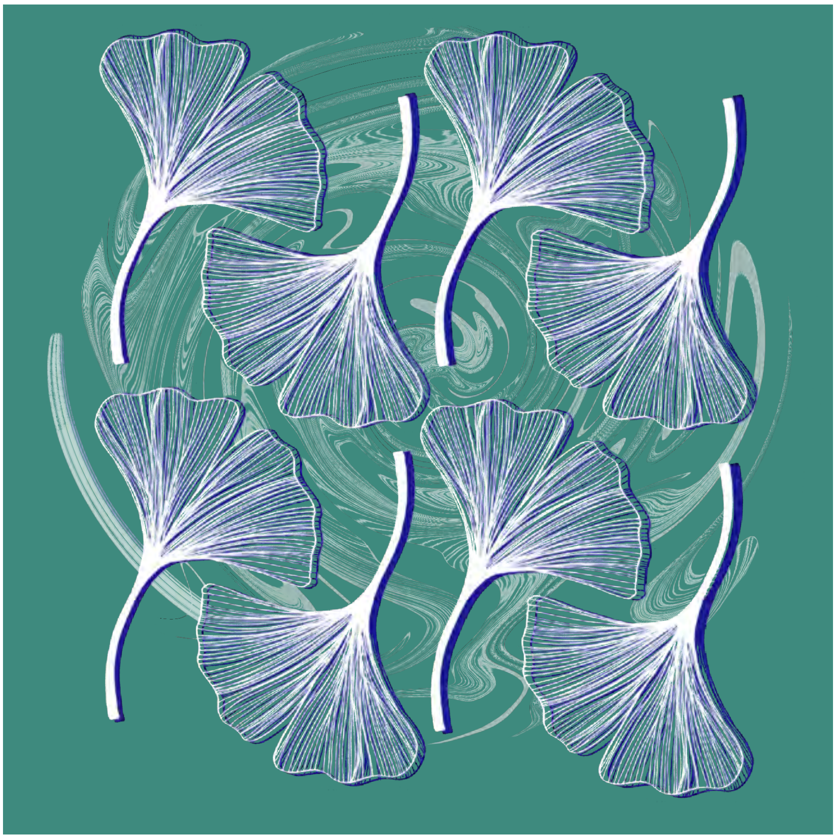
In our 1B Plant and Microbial Sciences (PMS) course we focus on fundamental biological processes used by plants and microbes.

This basic biological knowledge will be required to rationally manipulate food and bioenergy crops. Importantly, the course also considers natural diversity and conservation of resources, particularly in the face of environmental challenges, including climate change. In summary, we provide a cutting-edge synopsis of plant and microbial science that has direct relevance to the future challenges that society faces.

Our course provides a truly integrated view of plant and microbial sciences that incorporates molecular, cellular and ecological approaches to this vital subject.

Under each topic the lectures address both current understanding of the relevant processes at the cellular and molecular levels, and explore their relevance to the major issues and ideas that arise from studying plants and microbes in the field.

The practicals and field course provide an integrated training to prepare you for future independent project work.



Please note: The information in this booklet is correct at the time of publishing

Previous Course Requirements

Students considering taking IB Plant & Microbial Sciences are likely to have taken at least one of Biology of Cells IA, Physiology of Organisms IA or Evolution and Behaviour IA. It is possible to take IB PMS without having taken any of these courses, but students are advised to seek background reading before they start the course, and/or additional supervisions.

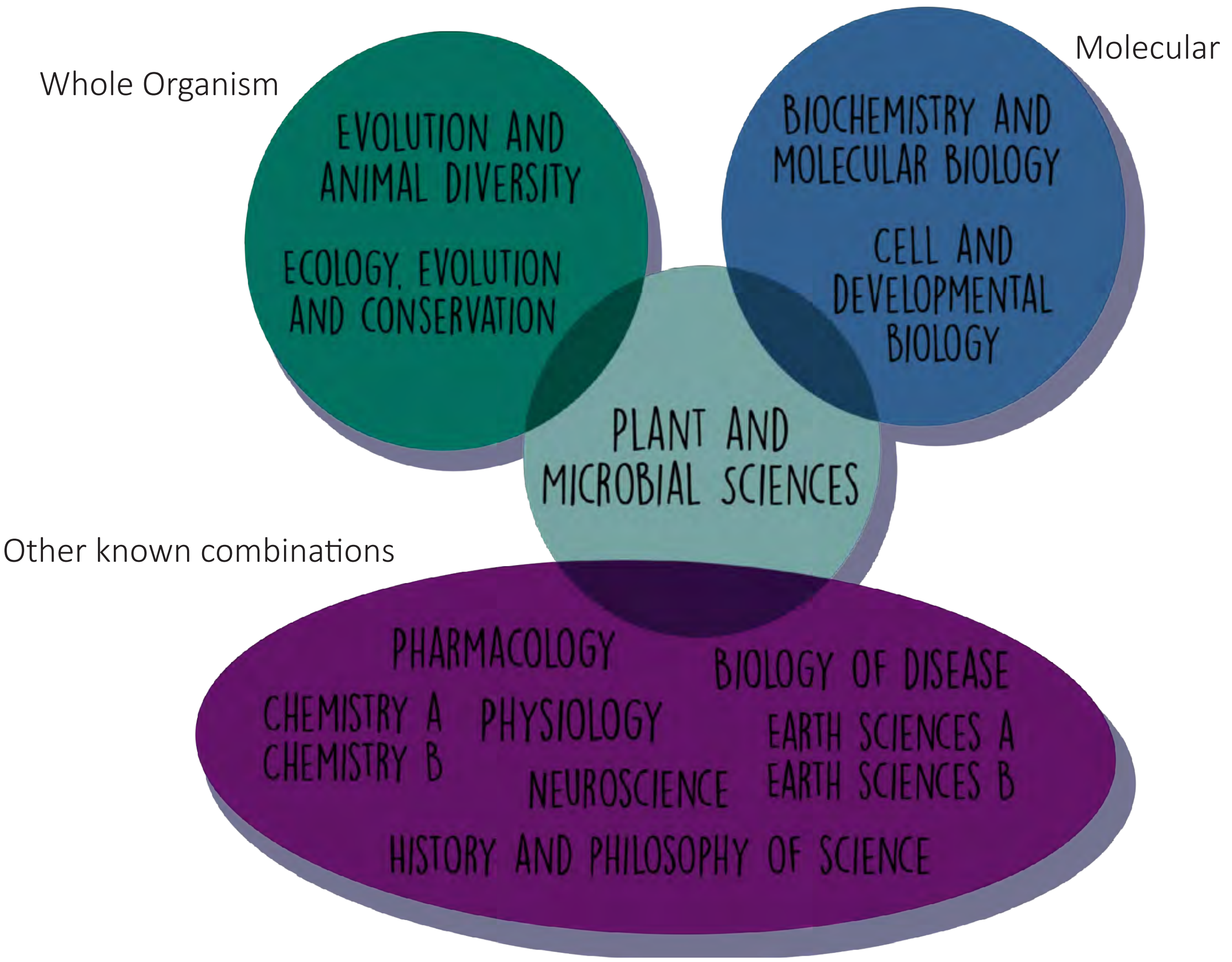
For more information please visit:
http:www.plantsci.cam.ac.uk/teaching/pms/reading-list

The IB PMS course is an essential background for the more specialised options in Part II Plant Sciences, as well as providing a strong scientific basis for topics in Part II Biochemistry, Genetics, Zoology and Ecology.

The strong microbiological component makes it an essential feeder for courses with microbiological content at Part II.

What can I combine with IB PMS?

A lot! Previous students have combined IB PMS with:



The Lecture Course

As well as fundamental aspects of plant biology and microbiology, the lecture content will be supplemented with a series of thematic resources designed to illustrate how these topics relate to current world issues.

Michealmas Term Lectures

- Origins of modern agriculture
- Evolution of photosynthesis
- Management of reserves
- Resource acquisition and stress management: nutrients, water and temperature

Thematic Topics

Biofuels
Sustainable crop productivity

Lent Term Lectures

- Plant development
- Comparative microbiology
- Interactions of plants with micro-organisms:
  - epidemiology
  - Pathological and beneficial plant-microbe interactions
- Feeding the world whilst conserving nature

Thematic Topics

Bioremediation
Crop protection

Easter Term Lectures

- Feeding the world whilst conserving nature part 2
- Harnessing the genetic resources of plants

Thematic Topics

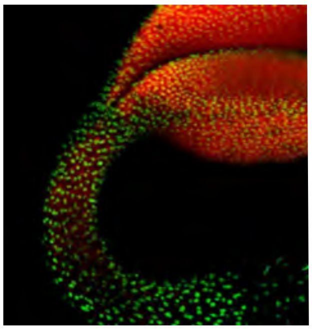
Climate change
Sustainable crop productivity

Practicals

Laboratory and field-based research are both essential for our further understanding of the function of plants and micro-organisms. The practicals provide a thoroughly integrated understanding, quite different from Part IA courses, by:

- Providing experience of the major techniques used in plant and microbial science research
- Developing skills in the design, interpretation and writing up of experiments
- Addressing theoretical problems through experimentation
- Increasing awareness of the social and industrial implications of plant and microbial science research
- Developing the ability to present and communicate scientific issues

The Molecular Techniques theme is designed to enable you to appreciate the core tools used to understand gene expression and familiarise yourself with one of the model plants, *Arabidopsis thaliana*, in an investigating spanning Michaelmas and Lent terms



Light microscope images of a GFP expressing

In the Plant Physiology practicals you investigate the impact of Rubisco antisense transformants on the growth, photosynthesis and nutrient uptake in another key model plant, tobacco (*Nicotiana tabacum*).

Plant infected with a GFP-tagged virus.

The Microbial Pathology practicals introduce key concepts in plant pathology and microbiology including:
handling and detection of oomycete, bacterial and viral pathogens; analysis of the effects of pathogens on the host plant, and advanced diagnostic methods. These practicals form a research project spanning several weeks.

State of the art Teaching Laboratory

Cambridge University Botanic Garden

The Whole Plant theme considers the diversity of plants and their morphology within the setting of the Botanic Garden. It also includes a field trip to Hayley Wood to consider conservation strategies.

Field Course to Portugal

All IB Plant and Microbial Sciences students have the opportunity to attend a one week long field course to Portugal at Easter. It provides marvelous exposure to plants in the Mediterranean environment, allowing you to understand plant diversity and adaptations to drought and high light, and revision of core course material through trips to a variety of habitats and evening talks.

You will also pursue a short group research project of your own design. Demonstrators are on hand to help you apply methods used in the practicals to novel investigations. Equipment is available for experiments within each of the key practical themes, from biochemical to physiological and ecological.

Currently, the cost of this is mainly covered by the University, but a small charge is made for subsistence. Many Colleges provide grants to cover this minor cost.

Origins of modern agriculture

Prof Jim Haseloff http://www.plantsci.cam.ac.uk/research/jimhaseloff

Incredible genetic variation exists in the plant kingdom, which people have harnessed through the domestication of crops. The advent of plant molecular biology has opened new doors into how we can access this variation and use it to improve our crop species. Plant-based agriculture underpins production of the world's food, and many materials and chemicals. As humans face the challenges of population growth, diminishing resources and environmental degradation in the 21st century, we are turning increasingly to tools for engineering plant improvement.

The course begins with an overview of the topics that will be covered during the year – a step-by-step account of important mechanisms of plant growth at the molecular, cellular, organ, organism and population scales. We start with the basics, describing both origins of crops through millennia of agriculture and human selection, changes in agronomic practices, and the technologies behind the biotechnology revolution. In the concurrent practical classes, you will gain hands-on experience with *Agrobacterium*-mediated plant transformation and assays for gene expression. We will also examine some of the ethical, societal and environmental implications of the new genetic technologies, including potential benefits, where genetically-modified plants and microbes might be used to improve the sustainability of agriculture and reduce our impact on the environment.

We will also look at the advent of new Synthetic Biology approaches for the systematic, large-scale engineering of plant and microbial genomes, and their implications for human use of plants.

Some of the crops derived from wild mustard (*Brassica oleracea* L.)

Evolution of Photosynthesis and Management of Reserves

Prof Julian Hibberd http://www.plantsci.cam.ac.uk/research/julianhibberd

The first organisms that conducted oxygenic photosynthesis on Earth are thought to have evolved more than 2.5 billion years ago. By examining photosynthetic species that are alive today (from prokaryotes to higher plants), it is possible to gain insights into how photosynthesis evolved. The current diversity of photosynthesis reflects both evolutionary history, but also the mechanisms that allow photosynthesis to adapt to the large variety of environments in which photosynthetic organisms flourish.

We will examine photosynthesis from perspectives that range from its evolution, to the structure of the light harvesting apparatus, to the response of different vegetation types to the current environment.

A purple bacterium (4µm thick) – it is photosynthetic but does not evolve oxygen

A cyanobacterium, each cell is about 10µm wide. It is photosynthetic but its photosynthetic membranes lie naked in the cell

Advanced plant photosynthesis: whether mosses, ferns or rainforests, all couple two photosystems in chloroplasts

The fixation of CO_2 by plants is only the first stage on the road to carbon assimilation by plants. The sugars produced by the action of the Calvin cycle must be converted to sucrose for transport to non-photosynthetic parts of the plant and to starch for storage during the night. On a longer timescale, plants must utilise the fixed carbon for biosynthesis to grow and develop, and to lay down carbon and energy reserves to enable survival as seeds, or perennial organs during the winter. Plants must also assimilate nitrogen from the soil for incorporation into proteins and nucleic acids. These lectures consider how plants carry out this primary metabolism, together with an overview of how it is regulated.

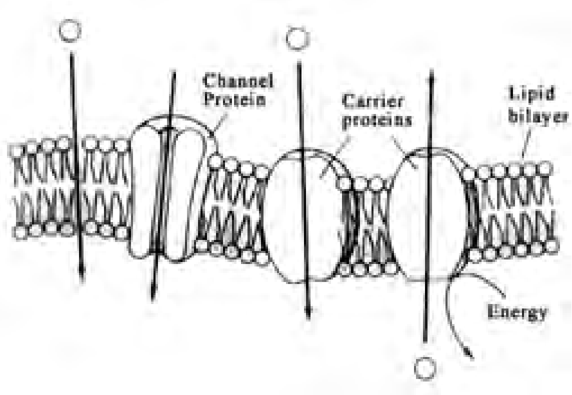
Resource Acquisition and Stress Management: Nutrients, Water and Temperature

Dr Julia Davies http://www.plantsci.cam.ac.uk/research/juliadavies
Dr Sonja Dunbar https://www.plantsci.cam.ac.uk/directory/dunbar-sonja
Prof Howard Griffiths http://www.plantsci.cam.ac.uk/research/howardgriffiths
Dr Andrew Tantentzap https://www.plantsci.cam.ac.uk/directory/tanentzap-andrew

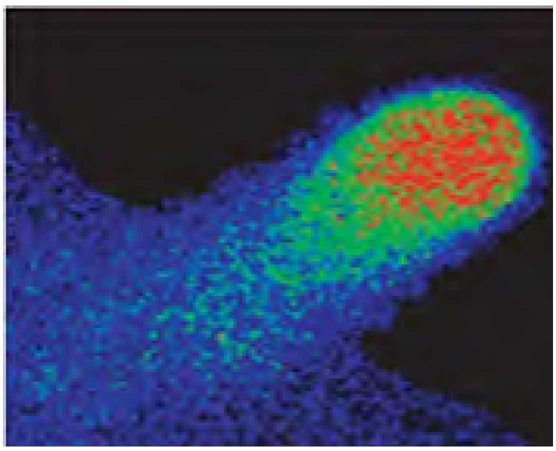
Nutrients

Nutrients and water limit most plant growth. Thus, an understanding of the molecular biology, physiology and ecology of how plants function and how they respond to these limitations is essential for an understanding and management of both crops and natural systems. We will discuss ion uptake and movement of ions within plants, and plant mineral budgets with emphasis on those elements that limit growth. For water we describe its uptake into plants, its movement through plants and the stomatal control of water loss. Throughout we try to relate the natural distribution of plants and the cultivation of crops to their physiology and molecular biology.

Understanding uptake and management of nutrients and water involves study at several levels: the whole plant; the tissue; the cell; the membrane, and the gene. This course considers processes at these different levels in an integrated way. How are nutrients taken up by the roots and compartmentalised in the plant? What is known about pumps, carriers, ion channels and aquaporins in the different sorts of cell involved?



Channels and carriers in a membrane



Cytosolic free calcium is involved in root hair growth

Opening and closing of a single K^+ channel protein, recorded using patch clamp electrophysiology

Water

Stomata act as gatekeepers controlling gaseous influx and efflux. We place their regulation in terms of water flow across the entire root-shoot continuum. Contrasting ecological strategies of Mediterranean plants will be used to illustrate how xylem flow, cavitation repair, and stomatal control are integrated in response to summer drought.

Guttation in strawberry leaves: an example of root pressure helping to repair cavitated vessels

Arbutus unedo regenerating after fire: how sprouters, seeders and geophytes interact in the Mediterranean Macchia

Temperature

Plants grow in all places on Earth - from the Arctic tundra to equatorial deserts - and so have evolved to tolerate a wide range of temperatures. This lecture block explores how plants have evolved to tolerate extreme temperatures with a combination of physiological changes and molecular mechanisms. It will also consider how temperate influences distribution of plants, using the Mediterranean as a case study.

Plant Development

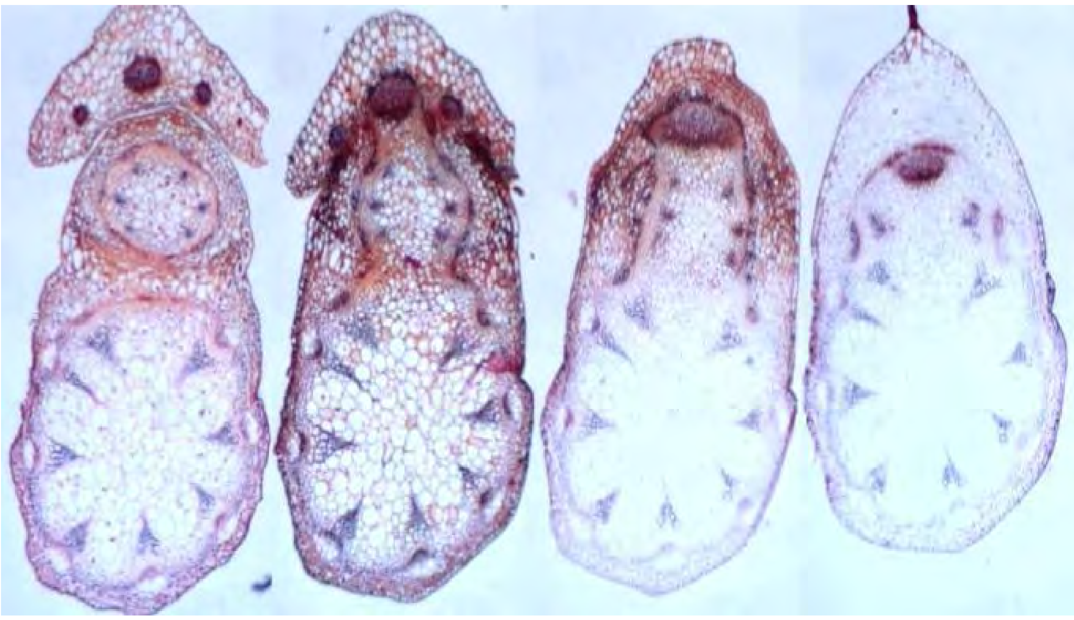
Dr Sarah Robinson https://www.slcu.cam.ac.uk/people/sarah-robinson

Animal development is typically determinate - it results in reproducible body plans driven by genotype. In contrast, plant development is typically highly plastic, such that plants of identical genotype can develop with quite different body plans. This difference reflects profoundly different selective pressures acting on plants and animals.

Plants are autotrophic, using light energy to build their constituent complex macromolecules from water, carbon dioxide and minerals. This requires a large surface area both above and below ground, with flexible growth optimising capture of these resources, many of which are distributed unevenly in the environment. These large surface areas necessitate immobility, and therefore plants must adapt to the prevailing environmental conditions and must be robust to herbivory.

In contrast, animals are heterotrophic and acquire complex macromolecules from concentrated sources, namely by eating other organisms. This is often facilitated by locomotion linked to long-range sensory systems, which also support escape from unfavourable environments and predators. These different selective drivers underlie the different development patterns of plants and animals, yet fundamentally, the same basic problems need to be solved - how to progress from a single celled zygote to a complex multicellular organism with all the cells doing the right things at the right times and places.

In these lectures, the mechanisms employed by plants to deliver organized but flexible development will be illustrated with specific examples, including some of the experimental evidence that supports them.

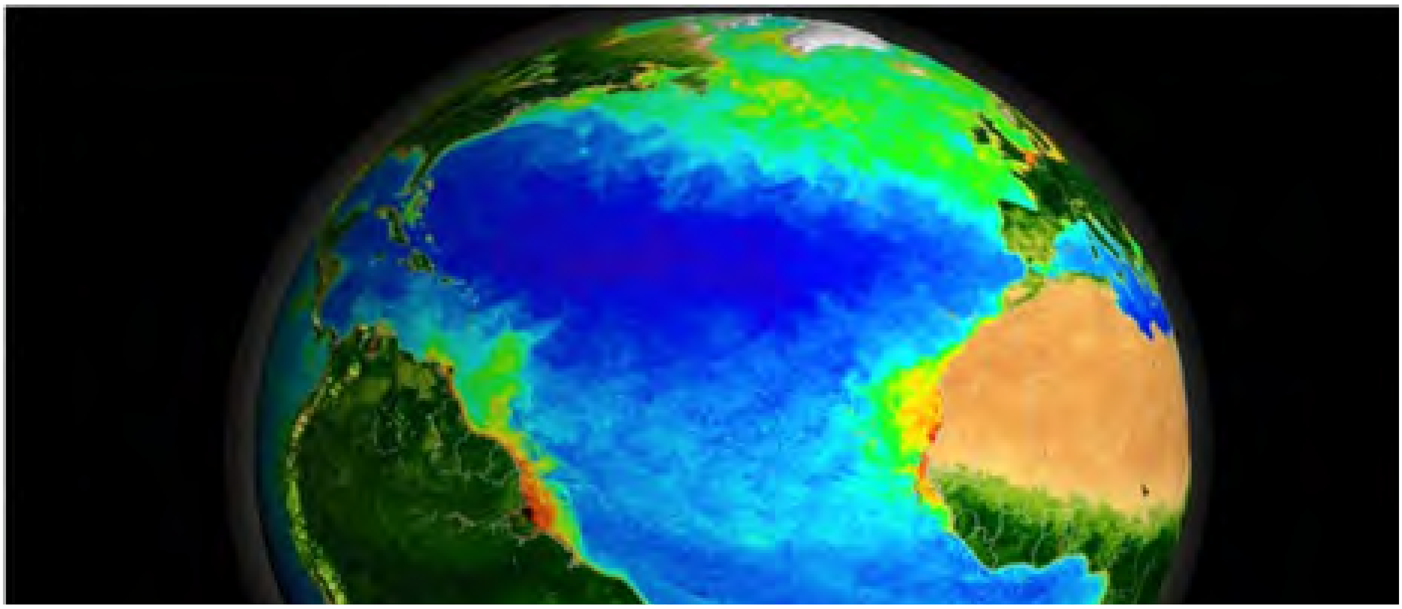


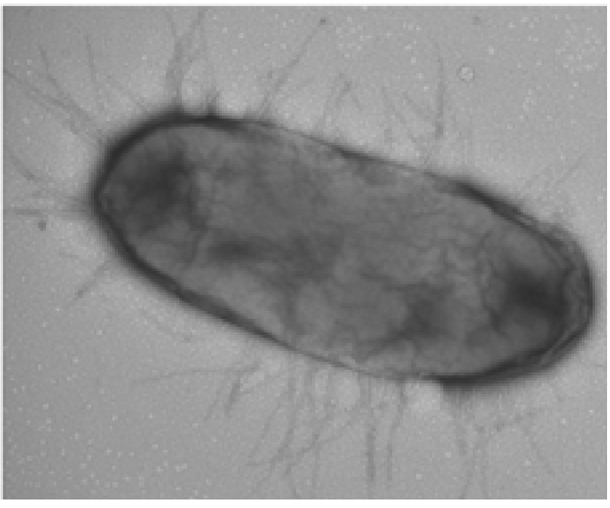
Sections through an Arabidopsis shoot tracing vascular connectivity of a branch

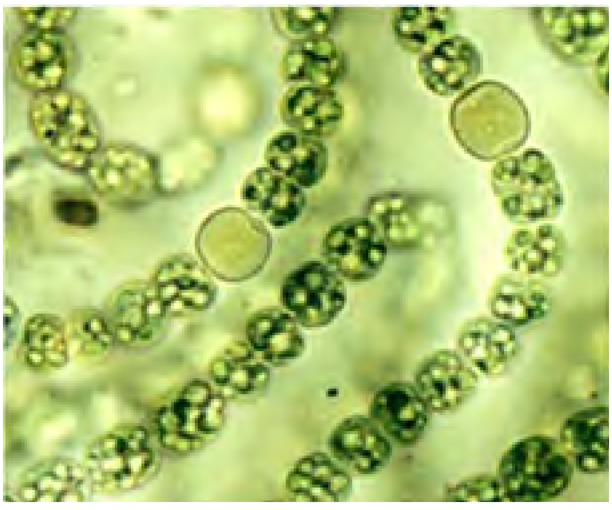
Comparative Microbiology

Prof John Carr https://www.plantsci.cam.ac.uk/directory/carr-john

The biotic interactions section of the course kicks off with an introduction to microbial diversity. We consider the form and function of the bacteria, archaea and eukaryotic microbes (including fungi, oomycetes, and algae) and viruses. The roles of these microbes in global nutrient cycles are discussed, and the signalling events leading to the development of microbial communities are examined. Cutting-edge approaches to quantify microbes and viruses in their natural habitats are introduced, and the ability of microbes to survive in 'extreme' environments is also discussed. The lectures also consider the possibility of using microbes to help increase bioenergy production and problems such as the removal of radioactive waste.







Top: Distribution of oceanic photosynthetic microbes, as imaged by the SeaStar satellite.
Bottom: left, a bacterial cell with projecting pili and right, a cyanobacterium, with chains of green vegetative and N_2-fixing heterocyst cells.

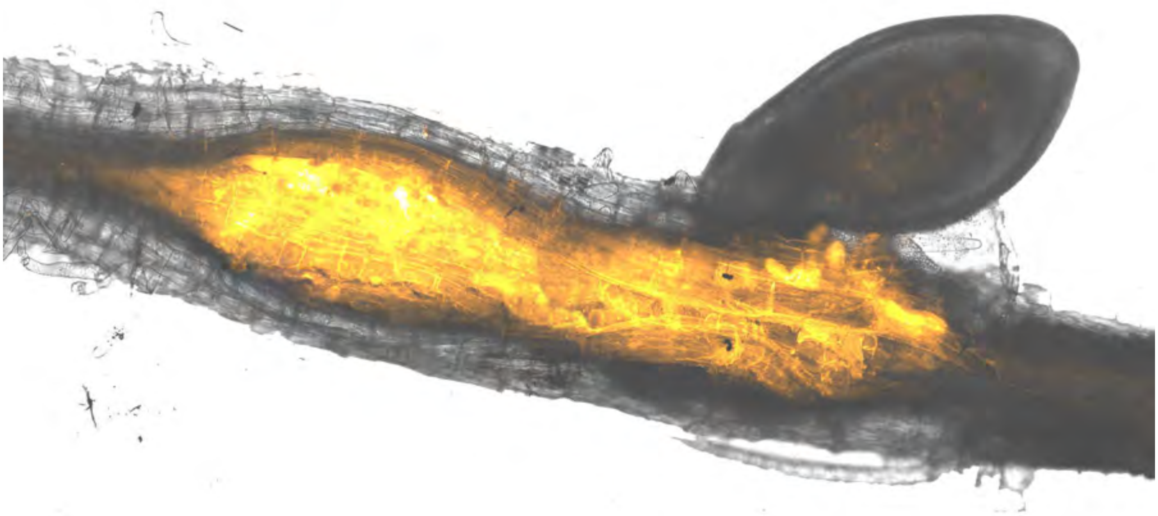
Interactions of Plants with Micro-organisms

Dr Nik Cunniffe http://www.plantsci.cam.ac.uk/research/nikcunniffe
Dr Sebastian Eves-van den Akker https://www.plantsci.cam.ac.uk/research/sebastianevesvandenakker

Global food security is one of the defining challenges of our generation. Micro-organisms and pests have a major impact on plant productivity, forming a range of associations, ranging from mutualism to disease. A better understanding of these associations is required to increase, or even maintain, crop yield and to feed the growing human population in a more sustainable way.

The devastation of food crops, as well as wild hosts, by filamentous (fungal and oomycete), viral, invertebrate, and bacterial pathogens represents the “down side" of plant interactions with microbes. First we consider pathogen epidemiology and discover how modelling helps us to contain the development of epidemics. Then we introduce an overview of plant-pathogen interactions, learn how pathogens overcome primary and secondary defence systems, and finally how we can use that understanding to deliver crop protection solutions.

Throughout the course, key concepts are illustrated at a number of levels, ranging from the analysis of signal transduction pathways, the use of gene edited and transgenic plants, and field studies.



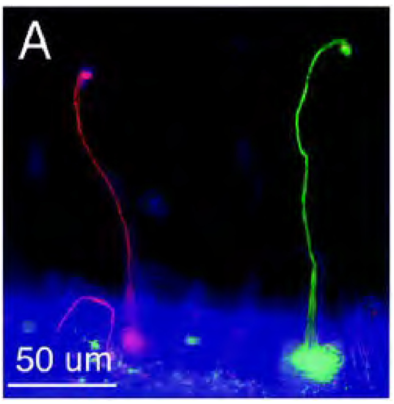
A plant-parasitic nematode infecting root

Beneficial interactions: Symbioses

Prof Uta Paszkowski http://www.plantsci.cam.ac.uk/research/utapaszkowski

Some microbes assist plants in their defence against attack and in their acquisition of nutrients. Development of such beneficial relationships requires the continuous and coordinated exchange of chemical signals, resembling a plant-microbial language. We will discover that mycorrhizal and rhizobial interactions involve completely different classes of microbes, but their molecular mechanisms and symbiotic trade-offs have a remarkable degree of convergence. Research extending these beneficial interactions to non-symbiotic plants and crops will also be discussed.

Bacterial nitrogen fixation occurs in newly formed root nodules



Root hair infection by beneficial rhizobia bacteria

Feeding the World whilst Conserving Nature

Prof David Coomes http://www.plantsci.cam.ac.uk/research/davidcoomes

The conservation module focuses primarily on global issues associated with human population growth. We examine evidence that humans have already exceeded the world's carrying capacity, and move on to consider the consequences for biodiversity of land-use intensification and habitat fragmentation. Next we assess critically the mounting evidence of an extinction crisis. Finally, we move from the global scale to our back doorstep, considering how British grasslands and woodlands are affected by land-use intensification, and we will visit a nature reserve to develop plans for the management of a locally endangered species.

Top left: Bolivia deforestation; top right: *Pulsatilla vulgaris*: a potentially endangered species found on East Anglian chalk soils; Bottom: Maize - food or biofuel?

Harnessing the Genetic Resources of Plants

Prof Ian Henderson http://www.plantsci.cam.ac.uk/research/ianhenderson

Incredible genetic variation exists in the plant kingdom, which people have harnessed through the domestication of crops. The advent of plant molecular biology has opened new doors into how we can access this variation and use it to improve our crops. In these lectures we will explore the genetics and epigenetics of plants and how we can continue to engineer their genomes.

In the first lecture we will continue the theme of conservation and how plant genetics and agriculture can play important roles. We will consider the effects of genetic monoculture of crops and how this is achieved from a breeding perspective. We will explore how genetic modification of crops can be used to improve the sustainability of agriculture and reduce our impact on the environment.

In the second lecture we will consider the benefits of producing crop hybrids or clones. We will examine the reproductive biology of plants and how the mechanisms involved can be modified to facilitate production of genetically identical or genetically diverse crops. I will explain how new genomics methodologies allow the genetic profile of our crops to be defined and manipulated at base-pair resolution.

In the third lecture we will examine cutting-edge genome-editing technologies, which are further expanding the possibilities for genetic improvement. Specifically I will describe how work in microorganisms led to the discovery of the TAL DNA binding code and CRISPR/Cas9. The utility of these tools in the context of crop improvement and plant genetics will be described.

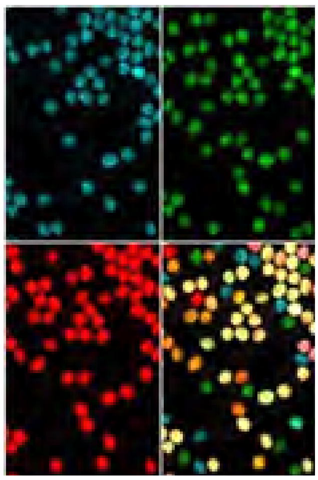
In the final lecture I will describe the epigenetic organization of plant genomes, in terms of DNA methylation, histone modifications and higher-order chromosome structure. I will provide examples showing the importance of epigenetic information for the expression and function of plant genes and routes to modify chromatin in order to control plant phenotypes.

These lectures relate to those of Jim Haseloff and provide further information relevant to the domestication and use of plants. Further connections will be made between lectures covering developmental biology, genetics, conservation and plant-microbe interactions.

From top left: A tuber of the potato variety ‘Majestic’; The mechanism of gene transfer by *Agrobacterium* as used in genetic engineering.

Bottom: A field of paddy rice; this close-up of inflorescences shows the full size fruits beginning to ripen

Right: Pollen from transgenic Arabidopsis expressing different coloured of fluorescent proteins that are useful to measure genetic recombination.

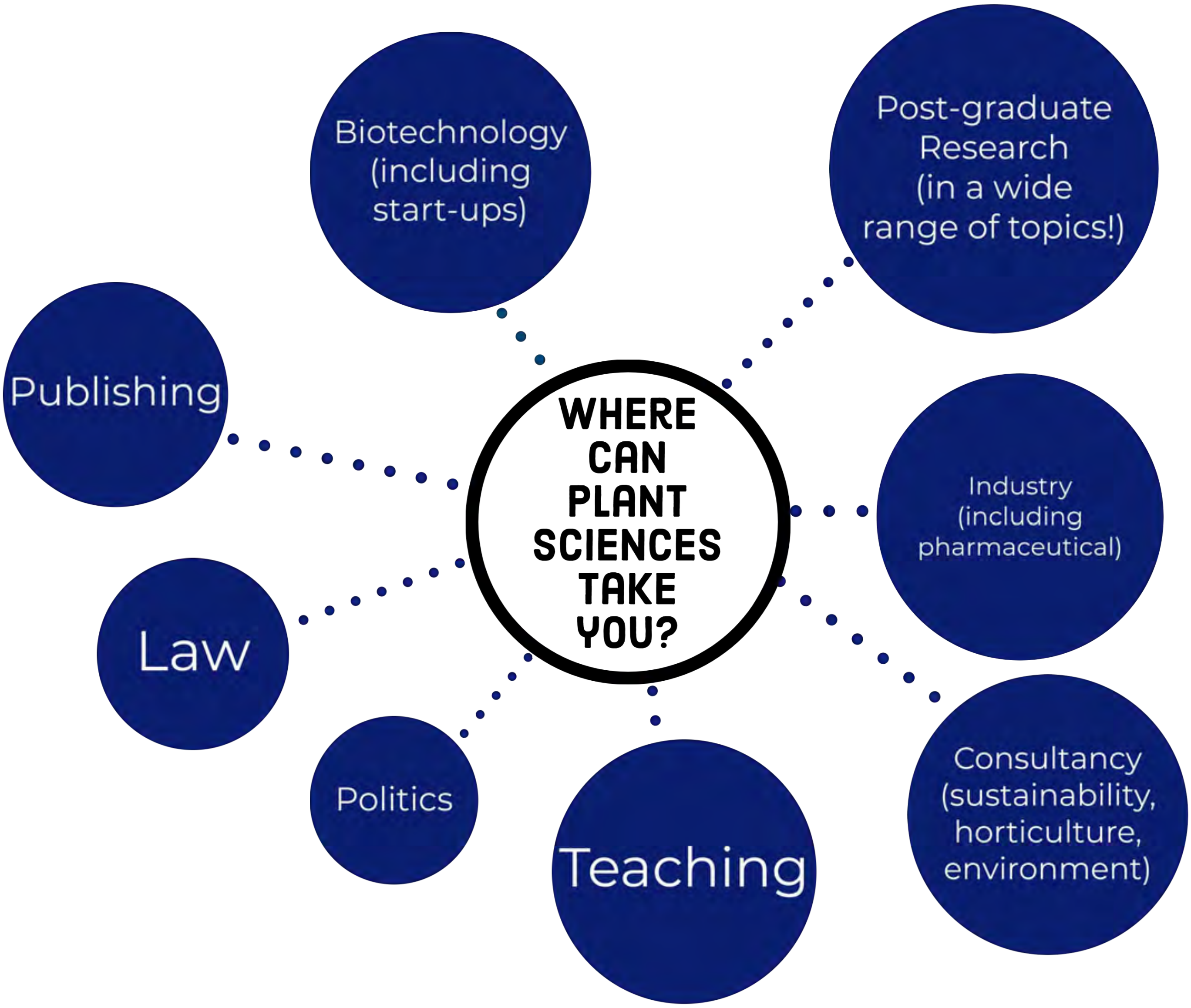


Career Opportunities

Taking IB Plant & Microbial Sciences doesn't restrict you to studying plants in Part II, but instead provides an excellent background to take microbiological, genetic, ecological, zoological and biochemical Part II courses. If you were to carry on with Plant Sciences however, your employment prospects on graduating would be excellent.

Data provided by the University's Careers Service show that a variety of employment has been taken up in recent years by our graduates. Almost half have gone on to do post-graduate research (both at universities and research institutes).

A number of our graduates have secured employment in the pharmaceutical industry, indicating that you don't have to be trained in animal biology to go into medically-related research. In addition, our teaching in plant biotechnology and microbiology will ensure that careers in these rapidly-expanding fields will be open to our graduates.



Plants and Microbes – Equality and Diversity

"Science knows no country, because knowledge belongs to humanity, and is the torch which illuminates the world."

Pasteur

Ours is an international community with students from diverse cultures. We are com-mitted to equality of opportunity and adhere to the University's dignity@study policy. We support students with disabilities and liaise closely with the Disability Resource Centre.

Women@plantsci Women are successful here. The first female plant scientist to be-come a Fellow of the Royal Society (Prof. Arber) took Part II Plant Sciences. Today, our female students have an outstanding track record, with 93% graduating with a Ist or II.i (the PhD entry requirement) between 2010 and 2014.

'Too many women don't fulfil their potential in science, in part due to a belief that it re-quires a "brilliance" they think they don't have and that the work ethic they know they can apply isn't enough' (Science, 347; 234).

Well, this is what Charles Darwin had to say:

"At no time am I a quick thinker or writer; whatever I have done in science has solely been by long pondering, patience and industry".

Join us!

The University of Cambridge and Department of Plant Sciences are committed in their pursuit of academic excellence to equality of opportunity and to a proactive and inclusive approach to equality, which supports and encourages all under-represented groups, promotes an inclusive culture, and values diversity .

Athena SWAN Bronze Award

Charter for women in science
Recognising commitment to advancing women's careers in STEMM academia

UNIVERSITY OF CAMBRIDGE

Department of Plant Sciences

DEPARTMENT OF

Plant Sciences

The Ginkgo is our Departmental logo. Our Ginkgo grows on the back of the building and started life as a cutting in 1896. Recent research shows that Ginkgos can live to be over 1,000 years old because they are excellent at resisting stress and do not have a pre-determined ageing programme. There is so much we can learn from plants!