Origins of modern agriculture

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

Incredible genetic variation exists in the plant kingdom, which man has 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-basedagricultureunderpinsproductionofthe 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 plantimprovement.

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 GM 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.

Crop varieties derived from wild mustard (Brassica oleracea L.)

Evolution of Photosythesis and Management of Reserves

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

The first photosynthetic 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 bacteria 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 CO2 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.

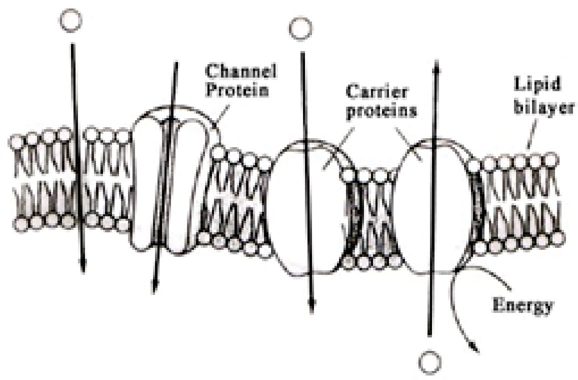
Resource Acquisition and Stress Management; Nutrients, Water and Temperature

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

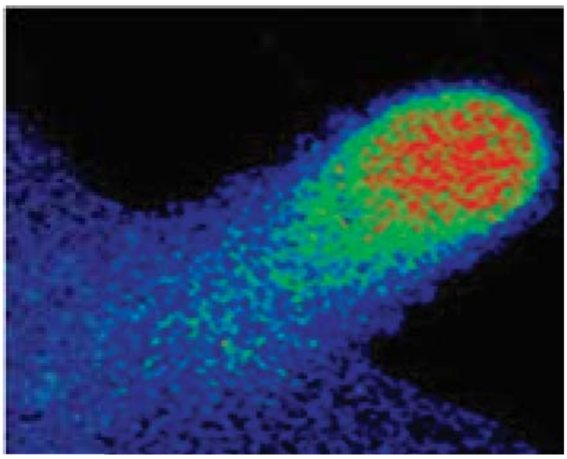
Nutrients

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. Thus 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

The effect of high and low temperatures on plant growth, cell physiology and gene expression will be examined as the basis for plant distribution. What limits growth at the treeline in high altitudes or the arctic, and are these plants any more stressed than a polar bear on an ice flow?

Plant Development

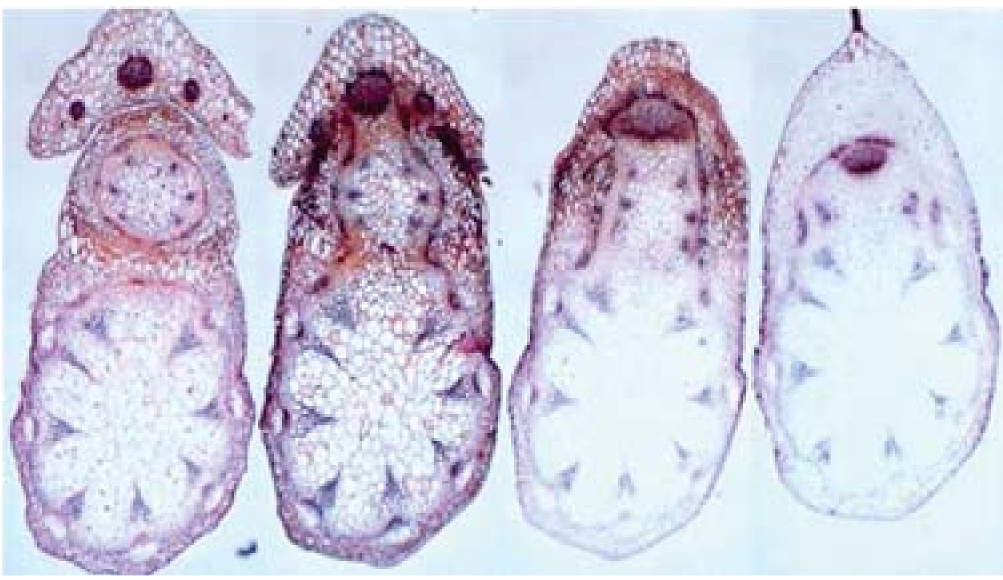
Prof Ottoline Leyser http://www.slcu.cam.ac.uk/directory/leyser-ottoline

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 in 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 marcomolecules 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 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.

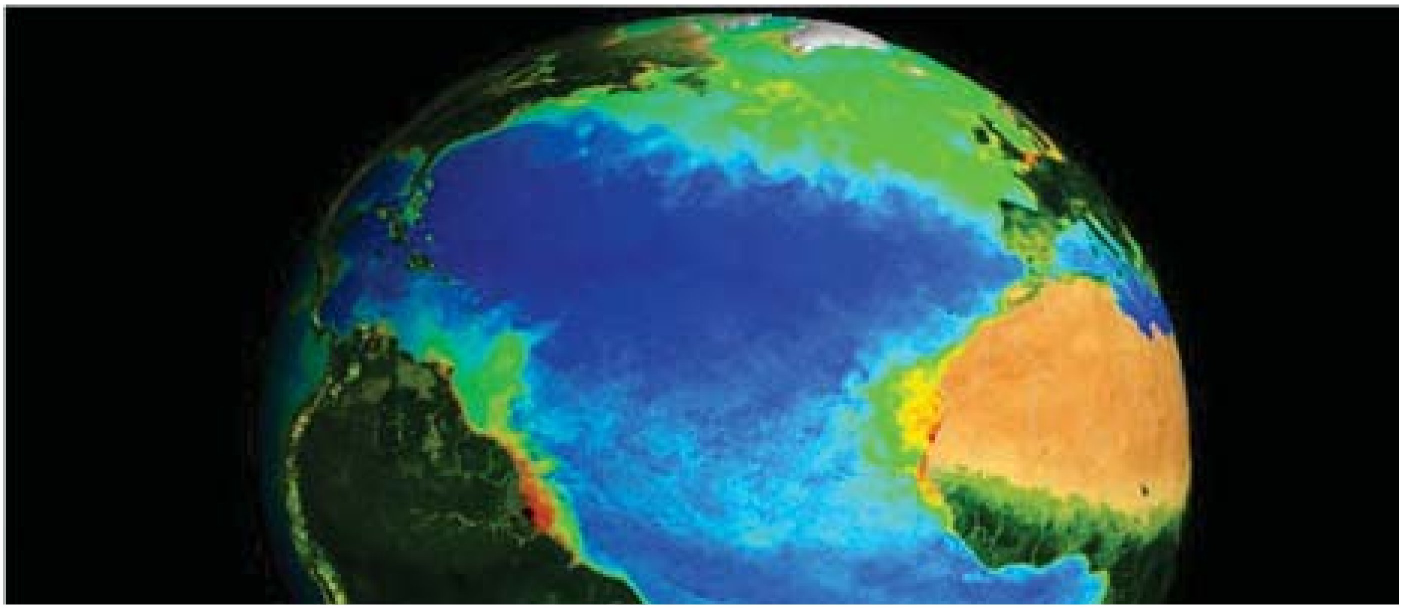


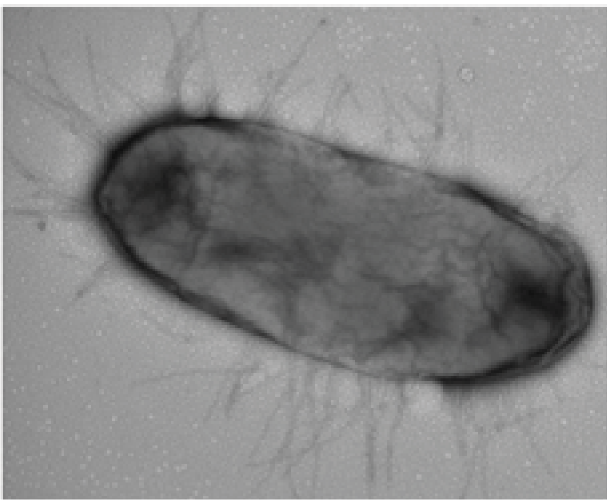
Sections through an Arabidopsis shoot tracing vascular connectivity of a branch

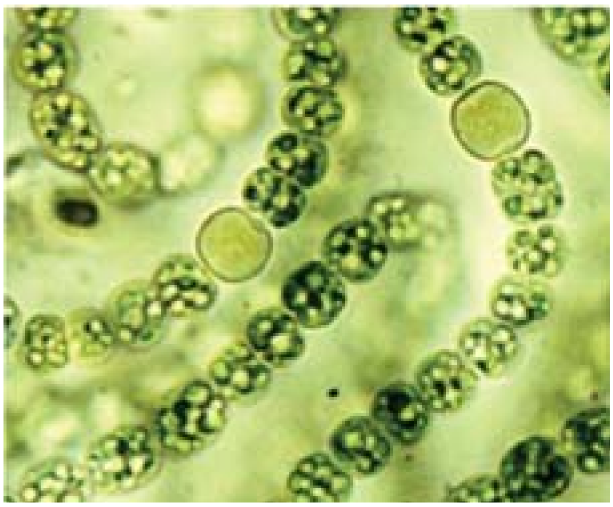
Comparative Microbiology

Dr 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 and algae) and the 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 radio- active waste







Top: Distribution of oceanic photosynthetic microbes, as captured from the SeaStar satellite.
From bottom left: E.coli; Cyanobacteria, with N2 fixing heterocyst cells.

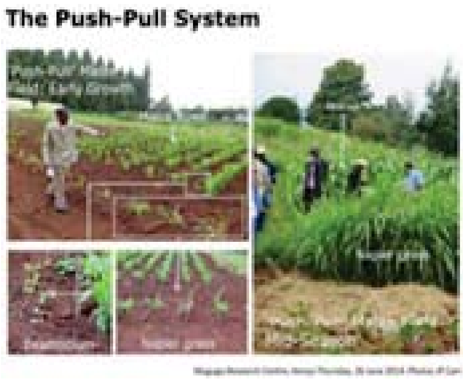
Interactions of Plants with Micro-organisms

Plant pathology, disease control and epidemiology

Prof David Baulcombe http://www.plantsci.cam.ac.uk/research/davidbaulcombe
Prof Chris Gilligan http://www.plantsci.cam.ac.uk/research/chrisgilligan

Micro-organisms have a major impact on plant productivity, forming a range of associations, ranging from mutualism to disease. A better understanding of these associations is essential if we want to increase crop yield, to feed the growing human population.

The devastation of food crops, as well as wild hosts, by filamentous (fungal and oomycete), viral 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, and finally learn how plants and microbes have tried successively to overcome primary and secondary defence systems.



Basic understanding of interactions between plants, pests and parasites can be used to devise environmentally friendly integrated disease management. In the 'push-pull' system a maize crop is protected from stem borer (a lepidoteran pest) by surrounding the crop with Napier grass, which emits volatile chemicals that attract adult stem borer moths and intercropping with Desmodium (a legume that enriches the soil with nitrogen) which emits moth-repelling chemicals. This causes moths to lay eggs on the Napier grass and saves the maize crop from infestation. As an additional benefit, Desmodium roots secrete chemicals that trigger premature germination of seeds of the parasitic plant Striga, protecting the maize from this noxious weed. At harvest time Napier grass and Desmodium can be used as livestock fodder. The deceptively simple push-pull system is befitting smallholder farmers across East Africa and helping to eradicate Striga, which is a threat to many crops.

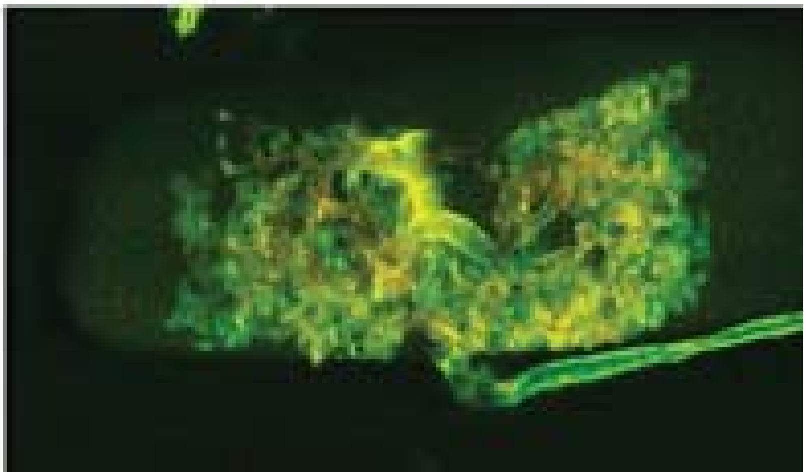
Throughout the course, key concepts are illustrated at a number of levels, ranging from the analysis of signal transduction pathways, the use of transgenic plants and field studies.

Beneficial interactions: Symbioses

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

Some microbes assist plants in their defense 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, and that 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.

Fungal assistance in exploring the environ-
ment



A fungal 'tree' inside a plant cell

Legumes engage in benifitial interactions with nitrogen fixing bacteria

Bacitrial nitrogen fixation occurs in newly formed root nodules

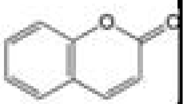
Interactions of Plants with Animals

Prof Alison Smith http://www.plantsci.cam.ac.uk/research/alisonsmith

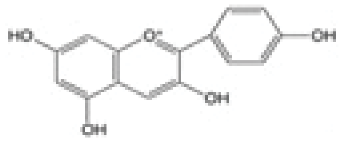
Plants have many interactions with animals, both beneficial where animals act as pollinators, or dispersors of fruits & seeds, but also harmful in the form of herbivores. Because plants are sessile, the major factor in both these interactions is the ability of plants to synthesise a myriad of novel chemicals. Some act as attractants (flower colour, scent), whereas others deter animals (toxins, astringents). Most of the flavour and palatability of our food is derived from these so-called secondary metabolites, and these also provide the majority of the medicines that we rely on today, from aspirin to beta-blockers and anti-tumour drugs. As well as illustrating how plants can produce three important groups of these compounds, terpenoids, phenolics and alkaloids, the lectures will consider the "cost" to the plant in terms of production, versus the resulting "benefits".

Phenolic compounds are found in all higher plants, but can have quite different roles

Coumarin: bitter tasting antiherbivory compound found in sweet clover



Pelargodinin: scarlet flower pigment characteristic of geraniums



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 their 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 visiting 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: Food or Biofuel ?

Harnessing the Genetic Resources of Plants

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

Incredible genetic variation exists in the plant kingdom, which man has 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. 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 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 change in plants. 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 by mankind. 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 padi rice; the close-up of inflorescences shows the full size fruits beginning to ripen.

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