Plant architecture and structural-functional modelling

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Plant structure-function analysis and modelling are important tools for studying arable communities, and for understanding their impact on crop productivity and arable food web composition. Structure-function analysis involves understanding how plant form, or architecture, influences the way plants interact with their environment. Plant architecture is defined by the three-dimensional arrangement of plant components in space, and determines the way in which plants grow and occupy different parts of the vegetation canopy (Fig. 1). The architecture varies systematically between species and also within species, for example between different crop cultivars or between ecotypic lineages of arable weeds.

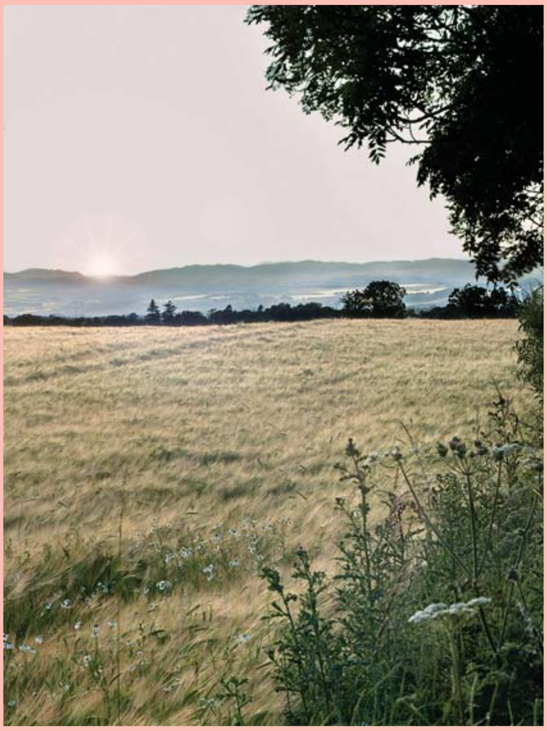

Figure 1 The role of plant architecture for community composition in the habitat can be observed in the variety of ways that crop and weed plants occupy, and contribute, to different sections of the canopy.

Knowledge of the 'rules' governing plant structure, and of the variability or plasticity of plant architecture, is important for understanding how plants interact with their environment at molecular, physiological and ecological scales. Variation in plant structure affects the way in which plants compete for and acquire resources, both above- and below-ground. Architectural effects on a plant's ability to capture light, acquire mineral nutrients and take up water all alter patterns of gene expression. At the community scale, plant structure may influence composition and diversity through interactions with other trophic groups, for example plant herbivores and natural enemies.

The ability to quantify plant architecture in three dimensions is therefore crucial for plant structure-function analysis. Traditionally, quantification of objects in three dimensions has been constrained by a lack of adequate tools, but recent developments in digitising techniques have facilitated accurate recording of plant architecture in three dimensions.

Digitising objects in three dimensions: The three-dimensional co-ordinates of plant components can be captured using a dedicated 3D digitiser connected to a PC. The 3D digitiser is composed of a probe, a detector and a pre-processing unit. The probe emits a signal, which can be sonic, magnetic or light. On a sonic digitiser, two spark emitters are spaced at defined distances along the probe, the tip of which is placed against the component to be digitised. When a trigger is fired, the two emitters spark consecutively. The noise created by the sparks is detected by the processor *via* a fixed array of microphones placed alongside the plant. The distances from each emitter to each microphone is calculated from the speed of sound, and this information, together with the known distances between the probe tip and the two emitters, is used to calculate the three dimensional co-ordinates of the plant component.

The way in which the computer software acquires the 3D information is defined by the user so that particular plant components (nodes, leaves, branches, flowers, etc.) can be digitised using a pre-defined set of points that is specific to the plant species under study. For example, the shape of a *Chenopodium album* leaf can be captured using 5 points distributed along the petiole and around the perimeter of the lamina. (Fig. 2)

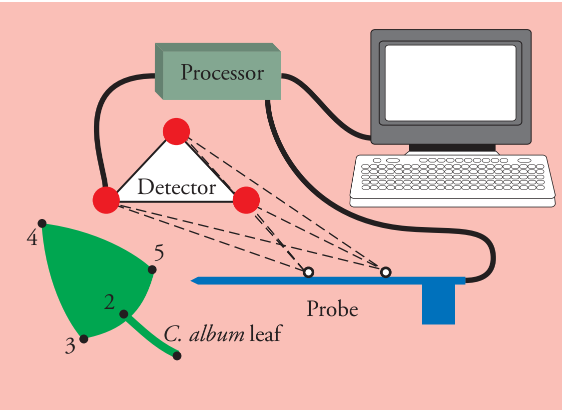

Figure 2 Digitising objects in three dimensions.

Initially, we have captured data on basic plant architecture for several weed species of arable systems. Measurements gathered from digitised plants (Fig. 3) reveal information about the 'rules' that govern plant form, enabling models of plant growth and structure to be constructed and parameterised. Modelling of plant structure in three-dimensional space will be a tool for hypothesis generation and is a critical step towards exploring the interaction between plant architecture and environmental variables, for example, the impact of resource availability or herbivory on resource partitioning. An L-systems approach to modelling plant architecture will be employed

L-systems for modelling plant architecture: *L*-systems, named after their inventor Aristid Lindenmayer, were introduced in 1968 to model the growth of plants. They use a simple symbolic language to capture the basic structure of plants and exploit the repetitive nature of structure to recreate the evolving architecture over time. Consider a plant starting with an apical bud, A. The starting point is known as the *axiom*. At each time step the apical bud produces an internode, F, from which a branch [ ] emanates containing a petiole, P, and a leaf, L. The new structure is terminated with an apical bud. The transformation is known as a *production rule* and can be written as

$$A \rightarrow F[PL]A$$

The plant then evolves by repeated applications of the same rule

Time step	Character string
0	A
1	F[PL]A
2	F[PL] F[PL]A
3	F[PL] F[PL] F[PL]A
4	F[PL] F[PL] F[PL] F[PL]A
5	F[PL] F[PL] F[PL] F[PL] F[PL]A

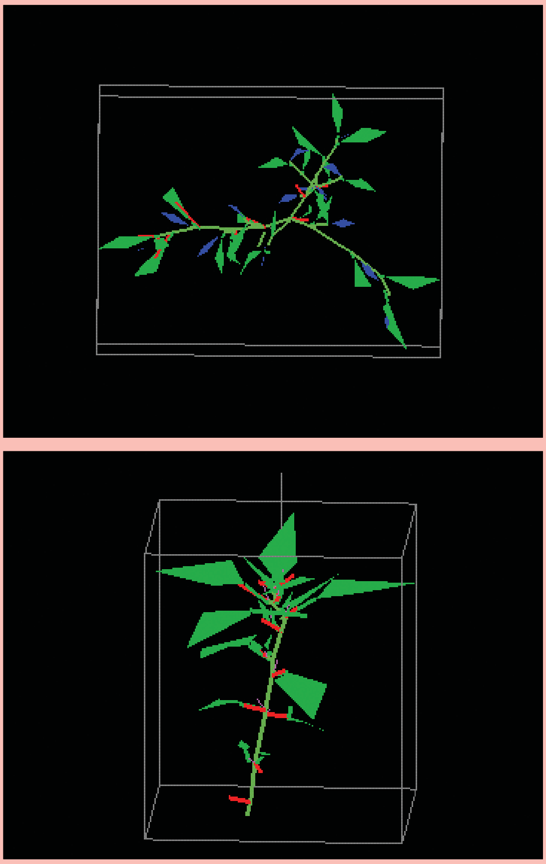

Figure 3 Images of 6-week old *Polygonum aviculare* and *Chenopodium album* plants acquired using 3D sonic digitising equipment.

Figure 4 Three plants growing in 3-dimensional space after 5 steps. After each time step the apical bud is rotated through a fixed angle about the main axis to represent phyllotaxis.

The corresponding graphical representation shows the result of this process. (Fig. 4)

The three dimensional architecture can then be used to calculate the local environment of, say, a leaf – how much light is intercepted, whether there is enough substrate to develop another bud or the impact of a pest - and such effects can be fed back to the subsequent growth and development of the plant. It is feasible to observe the evolution of communities of interacting plants and to explore how their differing characteristics confer advantages and disadvantages. Although developed in the 1970's, L-systems can only be used in this way through the increasing power of computers.

Future experimental work will investigate the degree of within-species variation in architecture and test hypotheses about architectural plasticity in response to competition among plants. An exciting possibility involves using architectural data to investigate the genes influencing resource-allocation in realistic conditions. Ultimately, this approach will improve our understanding of the architectural diversity of the arable weed flora and the importance of this diversity for weed-crop interactions and the arable food web.

Acknowledgements.

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