Protect and Survive: research on plant micro organism interactions to improve crop health

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Disease causing organisms

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All plants have intimate relationships with other organisms, Some of the least visible, but most important of these are micro-organisms. The outcome of a plant/micro-organism relationship may be detrimental to the plant, a condition we recognise as disease (Figure 4.1). By contrast, some relationships may benefit both the plant and the micro-organism, such as the associations of roots with 'mycorrhizal' fungi (Figure 4.2) and with nitrogen-fixing Rhizobium bacteria (see IGER Innovations 1997). Research at IGER on such economically important relationships contributes to the protection and survival of crop plants. In association with plant geneticists and breeders, this will enhance our exploitation of natural responses to provide reliable, healthy foodstuffs

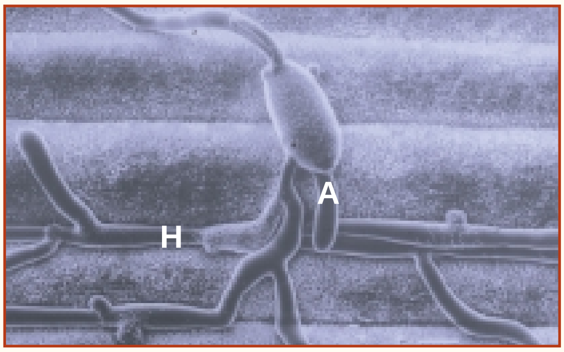
Figure 4.1 Ryegrass and crown rust: leaves of different plants derived from a single ryegrass genotype showing a range of responses to infection by one isolate of crown rust fungus, from resistant (right) to susceptible (left).

Figure 4.2 Arbuscular mycorrhiza (AM): cross fracture of plant root cortical cells showing AM hyphae growing between cortical cells, and in arbuscules within cell (highly branched invaginations of cortical cells). Hyphae grow out into the soil. Exchange of carbon (plant to AM) and phosphorus (AM to plant) occurs in the arbuscule.

Both plants and micro-organisms dedicate part of their genetic information to recognising each other and to controlling their relationships. In nature, plant protection and survival mechanisms minimise disease and pest damage and optimise plant growth and reproduction. Such mechanisms are often less effective when plants are grown as crops. Sometimes mechanisms for defence and survival may have been lost during the domestication of the crop plant. In other cases, natural defences are compromised in the agricultural environment, with genetically uniform crops and high intensity production.

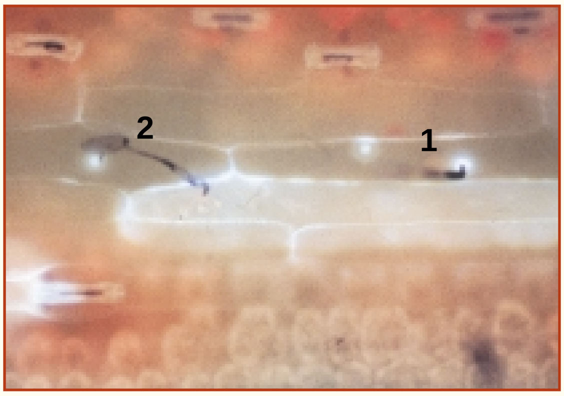
Powdery mildew attack

1. A powdery mildew spore on the leaf of a susceptible oat has formed a specialised infection structure, the appressorium (A), infected the leaf epidermal cell successfully, and started to form runner hyphae (H) on the leaf surface.



2. Powdery mildew spores have formed appressoria and attacked cells of the resistant oat cultivar Maldwyn. The oat has employed two different defence strategies. A localised autofluorescent host cell response beneath the appressorium of spore 1 indicates local accumulation of phenolic compounds by the living cell, and this has prevented penetration. Spore 2 has attacked a different host cell, and this cell has died (showing whole-cell autofluorescence) preventing further development by the fungus. Both of these defence mechanisms contribute to Maldwyn's resistance.

Current studies of cereal powdery mildew focus on



the adhesion to and recognition of leaf surfaces by mildew spores and on plant cell responses. Attempted infections may induce adjacent cells to become less accessible to subsequent attacks in resistant plants: in this way a leaf stays resistant in the face of repeated attacks. In contrast, when mildew establishes an infection in a susceptible plant the adjacent cells lose resistance allowing the disease to spread.

Disease causing organisms

Varieties of the plant species used in grassland farming are generally 'out breeders' and, because each variety is a mixture of genotypes, these crops maintain some of the natural diversity characteristic of wild populations. This diversity is the key to the exploitation of natural disease resistance. In contrast, small grain cereal crops are in-breeders and all plants of a variety are genetically uniform. This can make them prone to diseases. For example, plants with just one resistance gene (R-gene) to the powdery mildew fungus (Figure 4.3) quickly select

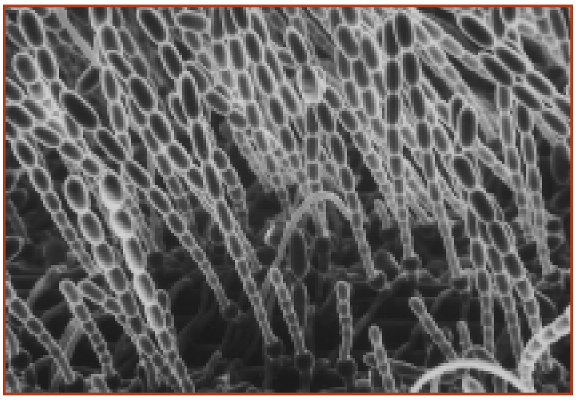


Figure 4.3 Chains of powdery mildew spores protrude from the oat leaf surface: a single colony can produce up to two hundred thousand spores, and there may be hundreds of colonies on a single leaf of a susceptible plant.

for a new race of the fungus which overcomes this resistance. In these crops, disease resistance is said to have broken down and control relies on regular sprays with chemical fungicides.

Two approaches to produce durable resistance in crops are being investigated. Resistance of ryegrasses to crown rust disease depends upon introducing enough different R-genes to combat the many races of the fungus. Our research is concerned with recognising ryegrass R-genes (Figure 4.1) and describing their relationships so that we can advise breeders as to which combinations are likely to provide long-lasting and effective resistance. Rust resistance may also be introduced into ryegrass from fescue, a related species. We are monitoring transfer of R-genes using the 'chromosome-painting technique' (see Chapter 2). We will determine whether resistance in fescue is distinct from that in ryegrasses and whether this contributes to durable resistance.

We also work on a remarkably durable form of powdery mildew resistance which is shown by the variety Maldwyn bred at IGER. This has remained effective for many years and now serves as a model to explore the mechanisms that contribute to durability. Such forms of resistance are more difficult to select in breeding programmes as they tend to be under the control of many genes, each with relatively small effect. Our research aims to understand the mechanisms of durable resistance so that we shall be able to breed these qualities into new cereal varieties (see box above).

Beneficial interactions

Relationships with arbuscular mycorrhizas (AM) confer benefits to plants especially where phosphorous is limiting. Plant roots are occupied by the fungus (Figure 4.2) but do not suffer damage. In fact the opposite is the case. This is because AM hyphae, supplied with essential carbon by their hosts' photosynthesis, grow out from the root into the surrounding soil, increasing the soil volume from which the plant-fungus association can scavenge for phosphorus. Variations in the effectiveness of these associations are related to the origins of the AM (Figure 4.4). We have recently shown that inbred lines of white clover differ in their responsiveness to AM: at similar levels of root infection and colonisation some plants grew more than others. We shall be using these contrasting responses to study and compare the characteristics of successful and ineffective associations. Improved understanding of these interactions will allow us to identify targets for plant breeders to improve the efficiency with which new varieties exploit their fungal partners.

Figure 4.4 Arbuscular mycorrhizas (AM) and white clover: significant growth response of white clover grown in pots with AM from field soil managed extensively with little fertilizer (C). In contrast, plants infected by AM from a field managed with regular applications of fertilizers (B) and plants without AM (A) grow poorly

Micro-animals

The word 'micro-organism' also encompasses the microscopic roundworms (nematodes) some of which are prominent pests of grassland crops (Figure 4.5). Some white clover plants are genetically resistant to one widespread pest, the stem nematode. Our objectives are to increase the proportion of plants with this natural resistance to provide farmers with varieties that will yield and persist better, despite the widespread occurrence of the nematode (Figure 4.6). We have identified near isogenic lines of white clover that will allow us to map the R- genes that control plant response to infection by the nematode.

Figure 4.5 White clover severely stunted and swollen following infestation by the stem nematode. Insert shows nematode worms and eggs stained red within plant tissues.

Figure 4.6 White clover and stem nematode: white clover selected for resistance (front plot) to stem nematode showing much better establishment and growth than susceptible clover (back).

Our research on responses to micro-organisms is closely linked to plant breeding research. This is because the development of genetic maps offers a solution to what has long been the major obstacle to improvement of the many traits required in crop varieties. It has not been possible for breeders to select for all the characteristics contributing to crop performance. The advent of molecular marker-assisted selection based on genomic maps will allow us to introduce the genes that either protect plants from disease or promote good relationships to help them survive and provide sustainable yields of wholesome food. As well as protecting plants from disease and having potential value for efficient use of nutrients in grassland farming, this research has exciting potential for comparing the processes of recognition in both beneficial and detrimental interactions.

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