DO COTTON PATHOGENS INDICATE POOR SOIL HEALTH?

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Soil health

Soil health has been defined as " the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health" (Doran and Zeiss 2000). However, the microorganisms within soil ecosystems clearly did not evolve with the specific purpose of supporting and sustaining the repetitive monocultures of modern agriculture.

Soil ecosystems are among the most complex known. Agricultural soils are, by default, disturbed ecosystems. The response of ecosystems to disturbance can be measured by their *resilience*, being the time taken to return to equilibrium, and *resistance*, being the degree of change resulting from the disturbance (Pimm 1984). Soilborne plant pathogens are frequently considered to be indicators of poor 'soil health'. In contrast, we hypothesise that plant pathogens in cropped soils may actually contribute to the resistance and resilience of soil ecosystems against the imposed disturbance of repetitive monoculture.

The profitability and sustainability of cotton production in Australia is currently threatened by soilborne pathogens (Nehl et al. 2003, 2004). We now report aspects of our research in cotton showing that soilborne pathogens are a problem for crop health, rather than soil health, and discuss evidence in support of the above hypothesis.

Green manure crops

Green manure crops are generally considered to be a 'beneficial' component of various farming systems. Woolly pod vetch (*Vicia villosa*) has recently been the focus of research on green manure crops for cotton farming systems in Australia. In addition to fixing substantial quantities of nitrogen (Rochester et al. 2001), vetch has a 'biofumigation' effect against black root rot (Nehl et al. 2000). As the vetch breaks down in the soil, ammonia is released in sufficient quantities to kill spores of the black root rot pathogen, *Thielaviopsis basicola* (Candole and Rothrock 1997).

In contrast, vetch residues can also increase the activity of *Rhizoctonia* and *Pythium*, the pathogens that cause seedling disease in cotton (Rothrock et al. 1995). We have observed the same phenomena in experiments using vetch in Australia. When woolly pod vetch was sown in a field near Wee Waa NSW and cultivated into the soil seven days before sowing cotton, seedling mortality was increased (Table 1). This effect was reversed by the fungicide tebuconazole, which is effective against *Rhizoctonia*, indicating that the greater seedling mortality was due to this pathogen. In contrast, vetch decreased the inoculum of *T. basicola* and decreased the severity of black root rot (Table 1).

Table 1. Increased seedling mortality and decreased severity of black root rot of cotton following incorporation of vetch (*Vicia villosa*) as a green manure crop in a field near Wee Waa, NSW

Treatment			
Vetch (t/ha)	Tebuconazole (g/ha)	Seedling mortality (% death)	Black root rot (0-10 scale)
0	0	25a	7.7a
0	50	18a	4.7b
5	0	57b	3.2b
5	50	31a	3.4b
		$p < 0.001$	$p <= 0.001$

Values followed by the same letter are not significantly different by pairwise comparison using the Scheffé test (n =6). The fungicide tebuconazole was sprayed over the seed at sowing.

In a second experiment, woolly pod vetch was incorporated either early (43 days before sowing cotton) or late (13 days before sowing cotton). Cotton seedling mortality was much higher with the late incorporation (Table 2), suggesting a transient increase in the population of fungal pathogens on the vetch residues. Similar observations were made by Rothrock et al. (1995).

Table 2. Increased seedling mortality of cotton following late incorporation of vetch (*Vicia villosa*) as a green manure crop at the Australian Cotton Research Institute

Vetch incorporation		
Date	tonnes/ha	Cotton seedling mortality (%)
21 Aug	5.0	19.9
20 Sep	5.9	33.7
		$p<0.001$

The potential for green manure crops to increase the severity of cotton diseases is not limited to seedling disease. When woolly pod vetch and Indian mustard (*Brassica juncea*) were sown in a field near Boggabilla NSW and incorporated 40 days before sowing cotton, the severity of Fusarium wilt, at the end of the subsequent cotton crop, was increased substantially (Nehl et al. 2002).

Distribution of disease

The incidence of Fusarium wilt of cotton was recorded across a transect of a cotton crop near Warren NSW and the incidence of black root rot was assessed at three sites in a cotton crop near Goondiwindi QLD. The distribution of Fusarium wilt and black root rot across these crops was variable (Figure 1) and incongruous with the 8 m width of the implements used for tillage, sowing and fertiliser application.

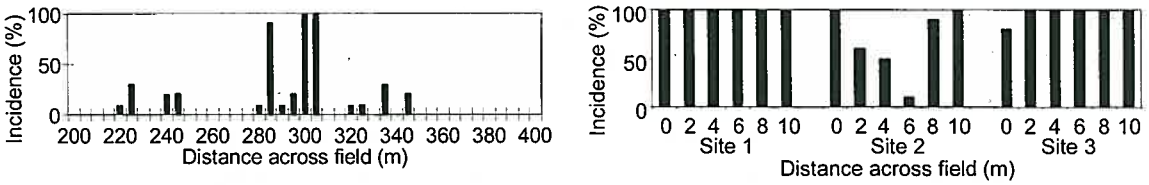

Figure 1. Incidence of Fusarium wilt of cotton in a field near Warren, NSW (left) and black root rot of cotton in a field near Goondiwindi, QLD (right)

Resolution of a paradox

In recent years farmers have gained a greater awareness of the biological nature of soils. When diseases occur, farmers are frequently told that this represents a soil health problem. However, using the presence or absence of plant pathogens to define 'soil health' presents farmers with some dilemmas: how can a practice that increases one disease, while decreasing another, be 'healthy'? Why would a soil in a 'poor' state of health at the end of a Fusarium-wilt-affected cotton crop in April, suddenly be 'healthy' when wheat is sown in May?

Our observations contradict the 'soil health' view on three counts. First, soil organic matter is generally considered to be an important attribute of 'soil health'. In our experiments with vetch, the incorporation of substantial amounts of organic matter increased seedling mortality. This increase was due to fungal pathogens because it was reversed by the fungicide tebuconazole. Fusarium wilt was also enhanced by the vetch green manure. In contrast, black root rot was decreased by the vetch green manure. The simultaneous enhancement of some diseases and inhibition of others by green manures presents a clear contradiction if plant disease is to be used as a criterion for the health of the soil ecosystem. Furthermore, crop residues can have

Secondly, farm operations, such as fertilisation, tillage, irrigation and pesticide control, are applied evenly across fields. Yet the distribution of soilborne diseases of cotton was incongruous with farm operations and more likely represented the distribution of the pathogen. Any detrimental effect of farming practices on the health of the soil ecosystem should reflect the pattern of their application, not the disjunct distribution of a pathogen.

Thirdly, we have observed many fields where soilborne pathogens cause chronic disease in cotton (Nehl et al. 2003, 2004), yet healthy cereal crops are produced in the same fields. Conversely, cotton is not affected by soilborne pathogens of wheat. The species and strains of *Fusarium* and *Rhizoctonia* that cause disease in wheat are not pathogenic on cotton, and *vice versa*.

The paradox created by using plant pathogens to define soil health is easily resolved with the recognition that soilborne diseases are *clearly* a plant health problem, not a 'soil health' problem. Fusarium wilt and black root rot become an issue for plant health only after the pathogens arrive in a cotton field. These diseases do not exist in a crop because the soil has been mistreated.

Acknowledgments

This research was funded by the Cotton R&D Corporation and NSW Department of Primary Industries. Technical assistance from Anowar Mondal and Peter Lonergan, and the generous cooperation of farmers, is gratefully acknowledged.

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