Session 11D

Functional Biodiversity in Cropping Systems 2

Chairman & Session Organiser:	Jon Marshall *Marshall Agroecology, Winscombe, UK*
Platform Papers:	11D-1 to 11D-4

Wheat stripe rust and its prospects for ecological control in China

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Occurrence and epidemics of wheat stripe rust

China is one of the biggest agricultural countries as well as the largest wheat producer in the world. Wheat is grown on over 28 million hectares (He *et al.* 2001) and the total wheat production exceeds 100 billion kg. Stripe rust (yellow rust) caused by *Puccinia striiformis* Westend f. sp. *tritici* Eriks is the most destructive foliar disease of wheat in many areas around China. Epidemics of the disease have occurred annually since 1950 and the annual losses of wheat yields due to stripe rust have averaged about 1 billion kg. The most severe epidemics occurred in 1950, 1964, 1990 and 2002, which caused yield losses of wheat of 6.0 billion kg, 3.2 billion kg, 2.65 billion kg and 1.4 billion kg, respectively. A total of 56 races or pathotypes, including 32 formally nominated (CYR1 to CYR32) and 24 temporarily designated, and their frequencies have been determined from the stripe rust samples collected throughout the country. These are based on their avirulence/virulence combinations to 19 Chinese differentials, of which CYR 32 and Su 14 was detected to be the dominant pathotypes with the frequency of 30.35% and 12.31% respectively in a total of 5445 isolates tested during 2001-2006. The limited sources of resistance derived from the 1B/1R wheat-rye translocation (*Yr9*) and Fan 6 derivatives with resistance from Hybrid 46 (*Yr3b, Yr4b*) have been widely used in wheat breeding programmes throughout China since the 1970s. Wheat resistance to the obligate parasitic rust determined by single genes was normally neutralised by the evolution of a new pathogenic race within about five years or eight to ten years after the cultivar became widely grown, leading to the severe epidemics and widespread occurrence of wheat stripe rust in China.

Prospects for the ecological control of wheat stripe rust in the over-summer areas

A great deal of effort has been spent on the epidemiology of wheat stripe rust and strategies for its control in China over the years. It has been found that south of Gansu and north-west of Sichuan are the most important over-summer areas of *P. striiformis* f. sp. *tritici* that act as major sources of inoculum for the autumn-sown wheat in the eastern areas and as a variable zone of rust virulence and wheat cultivar resistance to stripe rust (Chen & Xie, 1999). Ecological control of wheat stripe rust in those areas has been considered as the major strategy of sustainable disease control. Effective measures have been put forward and developed as follows in recent years: (1) *Improving cultivar resistance* and reasonably deploying resistance genes to enhance genetic diversity of wheat rust resistance. In order to achieve the sustainable control of wheat stripe rust in the areas of pathogen sources, genetic control technical system has been established based on a principle of genetic diversity, which comprises enriching resistance genes in the commercial cultivars, enforcing gene distribution in the over-summer and over-winter regions and utilising durable resistance, slow-rusting and adult plant resistance (APR) controlled by multi-gene, etc. After 15 years teamwork, a series of improved disease-resistant cultivars (or lines) has been developed by incorporating the resistance genes *Yr3b, Yr4b, Yr5, Yr10, Yr11, Yr12, Yr13, Yr14, Yr15, Yr16, Yr17, Yr18, YrC591, YrSp* etc., as well as the durable resistance cultivars and the other resistance materials. DNA molecular markers closely linked or co-segregating with the resistance genes *Yr2, Yr5, Yr7, Yr8, Yr9, Yr10, YrSp, YrJu4, YrKy2, YrC591* and two sets of wheat near isogenic lines with the resistance genes *Yr1, Yr2, Yr5, Yr7, Yr9, Yr10, YrV23, YrSp, YrKy2, YrJu4*, based on the recurrent parents of Mingxian 169 (winter habit) and Taichung 29 (spring habit) respectively, have been successfully developed. These provide a useful aid to putting the genetic control of wheat stripe rust in China into a phase of implementation and improvement. (2) *Changing cultural practices* to raise crop diversity. The areas of 1600-1800m elevation to the south of Gansu and 1900-2500m to the north-west of Sichuan are considered as the 'hotspots' for wheat stripe rust, where it occurs over summer and winter acting as the major sources of inoculum, not only for the local epidemics, but also for the autumn-sown wheat over wide areas where the rust is absent. Maize, upland rice, oil sunflower and other vegetable and forage crops with highly economic value have been introduced and extended, to cut down the wheat plantation in the elevated and upland areas. Now plastic-mulched maize has been extended to a total acreage of more than 70,000 ha with the economic benefits two to three times greater than wheat, leading to a reduced wheat acreage of 40% in the 'hotspots'. (3) *Eradicating volunteer seedlings* of wheat. It has been found that wheat volunteer seedlings play an important role in the life and disease cycles of *P. striiformis* f. sp. *tritici* in the over-summer areas of the pathogen, working as a 'green bridge' of the inoculum from late-matured wheat to early-sown seedlings. The results of surveys indicated that furrowing deeply more than two times can ultimately control the volunteer wheat after harvest. (4) *Regulating wheat planting date* to reduce the amount of inoculum in the areas of the pathogen sources. The results of tests in field plots and broad surveys have shown that planting date of winter wheat was positively correlated with the time of disease occurrence and negatively correlated with the incidence of stripe rust infection in autumn. Later planting in the suitable sowing dates could postpone breaking epidemics of stripe rust in the following spring for three to eleven days and decreased disease severity by 50%. (5) *Returning land to forestry and pastures* instead of wheat. The climate in the upland areas above 1800m south of Gansu is suitable for pasturage and the development of fruit plants and medicinal materials. The government is strategically considering returning wheat areas to forestry and pastures. Conclusively, establishment of a new agro-ecosystem in the areas of inoculum sources is commended as a more economical and practical approach to the sustainable control of wheat stripe rust epidemics in the whole country of China.

Acknowledgments

We thank all members of the Chinese National Wheat Rust Collaboration Group for their contribution to the project and many colleagues in different regions in China for providing samples and information. We acknowledge financial support from Ministry of Agriculture, and Ministry of Science and Technology, China.

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Targeted herbicide use in winter wheat for biodiversity benefits: is it a practical option?

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Introduction

The effect of intensification of farming in the UK, on arable plants, invertebrates and mammals is now well documented (Robinson & Sutherland, 2002). This overall decline in biodiversity has been driven, at least in part, by a reduction in plant species, as they provide food and shelter for higher trophic groups. In recent years, financial incentives have been given to UK farmers to improve biodiversity on their farms, through environmental stewardship schemes. These schemes have focused on uncropped areas of the farm (e.g. field margins) and have been less used to encourage greater presence of arable plant communities within fields. The need for arable plants (weeds) in fields is still being debated (Storkey & Westbury, 2007), but may be required to optimise overall increases in biodiversity. It is clear that some arable plant species, especially broad-leaved ones, are of importance in providing ecosystem services (Marshall *et al.*, 2003). Increased in-field biodiversity is not favoured by many farmers because of the perceived risk to yields. The research reported here explored the encouragement of diversity within fields by exploiting differences in herbicide sensitivity.

Materials and methods

A series of replicated field experiments in winter wheat were done between 2001 and 2005 to explore the feasibility of manipulating herbicide products and doses to retain desired broad-leaved species, whilst retaining control of aggressive, unwanted species and without jeopardising yields. The experiments aimed to encourage *Tripleurospermum inodorum, Senecio vulgaris* and *Stellaria media*, as these species were known to have biodiversity value, whilst eliminating the unwanted species *Galium aparine*. Six experiments in 2001-2003 focussed on reducing doses of the herbicides metsulfuron, fluroxypyr and mecoprop, known to control these species when used at full rate. The natural flora of each experiment was augmented by sowing seeds of the non-target species into the plots at drilling. Herbicide applications were made in early spring and weed survival was assessed the following summer, along with crop yield. In 2004 and 2005, the work focussed on choosing herbicides that were intrinsically less effective on the non-target species at all doses. The same methods were used in these seven experiments as in 2001-03, except a wider range of products were compared at fewer doses.

Results

The results of the initial experiments were not encouraging, as lower rates of products were found not to be consistently safe on the non-target species. Consequently, it was not possible to achieve reliable partial control. More success was achieved with the latter experiments, choosing appropriately selective products. In Table 1, which summarises the results of the seven experiments, some products were clearly able to control the target weed (*G. aparine*), whilst having only small effects on the non-target ones. Amidosulfuron,

Table 1. Overview of the selectivities of herbicides tested in relation to the weed species to be retained or controlled (✓ = well controlled, ? = variable control, x = no control)

Herbicide	Non-target species			Target species
	S. media	*T. inodorum*	*S. vulgaris*	*G. aparine*
amidosulfuron	x	✓	?	✓
carfentrazone + mecoprop-p	?	?	x	✓
florasulam	✓	✓	✓	✓
fluroxypyr	✓	?	?	✓
mecoprop-p	✓	?	?	✓
metsulfuron	✓	✓	?	X
pendimethalin	✓	X	x	?

pendimethalin and even mecoprop seem to have some potential to retain desirable species, whilst retaining control of the target *G. aparine*. A consequence of not fully controlling the desired species was that they potentially could reduce crop yields. Partially controlling weeds can result in appreciable competition with the crop, if climatic conditions favour weed growth in late summer. An overall regression analysis of nine relevant experiments linking weed biomass in June to crop yield demonstrated a linear response [$Y = 0.095x - 5.52$ (% variance accounted for = 64%): where Y = % yield loss and 'x' = weed wt (g/m^2) in summer]. This showed that the crop would tolerate a low level of weed infestation without a detectable reduction in yields ($106 g/m^2$ = 5% yield loss). As the 'non-target' species tended to be less aggressive, an appreciable population would deliver less than $100 g/m^2$ in summer.

Discussion

This work has shown that it is possible to adjust broad-leaved weed control with herbicides, such that desirable species are retained and unwanted ones removed. How much weed is needed in fields to deliver more biodiversity is still being debated, but this work showed that picking the correct product, rather than manipulating product dose, was more likely to deliver the desired effect. This approach needs further validation and additionally the issue of whether seed return from these retained weeds impacts in practice on the productivity of following crops needs to be resolved. A further complicating factor is that the approach suggested here is less likely to succeed if *Alopecurus myosuroides* is present as a major weed, as the products currently used to manage this species tend also to control a wide range of other species. Thus, effective control of this grass weed inevitably results in the control of a range of broad-leaved species that might have delivered some biodiversity services.

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Impact of agricultural land management systems on soil microbial diversity and plant disease

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Materials and methods

The study was initiated in in July 2000 in Fort Pierce, Florida on a commercial tomato production farm previously subjected to 10 years of continuous conventional tomato production, including soil fumigation with methyl bromide and chloropicrin. Five land management systems were arranged in a randomised complete block design with six replications of 0.16-ha plots.

Land management systems were:

Conventional – an annual crop of tomato produced using conventional production practices, including soil fumigation with a 62:35 formulation of 1,3-dichloropropene:chloropicrin and the herbicides napropamide and trifluralin;

Bare fallow – continuous tillage to keep soil vegetation free of any plant material;

Weed fallow – soil undisturbed and weeds allowed to revegetate naturally;

Organic production – annual cover crops of Sunn hemp (*Crotalaria juncea*) and Japanese millet (*Echinochloa crusgalli* var. *frumentace*a) combined with annual applications of poultry manure and urban plant debris at 22 and 67 t ha^{-1}, respectively;

Bahiagrass pasture – an improved stand of a perennial pasture grass (*Paspalum notatum* var. Argentine bahiagrass*)*.

Tomato (*Lycopersicon esculentum*) was cultivated in the south half of each replicate plot in years four (2003) and five (2004). Organic production guidelines were adhered to in the organic land management treatment. An alternative, low-input production system that included strip-tillage was adopted for production of fresh market tomato in the bahiagrass pasture treatment. Conventional fresh market tomato production practices, except soil fumigation, were applied to the weed and bare fallow plots except for omission of soil fumigation. Two major hurricanes (Francis and Jeanne) struck the experimental farm site on September 5 and 25, 2004, causing significant wind damage and flooding to the experimental site. Soil samples were collected from the land management treatments at the end of years three (July 2003) and four (July 2004). In each replicate plot, soil cores from 14 evenly spaced quadrats were removed using a 2.5 cm wide x 15 cm deep probe and bulked prior to analysis. Soil samples were also collected prior to transplanting tomato in years four (September 2003) and five (September 2004) using the same procedures. Soil samples were again collected when tomatoes were harvested in years four (December 2003) and five (January 2005) by bulking soil extracted from the root zone of four tomato plants from each plot. DNA was extracted from soil samples and PCR primers specific for the internal transcribed spacer region 1 (ITS-1) region of fungal ribosomal DNA (rDNA) were used to distinguish genetic diversity by separating labelled fragments using capillary electrophoresis and detection using laser-induced fluorescence. The incidence and severity of Fusarium wilt of tomato, caused by *Fusarium oxysporum* f.sp. *lycopersici* race 3, was monitored during the cultivation tomato crops.

Results and discussion

Increased diversity of fungal rDNA ITS-1 amplicons, as measured by the Shannon-Weiner index, was associated with land management practices that minimise soil disturbance (bahiagrass pasture and undisturbed weed fallow) when compared with organic or conventional land management systems. Diversity declined in the undisturbed weed fallow plots following successive years of conventional tomato cultivation when compared with diversity in the bahiagrass plots, where conservation tillage practices that minimised soil disturbance were employed to cultivate tomato. Three years after initiating the five land management systems, soil fungal communities in replicate plots could be separated into 11 clusters based upon similarities in the distribution of their ITS-1 amplicons. Communities from bahiagrass and organic plots were grouped into their own respective cluster, indicating a consistent effect on their genetic composition. Four of six plots in the undisturbed weed fallow system also shared 40% similarity in genetic composition, perhaps due to similarities in the weed communities.

Fungal communities in organic plots remained similar to each other and unique from communities in other land management systems, despite successive years of organic tomato cultivation, two hurricanes and changes in the dominant ITS-1 amplicons. Fungal community composition in plots subjected to other land management regimes initially diverged, separating into as many as 13 distinct groups upon resumption of tomato cultivation, but eventually converged into two main groups dominated by a 341 base pair amplicon corresponding to *Fusarium oxysporum*. The incidence of Fusarium wilt of tomato was significantly impacted by land management and crop cultivation practice. In year 4, the incidence of Fusarium wilt remained below 2% in the organic and conventional system and the bahiagrass system where conservation tillage practices were adopted. Disease incidence was significantly higher (14.5% - 15.6%) in the continuous tillage (disk fallow) and undisturbed system (weed fallow). In year 5, low levels of disease were observed only in organic plots (2.5%). Disease incidence in the other land management systems ranged from 22.1% - 39.5%.

In summary, agricultural land management systems impacted both the diversity and composition of soil fungal communities. Higher genetic diversity, while associated with land management practices that minimise soil disturbance, was not associated with land management systems that reduced the incidence of soilborne disease in this study. Impacts of land management practices on the genetic composition of soil fungal communities were more strongly associated with reductions in the incidence of plant disease. The results suggest that compositional effects within soil microbial communities can have a greater impact on ecosystem stability, as measured by incidence of plant disease and resistance to disturbance, than diversity.

Non-inversion tillage to conserve functional biodiversity for biocontrol of oilseed rape pests

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Introduction

Winter oilseed rape crops in Europe are invaded by a succession of insect pests, for which insecticides are the only recognised means of control. The development of pyrethroid-resistant populations of pollen beetles (*Meligethes* spp.) has accentuated the need for pest management strategies for this crop which reduce the use of insecticides and so protect their effectiveness. The potential of functional biodiversity for controlling pests in oilseed rape has been the subject of a major recent study funded by the European Union (Williams, 2006). Parasitoids are particularly effective, 20-50% parasitism being commonly reported in pests of oilseed rape in the absence of insecticide use. Most species parasitising oilseed rape pests kill their hosts only after they have reached larval maturity and so pest populations are only depressed after injury to the crop in the current year. Thus successful conservation biocontrol must aim to build populations of the parasitoids from year to year.

There is increasing evidence that parasitoids of oilseed rape pests are vulnerable to the disruptive effects of soil tillage (Nitzsche & Ulber, 1998). Most are larval endoparasitoids (Hymenoptera) that become active when the host has dropped from the plant to pupate. They develop to adulthood in the host's pupal cocoon in the upper layers of the soil, where they remain over winter. Fewer than 2% of parasitised pollen beetle larvae give rise to adult parasitoids the following spring under conventional agronomy (Ferguson *et al.*, 2003). Despite this, parasitism rates of 25-50% are usual. Reductions in tillage which even modestly improve parasitoid survival are likely to have a significant impact on biocontrol by parasitoids and may also benefit epigeic predators. The increasing adoption of non-inversion (or 'minimum') tillage by farmers for economic reasons, presents a good opportunity to take a long term 'farming systems' approach to conservation biocontrol in oilseed rape. Here we present the results of a two-year experiment testing the effect of conventional (inversion) and reduced (non-inversion) tillage before and after oilseed rape on the emergence of parasitoids and pests from the soil.

Materials and methods

Tillage treatments were tested in a randomised-block experiment with fifteen 24 m × 24 m plots sown with winter oilseed rape in year 1 (2004-5) and sown with winter wheat or left fallow in year 2 (2005-6). The three tillage treatments were: I = inversion tillage (ploughed) to 20 cm depth before and after oilseed rape; NI = non-inversion tillage to 5-10 cm depth before and after oilseed rape; NIF = non-inversion tillage before oilseed rape, no tillage after oilseed rape (plots fallow in year 2). The following were sampled: the pollen beetle and its ichneumonid parasitoids *Phradis interstitialis* and *Tersilochus heterocerus* (both Tersilochinae); the cabbage stem weevil (*Ceutorhynchus pallidactylus*) and its parasitoid *Tersilochus obscurator* (also Tersilochinae); the brassica pod midge (*Dasineura brassicae*) and its parasitoids *Platygaster subuliformis* (Platygastridae) and *Omphale clypealis* (Eulophidae). Pest adults on plants were sampled with beating trays; mature pest larvae dropping from plants were collected in water traps on the ground. Emergence traps on the ground collected newly enclosed pest adults in year 1 and parasitoids in year 2.

Table 1. Mean numbers of adult parasitoids emerging in year 2 and % increase in numbers emerging in NI and NIF plots compared to I plots. n = 5 plots for each treatment. Means log-transformed and analysed by ANOVA, %ages calculated from back-transformed means. 'All Tersilochinae' = the sum of *T. obscurator*, *T. heterocerus* and *P. interstitialis*.

Parasitoid species	Mean no. of emerging parasitoids per m^2					% increase compared to I plots	
	I	NI	NIF	SE	*P*	NI	NIF
Tersilochus obscurator	1.34	1.58	1.91	0.141	0.059	74	273
Tersilochus heterocerus	0.58	0.75	1.03	0.121	0.080	46	182
Phradis interstitialis	0.57	1.03	1.34	0.220	0.100	129	490
All Tersilochinae	1.50	1.75	2.10	0.144	0.050	78	304
Platygaster subuliformis	0.25	0.42	0.59	0.030	<0.001	49	121
Omphale clypealis	0.34	0.30	0.18	0.060	0.202	-8	-31

Results and discussion

Pollen beetle and pod midge larvae were 30% and 56% more abundant, respectively, in NI plots, perhaps because uneven crop establishment led to pigeon damage in these small experimental plots, which slightly delayed plant development. The rate of pollen beetle larval survival to emerge as adults (49%) did not differ between treatments.

In year 2, tersilochine parasitoids and *P. subuliformis* emerged in greatest numbers from the soil of NIF plots (not cultivated after oilseed rape) and least from I plots (ploughed; Table 1). The percent increase in abundance of these parasitoids in plots with non-inversion tillage or no tillage markedly exceeded the increased abundance of their hosts in the same plots in year 1. These results are consistent with the benefit of reducing tillage, particularly avoiding inversion tillage, to conserve soil-overwintering parasitoids after oilseed rape. Future dissection of host larvae to assess numbers of immature parasitoids entering the soil will allow more accurate assessment of the effect of tillage on parasitoid survival. Further work is needed to test the potential to integrate parasitoid conservation into today's changing farming systems that incorporate different types of non-inversion tillage.

Acknowledgements

This research was financially supported by the United Kingdom Department for Environment, Food and Rural Affairs. Rothamsted Research receives grant-aided support from the UK Biotechnology and Biological Sciences Research Council.

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