SESSION 7C

NON-CHEMICAL PEST, DISEASE AND WEED MANAGEMENT

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Platform Papers:	7C-1 to 7C-4

Using organic materials as alternatives to pesticides for weed, pest and disease management

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ABSTRACT

Consumer pressure and the removal of many pesticides from the market place has led to a renewed research interest in the development of ecological solutions to weed, pest and disease control. The use of organic materials from both on- and off-farm sources has potential value for weed, pest and disease management. In this paper we review, with examples, the use of fresh and composted plant materials and manures for managing weeds, pests and diseases in organic and conventional agriculture. Ultimately, uptake of ecological solutions such as these will depend on developing reliable practices which overcome variability in materials and human health concerns and that are economically viable.

INTRODUCTION

Crop protection in much of world agriculture is currently based on the use of pesticides. They are used to control the effects of fungal diseases and vertebrate and invertebrate pests on crop development and production, to reduce crop/weed competition and to protect harvested products from pest or diseases while in store. The current use of pesticides inevitably results in the presence of residues in food products, with a frequency and concentration of concern to the consumer (e.g. Baker *et al.* 2002). This has resulted in pressure to reduce the level and frequency with which residues are found in food crops. Crop protection in agriculture is currently highly dependent on chemicals. Attempts to reduce concentrations in food through reducing pesticide use in cropping systems is complex since conventional and arable and horticultural systems have been designed to rely on synthetic pesticides for over 70 years (Atkinson & Watson, 2000). In contrast to the short-term highly targeted approaches used in conventional agriculture, alternative farming systems such as organic tend to rely on longer-term solutions applied at the systems level which are preventative rather than reactive. Such systems aim to prevent or minimise the development of pest, disease and weed problems by providing conditions which favour crop growth and are unsuitable for the growth of pests, pathogens or weeds (Agrios, 1997).

Consumer pressure and the removal of many pesticides from the market place has led to a renewed research interest in the development of ecological solutions to weed, pest and disease control which have received little research attention over the past 30 years. In this paper, we review recent research on methods of weed, pest and disease control through organic matter management, which are likely to be acceptable in conventional and organic farming systems. Although composts, manures and other sources of organic matter have been applied to agricultural land for centuries, their deliberate use for preventing and controlling pests and diseases is more recent (Litterick *et al.* 2004).

Organic matter acts on pests and diseases in part through increasing soil microbial activity leading to increased competition, parasitism and predation in the rhizosphere (Workneh & van Bruggen 1994; Knudsen *et al.* 1995). The addition of organic matter will also modify both soil physical and chemical properties. Thirdly, breakdown of added organic materials may produce compounds toxic to pests and pathogens. Organic matter acts on weed control through competitive, nutritional and allelopathic effects as well as being a physical barrier to germination when surface applied. Complete elimination of weeds is not however desirable given their role in providing habitats for beneficial organisms, for example, in providing a bridge for mycorrhizal fungi between crops (Atkinson et al. 2002).

ORGANIC MATTER INPUTS

Organic matter from both on- and off-farm sources is potentially useful. Around 45% of household rubbish is made up of organic materials (http://www.wrap.org.uk/materials/). Along with animal manures and unused straw, these materials provide opportunities for managing weeds, pests and diseases while helping to meet recycling targets. Sewage sludge although not acceptable within organic production systems in the EU (Council Reg 2092/91) and resticted by supermarkets on food crops has the potential to control difficult soil borne pathogens e.g. *Phytophthora nicotianae* (Leoni & Ghini, 2005).

Here we define the nomenclature used in the remainder of the paper.

- **Cover crops** are grown to provide soil cover to prevent erosion by wind and water. When they are planted specifically to prevent nutrient leaching they are often called catch crops.

- **Green manures** are field or forage crops, often leguminous, incorporated into the soil while green to improve soil structure and organic matter content

- **Manure** is defined as animal excrement which may contain large amounts of bedding. Manure can be used fresh or following stacking, storeing or composting. Composting refers to the process of controlled biological decomposition of biodegradeable materials under managed conditions that are predominantly aerobic and producing a **compost** that is sanitary, uniform and stable (see Litterick *et al.* 2004 for further information). Compost can be produced from organic materials other than livestock excrement, commonly green and food wastes. Composting can not only kill pathogens but can also reduce the numbers of viable weed seeds.

- The term "**compost tea**" is used here to describe the product of recirculating water through a porous bag or box of compost suspended over or within a tank with the intention of maintaining aerobic conditions. Aerated compost tea (ACT) is used here to refer to any method in which the water extract is actively aerated during the fermentation process and non-aerated compost tea (NCT) refers to methods where the water extract is not aerated or receives minimal aeration during fermentation apart from during the initial mixing. **Compost extracts** are filtered extracts of compost which have not been left to stand or brew for any length of time.

USING ORGANIC MATTER TO MANAGE WEEDS, PESTS AND DISEASES

Uncomposted plant residues

It is well known that crop residues can suppress populations of plant parasitic nematodes or reduce infection when applied to soil. This has been applied extensively in developing countries (D'Addabbo, 1995) but increasingly in temperate commercial cropping systems e.g. marigold

(*Tagetes* spp.) and sudan-grass to reduce populations of root-knot nematode. Abami & Widmer (2000) report that the best control is achieved when nematode-controlling crops are integrated into the crop rotation and ploughed in *in-situ*. Incorporated organic materials have also been shown to stimulate specific nematode-trapping fungi e.g. Jaffee *et al.* (1998) although the reverse has also been shown Jaffee *et al.* (1994). Cover crops and green manures have also been shown to suppress plant diseases, for example, hairy vetch helped to control *Alternaria solani* and *Septoria lycopersicae* in outdoor tomatoes (Mills *et al.* 2002). However, results can be variable and dependent on both cover crop and climate and edaphic conditions (Abami & Widmer, 2000). Roots of some plants exude chemicals that deter potential competitors from growing in their vicinity through inhibition of germination and/or growth and the effects can continue after the incorporation of the inhibitive plant. This effect, known as allelopathy, is exhibited by both crop plants and weed species (Weston, 1996). Incorporated fresh plant residues can however adversely affect germination of both following crops and weeds within the crop (Conklin *et al.* 2002) again depending on both management and environmental factors. As demonstrated by Koike et al. (1996) it is clearly important to choose cover/catch crops which do not provide alternate hosts for diseases of the following cash crop.

The *Brassicaceae* contain high levels of glucosinolates in their vegetative and reproductive organs which are know to be active against fungi, nematodes and weeds. The quality and quantity of glucosinalates varies with genus, species and variety (Rosa *et al.* 1997). Used as green manure crops, plants such as *Brassica juncea* and *Eruca sativa* have been shown to have potential to act as soil sterilants potentially replacing methyl bromide (Lazzeri *et al.* 2004).

The benefits of both incorporated and surface mulched cover crops for weed control have been demonstrated by Ngouajio *et al.* (2003). A wide range of other uncomposted organic materials have been used successfully as mulches for weed control, these include woodchip waste (Smith *et al.* 2000) and municipal solid waste compost (Roe *et al.* 1993). However, these are likely to be more effective for annual than perennial weeds (Bond & Grundy, 2001).

Manures

Despite the vast literature on the effects of manures on soil fertility and crop productivity there is relatively little information available on the effects of manures on weeds, pest and diseases. Manures have been shown to reduce nematode numbers (e.g. Gonzalez & Canto-Sanenz, 1993) possibly through improving soil physical and chemical properties (Marull *et al.* 1997). There is also limited evidence that manures can enhance the suppression of soil-borne diseases e.g. *Phytophthora cinnamomi* in lupins (Aryantha *et al.* 2000).

The effects of manures on pest and disease incidence and severity are less reliable than that of composts and there is evidence in the literature which suggests that manures can also worsen rather than improve the problem. It is difficult to generalise on the effects of manure use on weed populations. In some cases manures can be a significant source of viable weed seeds, as many weed seeds are able to survive through the rumen and manure storage and handling process (e.g. Mt Pleasant & Schlater, 1994). There is also likely to be a nutritional effect of manure application, this may favour late-season weed emergence following mineralisation of nitrogen from organic forms.

Composts

Much of the literature on the effects of composts on plant pests focuses on the suppression and control of plant parasitic nematodes, little of it in temperate agriculture (Litterick *et al.* 2004).

Municipal compost (Marull *et al.* 1997), yard waste (McSorley & Gallagher, 1995) and brewery waste (Chen *et al.* 2000) are examples of diverse organic materials reported to have positive effects on nematode problems. The effects of composts on disease suppression are most reliable where composts are used within container production systems (Hoitink *et al.* 1997), although there are increasing examples in field grown crops e.g. composted cattle manure on black scurf in potatoes (Tsror (lakhim) *et al.* 2001). Disease suppression occurs as a result of both indirect effects through improved soil health and crop nutrition and direct effects of plant pathogens and beneficial microorganisms. The majority of proven results are in horticultural and ornamental crops (summarised in Litterick *et al.* 2004) perhaps reflecting the expense of the composting process and thus its use on high value crops. There is however potential for disease control in root crops, e.g control of stem rot in sugar beet and black scurf in potato (Postma *et al.* 2003). A recent important development in UK horticulture is the potential use of composted onion waste to reduce the survival of sclerotia of the allium white rot pathogen (*Sclerotium cepivorum*) (Anon, 2003). In addition to the control of soil borne diseases, composts applied to field soils can reduce foliar diseases, for example, Weltzein (1990) demonstrated a reduction in *Erysiphe graminis* on wheat and barley following the application of horse manure and straw bedding. Composts have the advantage over manures of generally being much more uniform and therefore easier to handle and apply evenly.

When applied in sufficient quantity, surface applied compost can also provide an effective mulch for weed control as illustrated by Brown & Tworski (2004) using composted poultry manure in apple orchards. Composted manure is less likely to introduce viable weed seeds than fresh or stacked manures or green wastes. The high temperatures experienced during the composting process has been shown to kill many seeds (Grundy *et al.* 1998; Tompkins *et al.* 1998)

Compost tea

The application of compost extracts or teas has been shown to reduce the incidence and severity of foliar disease in glasshouse and field grown edible and ornamental crops. (Scheuerell & Mahaffee, 2002b; Weltzein, 1991; Weltzein & Ketterer, 1986). Compost extracts and teas are liquid extracts of compost. They contain a wide range of different types of microorganisms and also soluble nutrients extracted from compost.

Examples of diseases controlled in this way include powdery and downy mildews, fungal and bacterial blights and leaf spots, apple scab and grey mould (Litterick *et al.*, 2004; Scheuerell & Mahaffee, 2002a). Crops which have been studied in this context include mainly edible cereal, vegetable and fruit crops such as maize, barley, sugar beet, potato, bean, lettuce, pepper, tomato, grape, apple and strawberry (Litterick *et al.*, 2004). The input materials used to prepare composts from which the studied teas were prepared, varied, although most included some form of animal manure. The compost production methods used, the type of extract/tea used and the experimental conditions varied greatly and it was difficult to compare results of work carried out on single diseases by different workers. It is important to emphasise that control has not been achieved with all pathogens in all tests. Efficacy of compost teas varies considerably depending on the crop, the input materials used to make the compost, the compost production system, the extract/tea preparation method and the experimental system used to test the extract/tea. Work is currently being funded by the UK Horticultural Development Council to determine the effects of compost teas on hardy ornamental nursery stock.

Integrated non-chemical crop protection strategies

The methods described in this paper are best used in combination with other cultural practices for weed, pest and diseases control. Carefully planned diverse rotations are clearly central to sustainable agriculture and the integrative prevention of weed, pest and disease problems (e.g. Dillard *et al.* 2004). The impact on weed control of including grass within the rotation is well established (e.g. Tomasoni *et al.* 2003). The selection of varieties with a high degree of resistance to locally significant pests and pathogens is an important consideration. Both seed rate and cultivar choice can have important effects on weed management e.g. Mennan & Zandstra (2005). Wheat varieties with planophile leaf structures, rather than erectophile leaves, have been shown to increase ground shading during growth and can significantly reduce weed biomass and seed yield (Eisele & Köpke, 1997). Variety and or cultivar mixtures with occupy slightly different ecological niches can also significantly reduce disease levels and weed growth in cereals (Wolfe, 2002). Intercropping with two or more crop types can also reduce both foliar disease and pest attack e.g. Theunissen (1997). Mechanical forms of weed control also increasingly offer viable non-chemical methods. Recent developments such as laser guided inter-row hoes are an important development for horticultural crops.

FUTURE PROSPECTS

There are clearly many opportunities for using organic materials to manage weeds, pest and diseases in both organic and conventional farming systems. Pressure to recycle waste materials from on and off-farm sources is likely to increase but widespread use of organic materials for weed, pest and disease control will depend on economics. Use of on-farm wastes may provide the cost-effective solutions as transport costs will be minimal. Using organic waste materials for this purpose may also be more financially viable in high-value horticultural crops. Ensuring that manures, composts and compost teas/extracts meet public health standards for use on crops for direct human consumption is also an important issue.

In terms of widespread uptake reliability is also clearly a key issue and the real solutions may require creative and innovative approaches, particularly those that combine technologies as demonstrated by Héraux *et al.* (2005) for weed management in field vegetables.

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Control of wheat streak mosaic virus in wheat via a gene from perennial intermediate wheat-grass

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ABSTRACT

Thinopyrum intermedium (= *Agropyron intermedium* = *Elytrigia intermedium*), a perennial relative of cultivated wheat (*Triticum aestivum*) carries genes conditioning resistance to a number of wheat pests and pathogens, including barley yellow dwarf virus, *Cephalosporium* stripe and wheat streak mosaic virus (WSMV). WSMV is one of the most important diseases affecting winter wheat in the western Great Plains of North America, and it also has been reported from most wheat growing regions of the world. Until recently no highly effective WSMV resistance has been available in the primary gene pool of wheat. A resistance gene known as *Wsm1*, has, however, been transferred to wheat from *T. intermedium*. Adapted wheat lines carrying *Wsm1* were used to measure its effectiveness and determine the presence of any negative epistatic effects. Sister-lines from six genetic populations were analyzed to compare agronomic and quality characteristics of resistant and susceptible lines in the absence of the virus, and under a naturally occurring viral infection. Over all populations, there was no significant difference in yield, but resistant lines had significantly higher grain volume weight in the uninfected locations. Within each population, significant differences in yield were observed only in one population. At the infected location, resistant lines were significantly higher in yield in five of six populations. Selections from the experimental materials, with grain yields competitive to currently grown cultivars, have been identified and advanced to regional and state-wide performance trials.

INTRODUCTION

Winter wheat (*Triticum aestivum*) production in the Great Plains of North America has long been negatively impacted by Wheat Streak Mosaic Virus (WSMV). WSMV is spread by means of the Wheat Curl Mite (*Aceria tosichella*), the only known natural vector of WSMV. Late season hail storms often result in stands of volunteer wheat from sprouted grain. If left unchecked, these so-called "green-bridges" serve as reservoirs from which WCM delivers WSMV to fall-sown wheat. Spring infection may cause some damage to wheat, but fall infections generally are more severe. True resistance to WSMV has not been discovered within the primary gene pool of wheat.

Resistance to WSMV does exist in some wild and semi-wild wheat relatives. A resistance gene (*Wsm1*) has been identified and transferred from *Thinopyrum intermedium* to wheat via wide hybridization and chromosome engineering (Seiffers *et al*., 1995; Friebe *et al*., 1996). Subsequent breeding has led to the development of adapted wheat lines carrying *Wsm1*.

Previous research on the agronomic and quality effects of lines carrying *Wsm1* has been restricted to spring wheats (Baley *et al*. 2001; Sharp *et al*. 2002). Baley *et al*. (2001) compared the agronomic performance of resistant to susceptible lines of spring wheat populations under both inoculated and non-inoculated conditions, and found that *Wsm1* added a benefit in the presence of virus and had no detrimental effects on end use quality or other agronomic traits. Sharp *et al*. (2002) compared classical and transgenic spring wheat cultivars resistant to mechanical inoculation of WSMV and found that although *Wsm1* provides the best source of resistance to WSMV, they found significant yield losses in absence of the virus, perhaps as a consequence of negative epistatic effects of *Wsm1* or closely linked genes.

The present study was designed to investigate the agronomic and quality effects of fall-sown winter wheats carrying *Wsm1*. The objectives were to determine the effects on yield and quality across diverse genetic backgrounds, and to identify high yielding resistant lines for future testing and cultivar deployment.

MATERIALS AND METHODS

Materials used in the study were derived from six breeding populations (Table 1) produced via matings with the Kansas breeding lines KS91HW174 and KS91HW184, each known to carry *Wsm1*. Heads (ears) were selected from either F5 (populations 1-3) or F3 (populations 4-6) generations. Seed from heads were split and planted in paired 1 m rows at Lincoln, Nebraska (NE) in September 1999. Susceptible ('Tomahawk'), and resistant (KS95H102) controls, were distributed every fifth and twelfth rows, respectively, among the paired rows. One row of each pair was mechanically inoculated with WSMV using a siphon-type Speedaire spray gun. The inoculum was isolated from 'Arapahoe' seedlings infected with WSMV Sidney 81 strain.

Table 1. Pedigrees of populations segregating for *Wsm-1*.

Population	Pedigrees
Population 1	CO850034//T-57/5*TAM107/3/(KS91H174/RBL//KS91HW29/3/Vista)
Population 2	Yuma//T-57/3/Lamar/4/4*Yuma/5/(KS91H184/Arlin 'S'//KS91HW29/3/NE89526)
Population 3	Yuma//T-57/3/CO850034/4/4*Yuma/5/(KS91H184/Arlin 'S'//KS91HW29/3/NE89526)
Population 4	M08/Redland//KS91H184/3*RioBlanco
Population 5	M08/NE94406//KS91H184/3*RioBlanco
Population 6	M08/Redland//KS91H184/3*RioBlanco

In the spring of 2000 lines were scored as resistant or susceptible based on visual symptoms (yellow-green mottling of leaves and stunting). In fall of 2001, lines were seeded at Hays, Kansas (KS) to verify resistant/susceptible scorings. Lines, along with resistant and susceptible checks were seeded in unreplicated 1m rows. Plants were infected with naturally occurring WSMV by native WCM reared on early-planted wheat. In the spring of 2002, the lines were rated as resistant or susceptible. During the conduct of the subsequent replicated field experiments, a naturally occurring infestation with WSMV was encountered at Sidney, NE. Lines were also rated as resistant and susceptible at this location.

For each of the six populations, no less than five and no more than seven entries each of resistant and susceptible lines were chosen at random for analyses. Resistant and susceptible check varieties were planted at random among the entries at six Nebraska locations. The locations were Grant, Lincoln, McCook, Mead, North Platte and Sidney. The Sidney location, due to the natural infection of WSMV, was analyzed as a separate experiment. The checks consisted of three susceptible cultivars; Millennium, Tomahawk and Wesley, and three experimental lines carrying *Wsm1*: KS96HW10-1, KS96HW10-3 and KS95H102. Analysis of variance and paired t-tests were used to test for differences among checks. Mean squares from the analysis of check lines were used to compute statistical contrasts between resistant and susceptible lines. Contrasts were computed both overall, and within populations. Lines were considered resistant only if consistently scored resistant at Lincoln, Hays and Sidney.

RESULTS

Across all populations, no significant differences were observed in mean grain yield of resistant and susceptible lines (Table 2). Resistant lines, however, demonstrated significantly higher test (grain volume) weights. Within populations, susceptible lines demonstrated significantly higher grain yields only in population 1. Significantly higher test weights were observed in resistant lines, even in the absence of virus, in four of the six populations.

Table 2. Mean grain yields and test weights, WSMV resistant vs susceptible lines, overall, and by population from five virus-free Nebraska locations in 2002.

			Yield (kg/ha)		Test wt
Popn	Class[a]	No.[b]	Means	Maximum	(kg/hl)
Overall	R	36	2878.7	3484.6	76.6*
	S	34	3101.5	3965.1	75.5
1	R	7	2423.6	2568.3	77.4*
	S	6	2995.6*	3156.4	75.9
2	R	6	3043.5	3163.4	77.3*
	S	6	3243.3	3660.1	76.2
3	R	6	3252.7	3484.6	73.5
	S	5	3512.2	3965.1	72.9
4	R	5	2818.7	3138.6	75.8
	S	6	3004.4	3231.0	75.9
5	R	6	2881.2	3329.2	77.5*
	S	6	2923.5	3335.6	76.3
6	R	6	2980.7	3254.9	77.6*
	S	5	2977.7	3312.4	75.6

[a] Class: R = lines with *Wsm1*; S = WSMV susceptible lines

[b] No. = number of lines;

* Designates significance at $P = 0.05$

Under a severe natural WSMV infection observed at Sidney, Nebraska, the advantages of *Wsm1* clearly were observed (Table 3). Significantly higher grain yields were observed both across, and within five of the six tested populations. Grain yields at this location also were diminished due to water stress. Nonetheless, grain yields of resistant lines were, on average, 37% higher. Deployment of cultivars carrying *Wsm1* could markedly increase financial returns for wheat producers in areas prone to WSMV infections.

Table 3. Means grain yield and test weights of resistant and susceptible lines at Sidney, NE, under severe WSMV infection.

Popn[a]	Class[b]	No.[c]	Grain yield (kg/ha)	Test wt (kg/hl)
Overall	R	36	1797.4*	76.3*
	S	34	1311.1	70.4
1	R	7	1963.2*	77.2*
	S	6	1322.9	71.3
2	R	6	1733.1	77.7*
	S	6	1743.5	72.0
3	R	6	2123.4*	72.0*
	S	5	1878.6	65.3
4	R	5	1699.4*	77.4*
	S	6	1064.0	71.1
5	R	6	1682.7*	77.3*
	S	6	1036.8	73.0
6	R	6	1538.6*	76.5*
	S	5	836.6	68.6

[a] Popn = population

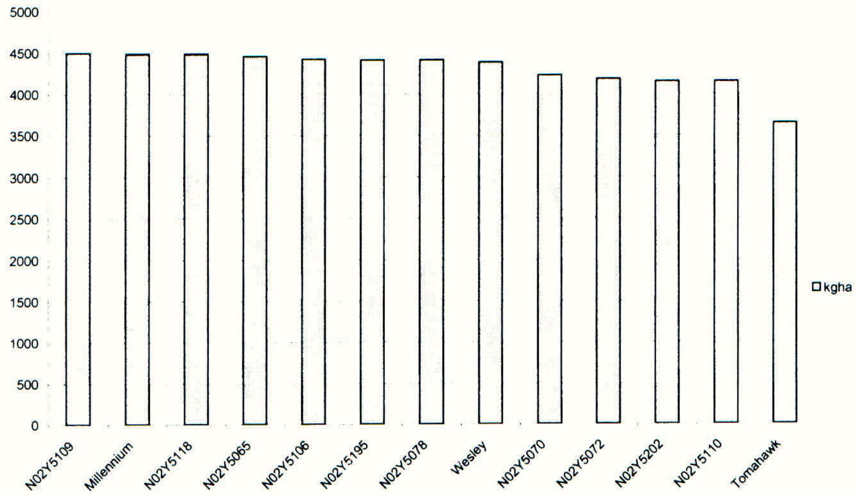
[b] Class = Resistant and susceptible

[c] No. = number of lines

* Values are significant at $P = 0.05$

Hard winter wheat cultivars must possess adequate bread making quality attributes for successful registration and release to producers. Quality parameters were assessed using composite samples from the five uninfected locations. Over all populations, susceptible lines demonstrated significantly higher flour protein content, and significantly larger loaf volumes (Table 4). Similarly, in three of the six populations, susceptible lines produced significantly larger loaves. In a fourth population, loaf volumes were significantly larger in the resistant lines. Quality assays demonstrate a potential negative effect of *Wsm1*; however, the effect is not universal, and evidently may be ameliorated via use of proper genetic backgrounds.

Several *Wsm-1* lines were deemed to possess agronomic and quality traits acceptable for hard winter wheat cultivars, and were advanced to a second year of testing in 2003. In the absence of WSMV, mean grain yields of several of these lines (Figure 1) were not significantly different from the susceptible cultivars Millennium and Wesley, the two dominant Nebraska cultivars as of this writing. The top four resistant lines have been advanced to USDA regional nursery trials, and Nebraska State-wide variety trials. Decisions on cultivar release will be made in 2006.



l.s.d. = 669 kg/ha

Figure 1. Mean grain yield (kg/ha) of WSMV resistant lines from four 2003 locations, relative to susceptible check cultivars Millennium, Wesley & Tomahawk.

Table 4. Means flour quality parameters for WSMV resistant and susceptible lines. Composite samples from five uninfected locations were tested.

Popn	Class[a]	No.[b]	FP (14% mb)	Abs (%)	BMT (min)	LV (ml)
Overall	R	36	12.5	61.7*	4.6	904.4
	S	34	12.4	61.1	5.1	934.0*
1	R	7	12.5	61.3	5.0	927.9
	S	6	13.2*	60.2	6.1	1048.3*
2	R	6	12.2	62.5	5.1	953.3*
	S	6	11.9	61.7	4.4	829.2
3	R	6	12.7*	60.0	5.5	967.5
	S	5	12.1	60.2	6.4	936.0
4	R	5	12.6	61.6	3.9	832.0
	S	6	12.5	61.0	4.6	920.8*
5	R	6	12.7	62.5	4.0	873.3
	S	6	12.9	62.0	4.3	909.2*
6	R	6	12.5	62.0	4.1	856.7
	S	5	12.1	61.2	5.1	966.0*

[a]Class: R = resistant; S = susceptible

[b]No. = number of lines, FP = flour protein content, Abs = water absorption, BMT = bake mix time, LV = loaf volume

*Indicates a significant difference at $P = 0.05$

DISCUSSION

The introgression of *Wsm1* into wheat began more than 30 years ago, with the release of CI 15092, a South Dakota wheat line carrying a substituted chromosome from *Thinopyrum intermedium* (Wells *et al.*, 1973). This was followed by the release of several resistant lines carrying translocated chromosomes (Wells *et al.*, 1982). Many of these early resistant lines suffered from poor agronomic and quality attributes (Seiffers *et al.*, 1995). Repeated cycles of crossing have been necessary to develop WSMV resistant lines with agronomic and quality properties suitable for cultivar registration. However, persistence pays dividends, and the first U.S. cultivars with true WSMV resistance may be released within 2006. With continued reluctance to deploy transgenic forms of resistance, the use of perennial relatives of wheat, many of which carry resistance to a number of wheat pests and pathogens, merits more attention. The length of time necessary for successful introgression and deployment in acceptable genetic backgrounds necessitates increased research efforts by current scientists, so that the next generation of wheat investigators may profit from their endeavors.

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An investigation into the design and performance of a novel mechanical system for inter and intra-row weed control

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ABSTRACT

An investigation is presented into the design and performance of a novel mechanical system for inter and intra-row weed control. A kinematic analysis was performed to check the proposed disc geometry. Also a mathematical model developed that can predict the required cut-out sector depending on row spacing, plant spacing and crops undisturbed area. After the kinematic and mathematical study a prototype was designed and built in order to physically test in soil bin laboratory experiments different blade geometries aiming to optimize and develop a new tool for precision inter and intra-row weed control.

INTRODUCTION

There has been an interest in mechanical intra-row weed control methods in recent years due to the public debate about environmental degradation and the growing request for organically grown food (Fogelberg & Kritz, 1999; Pullen & Cowell, 1997). Inter-row weeds (Figure 1) are easier to control because of the easy access of simple cultivation implements between the crop rows and because of this most of the research in mechanical weed control and technical developments have been focused on the elimination of the inter-row weeds. Intra-row weeds (Figure 1) are more difficult to control as they can be located both close to the crop and there is a danger of damaging the crop when attempting to kill the weeds between successive plants.

There are currently no commercial techniques available to viably control intra-row weeds and there had been no significant advances in inter-row cultivation apart from the introduction of guidance systems to improve their overall lateral positioning accuracy and the use of variable wing sweep geometries which aims to control intra-row weeds (Home, 2003).

MATERIALS AND METHODS

Aiming at treating at the same time inter and intra-row weeds (Figure 1), a blade with new geometry was designed after technical review of the current weed control mechanisms (Figure 2). After the technical analysis of the weeding mechanisms, an engineering design software was used to make the initial geometry of the blade (Autodesk Inventor Professional, version 9). Initially the inter and intra-row spacing of vegetables was taken into account when defining the geometric characteristics for the discs. The spacing that was used was 300 mm inter-row and 300 mm intra-row. Various disc geometries with different cut-outs were designed from 165 mm to 200 mm. diameter.

After finalising the initial design a kinematic analysis performed with Autodesk Inventor® Professional, version 9 to cross check if the proposed geometry is able to treat at the same time weeds in and between the crop rows, without damaging the crop.

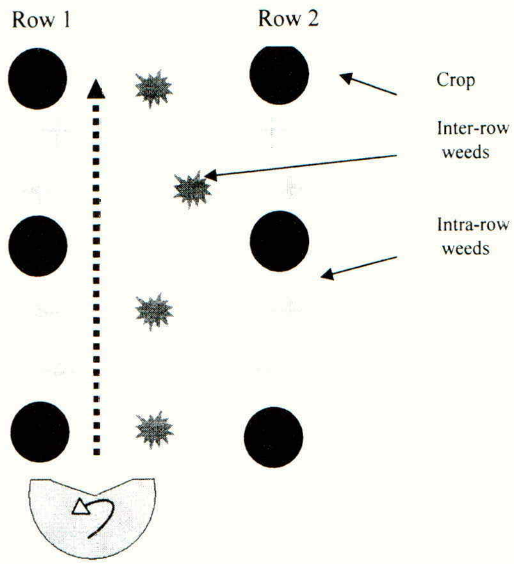

Figure 1. Representation of inter and intra-row weeds, with the proposed disc geometry

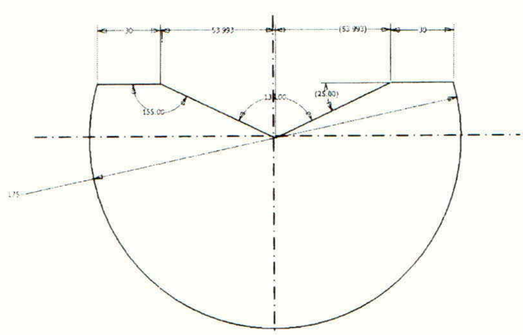

Figure 2. Proposed disc geometry

In parallel a mathematical model was developed (O'Dogherty *et al.*) that can predict the geometry of the disc's cut-out required depending on in row spacing, plant spacing and the crops undisturbed area. After the kinematic and mathematical study a prototype was designed and built (Figure 3) in order to physically test different blade geometries aiming to optimize and develop a new tool. During each test the working speed and the rotational speed of the disc was monitored by proximity sensors.

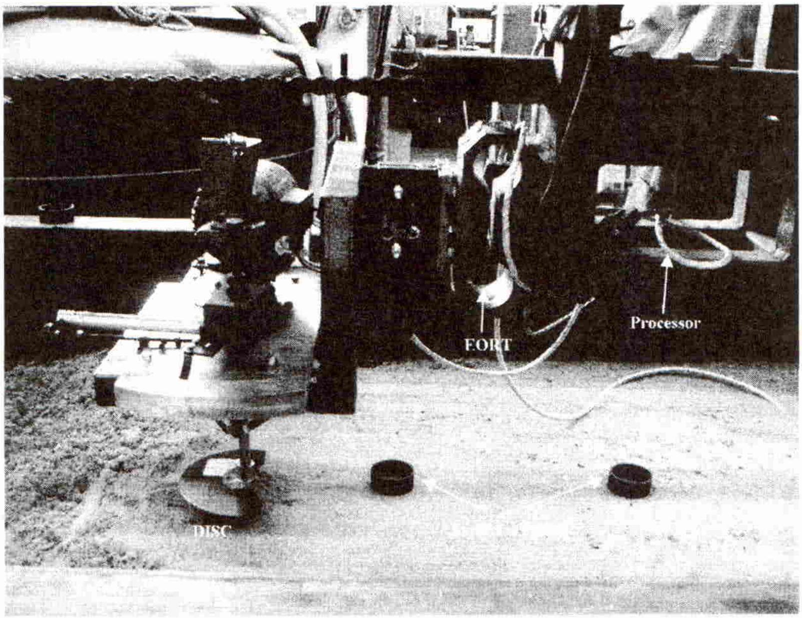

Figure 3. Prototype rig used to study the inter and intra-row weed control mechanism

The soil bin laboratory pilot experiments used an octagonal ring transducer (EORT) to monitor the forces acting on our implement, the horizontal (F_x), the vertical force (F_z) and the moment (M_y) in the plane of these two forces. The EORT is a machined steel block that has attached strain gauge bridges on it. During each run the strain gauge output voltages were relayed and recorded to a portable computer for further analysis. Further details on EORT design and operation are reported by Godwin (1975).

RESULTS

The discs characteristics that have been used in the pilot study are listed in the following table.

Table 1. Disc characteristics used in the pilot study

Characteristics	DISC 1	DISC 2	DISC 3
Diameter (mm)	175	175	175
Cut-out angle (deg)	120	120	130
Cut-out sectors (mm)	30	20	30
Thickness (mm)	3	3	3

The kinematic study performed for a plant spacing of 300 mm and the plants undisturbed diameter was 80 mm. A kinematic analysis for disc 3 can be seen in Figure 4. The disc centre from the plant centre point was varied from 50 to 70 mm for all the discs

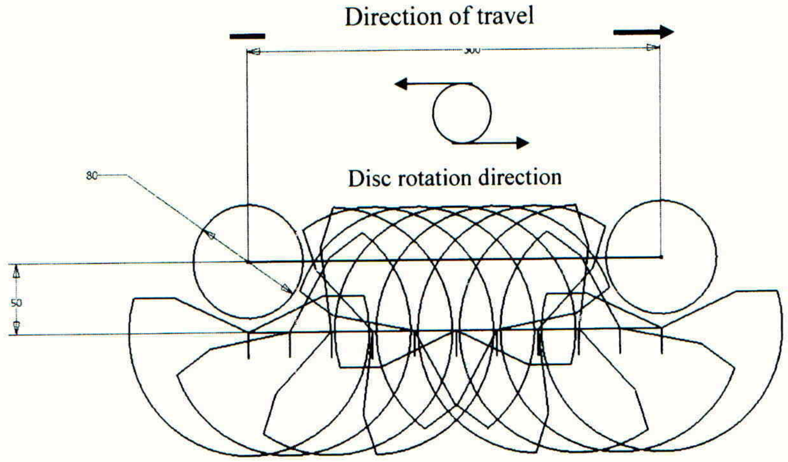

Figure 4. Kinematic analysis for disc 3 (diameter 175 mm; cut-out angle 130 deg; distance from centre of the disc to centre of the plant 50 mm).

The results from the mathematical model confirm the kinematic analysis. Figure 5 shows results from the mathematical model which relates the distance of points on the cut-out angle from the circumference of the undisturbed area with the distance the disc moves parallel to the row.

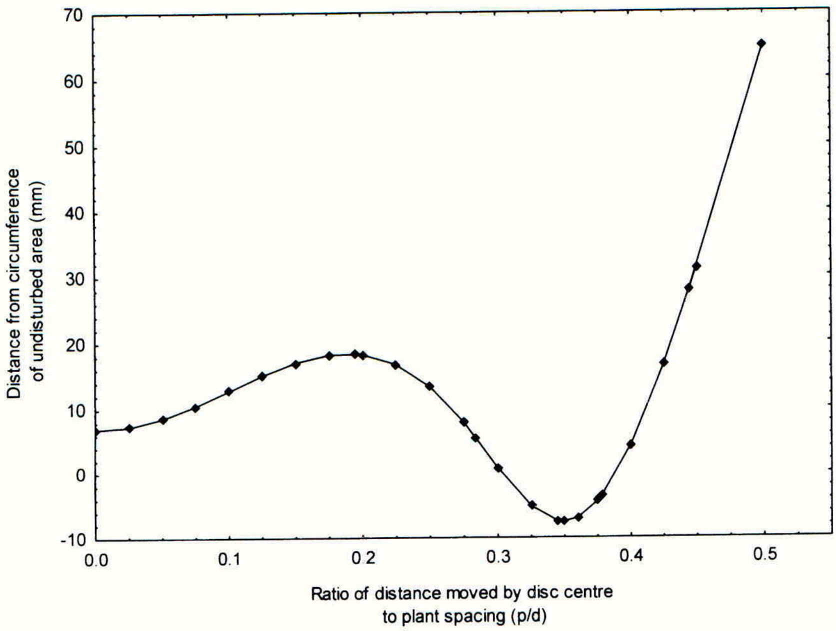

Figure 5. Initial results from the mathematical model (O'Dogherty *et al.*)

These apply to a 175 mm diameter disc, with a 140° cut-out angle, with its centre at 50 mm from the plant row. The plant spacing was 300 mm and only half of the rotational cycle was required because the motion of disc in relation to the undisturbed cycle was symmetrical. Negative values on the graph indicate where the point of the end of the cut-out edge at the disc circumference had entered the undisturbed area cycle which has a diameter of 80 mm. The maximum distance of movement within the undisturbed area was 7.5 mm. The final disc design which had cut-out sectors at the ends of the cut-out angle (Figure 6) overcame the problem of the small penetration at the undisturbed area.

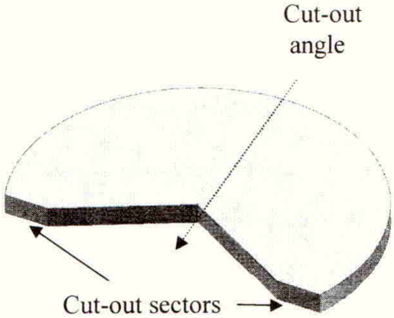

Figure 6. Disc design that used for the kinematic and soil bin laboratory study

The initial test at the soil bin laboratory facility of Cranfield University, Silsoe, showed the trajectory the disc followed without damaging the artificial plants (Figure 7). Also the draught and vertical forces and the moment measured with the octagonal ring transducer (EORT).

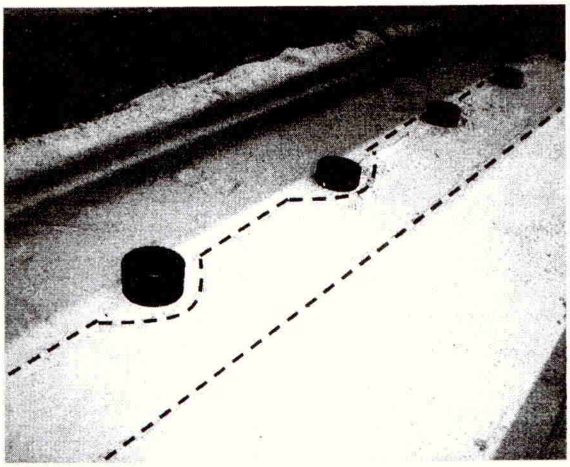

Figure 7. The trajectory the disc followed and the soil disturbance that caused working 5 mm below soil surface. The dashed line indicates the disturbed area of soil after the disc had been through

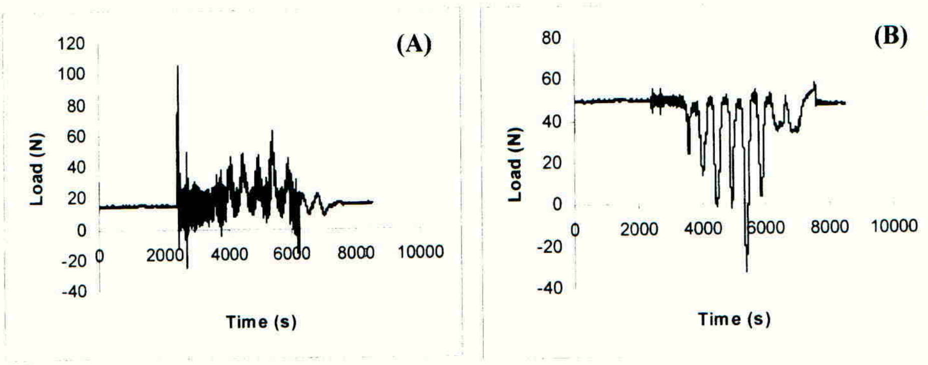

Figure 8. Results from the octagonal ring transducer. (A) Draught force (B) Vertical force shows the relationship between the effect of implement geometry on acting forces

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Weed management in organic farming systems: a learning approach

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ABSTRACT

Organic farming systems are diverse and are often adapted to exploit specific local environmental and socio-economic situations. Weed management in organic farming systems is primarily a practical activity and weeding operations are very dependant on crop, crop stage, soil conditions, and weather as well as the equipment or labour available to carry them out. All farmers carry out trials on weeding methods to establish 'what works' and, consequently, develop a significant amount of knowledge and experience about weeds and weeding in their specific circumstances. Researchers have access to a large amount of detailed knowledge about weeds including an extensive body of information on weed biology, competitive abilities, ecology and results from replicated weed control trials (mostly carried out on research stations). A considerable wealth of both information and experience relevant to organic weed management therefore exists. Weed management research in organic farming systems can be regarded as a process that helps researchers, advisors and farmers to evaluate this information jointly in order to develop suitable approaches to weed management. This is best done through a learning framework in which all participants are regarded as colleagues with different, but equally valid, perspectives and, above all, relies on effective communication between the various actors or stakeholders. The present paper describes some implications of this for research on weed management in organic farming systems.

INTRODUCTION

Weed management in organic farming systems has been reviewed in other papers (e.g. Parish 1990; Stopes and Millington 1991; Rasmussen and Ascard 1995; Bond and Lennartsson, 1999; Bond and Grundy, 2001). Broadly speaking, organic farmers take two principal approaches to weed management; they use cultural control measures with the objective of preventing weed build up by planning weed management measures into their rotations (e.g. cover crops or higher seed rates), and they apply direct measures (e.g. mechanical or thermal) which target specific problems or problematic weeds where necessary. It is generally accepted by researchers that weed management is the objective of weed control operations in organic farming systems rather than complete weed eradication (Stiefel and Popay, 1990). In effect, organic weed management can be seen as a question of balancing the detrimental effects of weeds (e.g. loss of crop quality or yield) with the beneficial aspects (e.g. biodiversity or pest control effects). However, it is not clear that all farmers share this view and in some cases farmers display strong feelings of antipathy to certain weeds (e.g. docks, ragwort) or feel a strong peer pressure to maintain clean fields (Turner *et al.*, 2004).

Weeds are still regarded by organic farmers, advisors, researchers, and even policy makers, as one of the major constraints to organic production and a perceived barrier to those thinking of converting to organic systems (Beveridge and Naylor 1999; Sumption *et al.*, 2004). This despite the apparently large quantity of formal research, both conventional and organic, that has been undertaken on the subject. Non-chemical weed control methods continue to be investigated in many research and development programmes that strive to develop new methods of overcoming weeds (Kropff and Walter, 2000). In parallel to this, an extensive body of informal, and largely unrecorded, knowledge based on farmer trialling and experience of weed management also exists. Some of this knowledge has been recently documented and catalogued on the internet as case studies aimed at helping farmers communicate information on organic weed management (HDRA Organic Weed Management, 2005a).

Perhaps because of this Bàrberi (2002), in an appraisal of recent organic weed management research, questioned whether the right issues have been addressed. In answer, we suggest that in order to arrive at practical and effective weeding strategies it is not sufficient simply to generate and transfer new technology or scientific knowledge. It is also necessary to improve communication between researchers, advisors and farmers by taking a partnership approach to research that places farmers concerns at the centre of the agenda and then tries to draw in other relevant knowledge and opinions. The present paper reports on the experiences of the DEFRA funded project entitled the 'Participatory investigation of the management of weeds in organic production systems' in rising to the challenge of helping organic farmers and growers to develop effective weed management strategies.

THE CONTEXT FOR ORGANIC WEED MANAGEMENT

When it comes to weeds and weed management a number of different stakeholders have been identified. In practical terms important actors are farmers or growers, advisors and, to some extent, researchers. It should however, be recognised that a range of other players also exist who can have a direct impact on weed management decisions. Some of the more important include DEFRA, who are responsible for implementing the policy framework and research agenda, and food multiples and processors who set both the quality criteria and prices for produce which, in turn, sets the economic context for weed management decisions. Organic certification bodies also have a role in setting 'organic standards' that directly affect weed management practices. Increasingly the general public or consumer groups are becoming more vocal about food issues, about access to rural areas and about what they expect to find in rural areas, including the presence of a diverse array of plants which may or may not be considered weeds.

It can be argued that farmer attitudes to weeds and weed management strategies are the outcome of an interaction between these stakeholders, the tensions they generate and a myriad of smaller ones that also arise from other sources within a particular social context. The various forces and actors are likely to be important at different levels in farmers' decision making processes and these have been summarised in the weed management project at three different system levels.

1. Field level; at the level of the field the most important effects are weed-crop-environment interactions (e.g. water, soil, temperature) and these will have the most bearing on the practical outcome of any weed management efforts. It is in this area that most traditional weed control research has been concentrated and has produced some technologically efficient means of direct weed control (especially herbicides which are however excluded from organic farming systems). It has also become widely accepted that many of these technologically efficient methods have also had adverse effects on the environment and farm system sustainability. It has also generally been overlooked that a great deal of farmer innovation, particularly in machinery design and adaptation, has also been concentrated at this level. Farmers continually trial a range of solutions to problems that they encounter on a day to day or season to season basis, innovations which they may or may not share with other farmers depending on the context.

2. Farm level; organic agriculture generally aims to establish the farm as a self-sustaining system. At this level crop rotation is an important weed management tool for organic farmers and they frequently adjust cropping patterns to manage weeds (e.g. by using cover crops or break crops and alternating crops with different sowing periods or tillage requirements among other measures). Whilst the farmer retains some control at this level other aspects of the farm such as the background flora or soil type that can have an effect on weed management might not be so readily altered. There has been a great deal of farmer innovation in designing organic rotations or cropping systems that aim to manage weeds, especially perennial weeds like docks and creeping thistles. From a more traditional research perspective although there have been studies on the long-term effects of rotations on weed flora they have been difficult to manage from an administrative or funding point of view and definitive conclusions are often not possible, though it is fair to point out that farmers also do not fully appreciate or understand the implications of long term management strategies.

3. Socio-economic level; farm systems are embedded in regional, national and (increasingly) global socio-economic systems. Many of the factors at this level (e.g. market prices, trade rules or national land use policies) are largely out of the immediate control of the farmer but can have a direct effect on farm practices and the viability of weed management methods. Many of these factors are arguably the most important when it comes to farm viability and are very influential in driving the types of innovation seen at the farm or field level. Ultimately it is the ability to market produce and make an economic return that determines the survival and sustainability of the farm system. Innovations in this area are generally in the marketing sphere (e.g. by direct marketing) and have not traditionally been taken directly into account in weed management research. However, farmers must ultimately have some idea on the effect weeding operations have on overall enterprise profitability and cutting weeding costs is often a powerful driver for innovation at the previous levels.

In summary, weed research has taken the form of field trials that concentrate on resolving relatively simple technical or biological factors that predominate on the first, or at most, second levels described above. Such research has been successful at delivering short term solutions to weed control. However, the shortcomings of this approach have become manifest in three different ways. Firstly, technical or biological factors can interact in varied and unexpected ways so that decision making can rapidly become very complex. Secondly, organic farmers also work in a complex socio-economic environment (i.e. on the third level above), which can often be more important than the technical one and which can change over time, often quite rapidly. Thirdly, it has long been recognised that chance events such as the weather are also immensely important in weed control and, in the face of this uncertainty a pragmatic and flexible approach is paramount.

Making decisions about weed management in organic farming systems is therefore a complex process in which information, and the analysis of that information, is likely to be a key requirement. Case histories of weed management on organic farms and results from farmer-researcher weed workshops support this view. It is clear that weed 'problems' are essentially systemic and cannot be 'solved' by simple cause and effect analyses (HDRA Organic Weed Management, 2005b). Weed problems have many causes and consequences and there are different solutions to many that will bring different benefits in different situations. The resolution of weed issues will often require a deep understanding of land history, timing and spatial context among other things, knowledge which farmers have of their own farm systems but which it is difficult for researchers to acquire. In such complex, and local, situations it is often not clear where generic 'scientific' research can help, as each farm system is in some senses unique. In consequence, farmers and growers carry out a large amount of 'practical experimentation' on their farms. This trialling includes observation, informal investigation and simple comparisons (HDRA Organic Weed Management, 2005c). Some of this trialling work builds on the results of formal research programmes but much does not, often arising from chance, observations or practical considerations.

LEARNING FOR ORGANIC WEED MANAGEMENT

Farmers and growers are uniquely placed to decide what the priorities for weed management are in their specific situation. Farmers are therefore constantly engaged in a programme of experiential and practical learning, which allows them to cope with different weed management situations from day to day and from season to season, and which builds their knowledge of weed management practice. The experience of the organic weed management project is that researchers and advisors are best used to support this on-farm practical research rather than to supplant it and, further, that the more traditional approach of formulating recommendations based on research results is also likely to be of limited relevance to farmers without further adaptive and situation specific trials. In a complex system only a learning approach to weed research and weed management is likely to be able to deliver the necessary flexibility to allow farmers to adapt to changing situations.

Within the project, the key to creating such an atmosphere has been in opening and maintaining channels of communication between the various actors, especially farmers, advisors and researchers. It has largely done this by attempting to create spaces, platforms or forums in which these actors can meet and exchange knowledge about weed management and can come to understand each others perspectives. Discussion and comments have been recorded and are amenable to analysis using well established social science methods but, more importantly, are also made publicly available for comment and development. Communication has involved the provision of detailed scientific information about weeds, arising from detailed literature reviews, to farmers and advisors. It has also involved the collection and collation of farmer and advisor experience and the matching of this to the collected scientific information as well as helping farmers and advisors to take a more systematic and 'scientific' approach to their observations and trials. The various approaches taken are described in more detail in the following section.

LEARNING APPROACHES

Over a number of years the project has developed an approach to information sharing and this is briefly reported below. The approach has as its basis the attitude that learning, adaptation and innovation are the keys to achieving any desired outcome. It should be emphasised that many of these approaches are not new but have themselves been adapted from those developed over many years in other situations, especially in community based social programmes (e.g. Flower *et al.*, 2000) and in developing world agriculture (e.g. Van Veldhuizen *et al.*, 1997).

The principle methods have focussed on:

1. Scientific/grey literature review(s); a major part of the project has been in reviewing the available knowledge and information on organic weed management. A key part of this process has been in consulting farmers and advisors as to how they would like to access this information. As a result of this an openly accessible website has been developed with a 'layered approach' to dissemination of information. Users can move from general information on specific weeds or management methods to progressively more detailed reviews of knowledge on individual weeds or weeding methods, ultimately leading to original references to scientific papers. Users can therefore access information at a level that suits their purposes. Some of this information is also been presented synthesised in different ways e.g. as weeding strategies for different crops.

In the weed management project farmers themselves have expressed a strong desire for receiving condensed but relevant information on weeds and weed management. This has been summarised as information on one or two sides of A4 paper that can 'be read over a cup of coffee'. Therefore much of the website material has been developed in a manner in which it can easily be modified for use in leaflets, popular press articles, and technical booklets. The spirit of the project has been to allow people to freely use the material as long as the source is acknowledged.

2. Case studies; the project has collected a large number of case studies on organic weed management practice across a range of farm types. These case studies provide a range of important stories about how organic farmers have learnt to manage and, in many cases, to live with weeds in their farm systems. They were collected using semi-structured interview techniques with farmers on their holdings and have been written up using a standard template structure. They are freely available through the project website and comprise a unique learning resource for farmers, advisors and researchers who can match the case studies to their own situations by using the background information provided with each. The project is following up the case study farms as their weed management strategies evolve in order to monitor and document how farmers develop their strategies with the longer term goal of better feeding into this process in the future.

3. Workshops and focus groups; rather than traditional seminar type meetings in which speakers are asked to deliver talks with limited time set aside for discussion this project has attempted to hold workshops focused on discussing, analysing and resolving situations with background talks on technical issues. From the outset, an initial round of stakeholder consultations was held which were condensed into the three major themes that have subsequently been developed by the project. These were management of docks and perennial

weeds, elaboration and understanding of systems approaches to weed management, and collation and dissemination of knowledge about weeds. Focus groups were also formed around these themes composed of farmers, advisors and researchers both to discuss the issues arising as part of the themes and in order to ensure that the project continued to address issues of relevance to these groups of stakeholders. Participation and learning as part of these groups has been high and they are all openly recorded on the project website. Apart from researcher organised workshops the project is currently advertising itself as a resource to farmer groups who wish to analyse and develop solutions to specific problems.

4. Farm walks and open days; experience during the project has shown that the best way of creating a learning atmosphere is open discussion during field walks or practical demonstrations. The project has concentrated on developing a programme of walks and open days with a mix of farmers, advisors and researchers. Discussion is facilitated and recorded for development and incorporation into the pool of knowledge on organic weed management that is being built up by the project. It has become increasingly clear during the course of the project that such events are best programmed through existing farmer groups and the project has widely advertised itself as a resource to these groups and the challenge has become to record all the information that is exchanged at such events.

5. Trials; the project has developed a programme of 'researcher led' and 'farmer led' field trials, in the former case by concentrating on the aspects of dock management and in the latter by offering a range of specific weed trials and simple observational trials (arising from topics identified at stakeholder meetings). Subjects have included seed rate in cereals, ballast rolling thistles and manual dock pulling. In conjunction with the trials researchers have also been supportive in helping to monitor the effect of weed management practices and in devising ways in which farmers can do some of their own assessments (e.g. by using their own qualitative indicators and scoring the results). It has also become clear that trials are probably best developed through existing groups and will require a great deal of researcher back-up, at least in the initial stages.

IMPLICATIONS FOR WEED RESEARCH PROJECTS

The experiences during this project imply that in order to be effective weed research projects need to build a different form of communication system between the principle actors, one that places the farmer at the centre of the decision making process. Such a research system will aim at knowledge development, combining farmer, advisor and researcher knowledge for more effective weed management options, rather than generating new 'scientific' knowledge as traditionally conceived. Central to this is sharing information between stakeholders on an equitable basis. One way of doing this is by providing freely accessible web-based weed management information in a form that allows all stakeholders to access and develop it. It is also important to provide the context in which this information can be developed, by holding events like farm walks and running workshops with farmer groups or on weed themes. These events are best organized through existing farmer groups or networks and should be held at times convenient to farmers (time of day and right time of year). The project has also developed case studies as a powerful way to convey information about weed management and has started to develop trials that will allow the groups to develop their own weed management strategies based on problem and solution analyses. Ultimately the project aims to foster closer links between farmers, advisors and researchers in defining weed research agendas, in designing knowledge/protocols for on-farm trials to support on going farmer research, and only in the final stages, define specific topics for basic or applied research in the traditional sense.

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