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THE IMPACT OF INTEGRATED FARMING SYSTEMS ON SPRAYING OPPORTUNITIES AND CONSEQUENT RISKS TO PRODUCTION AND THE ENVIRONMENT

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EXECUTIVE SUMMARY

1. The aim of this study was to determine whether there is any difference between the riskiness of Integrated Farming Systems (IFS) and conventional systems in terms of spring spraying opportunities and in effects on production and the environment.

2. Herbicides have been chosen as 'role model' agrochemicals because they are active against plant material and can be mobile in wind or water. This has implications for water quality and vegetation in non-crop environments. Two sets of limitations to pesticide (as defined by herbicides) application have been studied, those arising from features of the climate and those caused by soil conditions.

3. This study takes three approaches, the first looks at spraying opportunities and requirements at all IFS sites, the second seeks to apply the rotations to two different sized suitably equipped farms of 200 hectares and 350 hectares and thirdly it looks briefly at the risk implications of each situation. Contact herbicides were chosen as the most likely products to be used regularly, and one application during January to March on winter wheat and winter oilseed rape in all the rotations, was used as a model.

4. Where spraying opportunities are limited by the weather, there are two possible outcomes; operators push ahead and spray in unsuitable weather, or they delay treatment and spray later in sub-optimal conditions for control. The consequences for these courses of action are summarised. In both scenarios where sprays are used sub-optimally, it is implicit that some yield loss will occur.

5. A single spraying opportunity is defined as a continuous 5 hour period. This is taken as the minimum time period for which it is worthwhile carrying out a spraying operation. It is assumed that spray applications in the field trials took place during one or several of these periods, depending on the extent of the spraying needed.

6. The number of spraying opportunities depends on the climate, whereas the requirements for application depend on the rotation. If there is no requirement to spray, then there is no problem, but if there is a high requirement and insufficient opportunities, then there will be consequences for production and/or the environment.

7. There was seen to be little limitation to spraying opportunities from April onwards, so the study concentrated on the 'early spring' from January to March.

8. Although meteorological information suggests that it is possible to carry out a spraying operation, there may be soil limitations which may prevent efficient machinery operation, or produce excessive crop damage.

9. After looking at the requirement for spraying opportunities of each site and farm size, the extent to which the spraying expectations were met was determined for different sized farms under IFS or conventional systems.

10. Although the model used the average number of opportunities during the early spring, there was considerable variation depending on the site, with increasing opportunities from north to south. Years in which there was insufficient time were referred to as 'bad years'. The occurrence of 'bad years' shows that where spraying opportunities are limiting, an operation may have been started and left incomplete due to wind or rain when there may have been an environmental risk.

11. Because of the small differences and the variability in the 'real life' system comparisons, better comparative data on machinery performance are available from the modelled output. The time required to cover the ground was the same on both farm sizes since the advantage of the larger equipment matched the increased acreage.

12. The results from the model suggest that the IFS has fewer bad years with insufficient spraying time, in spite of the fact that it used a larger number of contact sprays than the conventional system overall. This makes integrated systems less risky during the January - March period.

13. In the field trials the more stringent requirements for applying contact herbicides put a greater load on the IFS spraying logistics than did the conventional regimes, but at some sites IFS treatments 'evolved' during the trial to reduce this burden.

14. Even with a satisfactory number of spraying opportunities, there are other factors occurring before and after the immediate spraying interval that will affect product efficacy and possibly the need for further treatment.

15. Where effective spray planning and integrated farming methods avoid reduced efficacy they will make a significant contribution towards reducing the spread of herbicide resistance. However, failure to apply herbicides in the limited windows of opportunity between January and March does not represent a critical failure risk for herbicide programmes in either conventional or Integrated farming operations.

16. There is a greater degree of correlation between the number of spraying opportunities forecast by the model and the number of applications on the Integrated systems, than with applications on conventional systems. The greater use of autumn sown crops and autumn applied residual herbicides may account for the poor correlation in conventional systems.

17. Looking at the results of the IFS project, it is clear that there was often little difference between conventional v IFS approaches. It has been acknowledged elsewhere that IFS was not a fixed system and much of it had to be learnt as the project developed. The relatively small differences in herbicide application programmes in this study exemplify some of these problems.

1. INTRODUCTION

Background to IFS

Pressures on UK farmers to reduce inputs of agrochemicals have generally been less than in some European countries, where particular environmental problems associated with intensive pesticide use and nutrient leaching have had to be addressed. However, in the last decade, declining farm incomes, the reform of the CAP, the influence of GATT and the threat and reality of reduced grain prices have increased the need for farmers to reduce costs per unit of output to maintain profitability. There have also been strong pressure from the EU, the national government and consumers for farmers to become more concerned over environmental protection, food traceability, quality and safety.

Farmers have responded to these pressures in different ways. A small percentage have adopted an organic system of production and some farmers have continued with high input intensive farming methods to remain economically viable. However, many farmers have moved away from using high rates of inorganic fertilisers and from using prophylactic and insurance pesticides at full recommended rates, effectively moving towards an integrated system, as a means of coping with these pressures. Although reduced fertiliser and pesticide use will save costs, yields and profitability will be maintained only if husbandry practices are also modified to help limit leaching risk, pest, disease and weed problems, to develop a truely integrated system on the whole farm.

Definitions

The concept of Integrated Farming Systems (IFS) or Integrated Crop Management (ICM) has many definitions, some of the main ones are listed below:-

UK - Sustainable Development White Paper

To provide an adequate supply of good quality food and other products in an efficient manner. To minimise consumption of non-renewable and other resources, including by recycling. To safeguard the quality of soil, water and the air, and to preserve where feasible and enhance biodiversity in the importance of the landscape.

UK - British Agrochemical Association in conjunction with the ATB, LEAF and Sainsburys.

ICM is a method of farming that balances the requirements of running a profitable business with responsibility and sensitivity to the environment. It includes practices that avoid waste, enhance energy efficiency and minimise pollution. ICM combines the best of modern technology with some basic principles of good farming practice and is a whole farm, long term strategy.

UK - Integrated Arable Crop Production Alliance

A whole farm policy aiming to provide the basis for efficient and profitable production which is economically viable and environmentally responsible. It integrates beneficial natural processes into modern farming practices using advanced technology and aims to minimise the environmental risks while conserving, enhancing and recreating that which is of environmental importance.

The aims of integrated farming in America and a number of European countries including the UK are broadly similar. An overriding principle of integrated farming is the consideration of all inputs and practices within a crop, within a farm and how they interact with each other. By understanding where, when and how these interactions occur, farming practices can be adopted to mitigate some of the actions that may cause adverse effects, such as effects on non-target species, pollution caused by leaching and run-off, loss of habitats, soil erosion and other issues associated with intensive arable farming practices.

European Research

In 1992, the European Commission financed a Concerted Action of farming system designers within the framework of the research programme on Agriculture and Agro-industry (AIR). Its general objective was to develop a representative European network of research teams working on Integrated Arable Farming Systems (IAFS). Two research projects in the UK joined this European network; the Less Intensive Farming and Environment (LIFE) project (Jordan et al., 1995) and the LINK Integrated Farming Systems (LINK IFS) project (Ogilvy et al., 1995).

LINK IFS (Integrated Farming Systems)
Sue Ogilvy, ADAS High Mowthorpe

Based on six sites in Hampshire, Cambridgeshire (2), Herefordshire, Yorkshire and Midlothian, on approximately 50 ha on each farm. This project started in 1992 and has now completed its first rotational phase. Four of the sites were maintained in 1998 to assist with technology transfer and the development of a new research programme. Funded by MAFF, SOAEFD, HGCA, BAA and Zeneca. Details in this report.

Messages from all the IACPA projects were published in October 1998 in a MAFF report "Integrated farming - Agricultural Research into Practice". (For a copy please contact MAFF Publications, Admail 6000, London, SW1A 2XX, tel: 0645 556000.)

Integrated Farming Practices

The replacement of external farm inputs (mineral fertilisers, pesticides and fuel) by means of on farm produced substitutes and better management of inputs is a major objective of integrated farming to reduce the environmental impact of agriculture. Partial substitution of inputs can be achieved by the use of natural resources, the avoidance of waste and the efficient management of purchased materials. This can lead to reduced production costs and less pollution.
Integrated farming includes the consideration of the following practices against background needs of providing a profitable income and the demands of the markets for crop produce:-

Crop rotations, soil protection, crop nutrition, crop protection, wildlife & landscape, energy efficiency, pollution and waste. Some of the principles and practices detailed above have been built into the LINK Integrated Farming Systems project.

1.2 Herbicides as the 'Role Model' Agrochemicals

In this report, the limitations due to weather and soil conditions in the spring on spray applications of herbicides are investigated. Herbicides have been chosen as 'role model' agrochemicals because they are active against plant material and can be mobile in wind or water. This has implications for water quality and vegetation in non-crop environments. Further, due to the immobility of weeds and their annual life cycle, the development of herbicides has lead to products that aim to give control from one application. This single dose makes treatment a more time sensitive operation than fungicides or insecticides; with these compounds the mobility of pests and diseases has necessitated the development of products that can be used several times in a season. Also as fungicides and insecticides are not phytotoxic *per se*, there is less restriction on the crop growth stages when they can be used.

While the above assertion that herbicides have been developed as single dose products is true, variations in efficacy and the different species and patterns of weed growth mean that in reality several different herbicides are often applied, particularly to autumn sown crops which remain uncompetitive against weeds for much of the autumn and spring.

Most fungicides and insecticides need the crop to be present to be effective. Soil acting pesticides like chlorpyrifos are an exception, but in most cases the crop is required to provide the substrate for the pathogen. In contrast, herbicides do not need the presence of the crops although its competitive effects can help increase their efficacy. Residual herbicides act in either the aqueous or vapour phase of the soil and kill weeds on germination and during the early stages of emergence. Because of the diluting effect of working through the bulk of the soil surface layer the applications have to be either significant in amount (e.g. up to 2500 g active ingredient (ai) per hectare of isoproturon), or extremely phytotoxic to the weeds (e.g. 6 g ai per hectare of metsulfuron methyl with residual and contact activity). The purely contact herbicides are more analogous to fungicides and insecticides in that they need contact with foliage, but the foliage is that of the weeds rather than crop. In contrast to the residual products they act on larger weeds. The extreme susceptibility of common weeds like cleavers to products like fluroxypr have given the products a significant market share.

Non-selective herbicides like glyphosate, glufosinate, paraquat and diquat are contact materials that are inactivated on contact with the soil. However, as they are non-selective they have the potential to kill all plants, but various factors reduce their activity, so in reality control is not 100% and herbicide use is often needed in following crops. If applied to perennial plants that are not actively growing due to drought or cold, the effects of both glyphosate and glufosinate are minimal. They work through disruption of amino acid synthesis and in periods of low growth this activity in the plant is much reduced and the herbicides become inactivated before they have had time to reduce protein synthesis sufficiently to kill the plants. In contrast, paraquat and diquat destroy the chlorophyll in green tissue. This desiccation of the foliage kills the plant through lack of photosynthesised carbohydrate, and symptoms appear far more rapidly than with the highly translocated protein disrupters. Desiccants are not translocated to roots and plant storage organs, so perennial plants with stored carbohydrate can recover. Because of the conditions needed for their successful use, non-selective herbicides have some time limitations on their application, but this is less than those used selectively in growing crops.

Another major classification feature of herbicides is their differentiation into grass weed killers (graminicides) and broadleaved weed killers, although some compounds are active on both types of plant, and indeed some compounds are also both contact and residual. This versatility contributes to the popularity of a product (e.g. isoproturon) and thus wider use.

Where spraying opportunities are limited by the weather there are two possible outcomes; operators push ahead and spray in unsuitable weather, or they delay treatment and spray later in sub-optimal conditions for control. The consequences for these courses of action are summarised below. In both scenarios where sprays are used sub-optimally, it is implicit that some yield loss will occur.

Table 1. Effects of delay or spraying in unsuitable conditions on crop and environmental factors.

Unsuitable weather conditions	Delay
Herbicides	
Increased spray drift Reduced application on target Poorer control Increased risk of resistance Damage to adjacent crops and vegetation Contamination of water Increased risk of leaching Increased risk of prosecution	Higher rates of product use Crop grows beyond permitted stage for use (*risk of crop damage*) Increased risk of no control
Fungicides	
Increased spray drift Reduced application on target Poorer control Control of disease on non-crop vegetation Contamination of water Increased risk of prosecution	Higher rates of product use Poorer control Failure to control latent disease inside the crop plants Crop grows beyond permitted stage for use (*after safe harvest interval*) Increased spread within and to other crops

Insecticides	
Increased spray drift Reduced application on target Poorer control Control of pest on non-crop vegetation Increased risk to non-target species Contamination of water Increased risk of prosecution	Higher rates of product use Poorer control Crop grows beyond permitted stage for use (*after safe harvest interval*) Increased spread within and to other crops

From the above, it can be seen that herbicides show more problems arising from application in unsuitable conditions and fewer - although possibly more critical problems - arising from delay. The adverse spring weather conditions, which are the main focus of this study, thus have a significant impact on the effective use of herbicides and therefore make them ideal 'role models' for comparing conventional and integrated farming systems.

2. METHODOLOGY

There were three stages to the study. The first was to ascertain the spraying opportunities at each site according to its climate, to compare the spraying requirements of Conventional and IFS rotations and to see what differences were introduced by changes in cropping and husbandry. The second was to take example farms of different sizes and apply the experiment rotations. Two farm sizes were used, 200 ha and 350 ha. Details of the rotations are in Appendix 3. The third stage was to decide which factors would be crucial in determining the risks associated with each system. In deciding which were significant factors in affecting risk, contact herbicides were selected as the most relevant group of products. Although they have more stringent application limits than residual products, they are often used alone or tank-mixed with residual herbicides during the January - March period.

After looking at the requirement for spraying opportunities of each site and farm size, the next step was to find the extent to which the spraying expectations were met and how these differed between sites and systems. The likely impact of the results on the two farm sizes is considered along with rotational aspects and soil types.

2.1 Spraying Opportunities - Definition

The criteria for calculating spraying opportunities for contact herbicides applied using low ground pressure (LGP) vehicles were:-

Temperature must be greater than 1°C whilst spraying
Temperature must not fall below 1°C next night
If temperature is <10°C then relative humidity must be greater than 80%
Hourly rain must be <0.1 mm
Total rain in 9 hrs starting 3 hrs before must be <2.0 mm
Rain in each of the three hours after must be <0.1 mm

The general model criteria were:-

Daylight but not outside normal working day (06:00 to 20:00)
Visibility greater than 100 m whilst spraying
No standing water, glaze or frozen ground at 12:00
Wind limit 1: Not greater than 9 Kt but always above 1 Kt
Wind limit 2: Not greater than 13 Kt but always above 1 Kt
Suitable conditions must prevail for 5 consecutive hours [1]

Sprayer performance is considered as conventional and although alternatives do exist, they do not fall within the criteria of the Code of Practice (MAFF Green Code, 1998).

N.B. Wind limit 9 Kt at 10m height, not sprayer boom height. (See also 6.4.2 Machinery Complement)

[1] In this report a single spraying opportunity is thus defined as a continuous 5 hour period. This is taken as the minimum time period for which it is worthwhile carrying out a spraying operation. For residual spray criteria, see Appendix 1.

2.2 The Ecomac Data Set

2.2.1 Ecomac as a Model

Ecomac was created to model for the first time the four technical inputs, agrometeorology, soil hydrology, mechanisation and business management that affect crop establishment. The intention of the model is to provide objective information to the industry on the most cost effective investment in arable cropping; to look at the effects of structural changes at the farm level, and to show how changes of crops, climate, technology and economics affect the way land is farmed.

In this project Ecomac has been used to compare available spraying opportunities with those required by both conventional and Integrated Farming Systems (IFS). The analysis used a model based on Meteorological Data from 1986-1995 and the field records from the MAFF funded IFS study done at six sites between 1993 and 1997. The objective has been to see when, if ever, spraying operations are likely to be curtailed more often under IFS than in conventional systems or vice versa, depending on location or soil type. January-March was noted to be a period when spraying opportunities are particularly limiting. In 1999, spraying during this period has been essential on many farms following a very wet autumn in 1998. Two sets of limitations to pesticide use (as defined by herbicides) have therefore been studied, those arising from features of the climate and those caused by soil conditions.

2.2.2 Ecomac Data Criteria for Spraying

The opportunity to apply herbicides has been modelled using meteorological data. The criteria which are described in section 2.1 depend on whether contact or residual herbicides are to be applied.

The model has a built in requirement of 5 mm soil moisture deficit. In spring, soils are generally moving into a drying phase from being at field capacity. On light soils where available water capacity is 12.5%, a 5 mm deficit suggests that 40 mm of soil are 'dry' and fieldwork may be possible. On heavier soils where available water capacity is 17.5%, a 5 mm deficit suggests that only 28 mm of soil are 'dry'. Clearly, there will be a difference in the way these two soils behave even with a low ground pressure (LGP) vehicle. Although meteorological information suggests that it is possible to carry out a spraying operation, there may be a soil limitation.

2.2.3 Ecomac Data Criteria - Field Operations

As shown in section 2.1, the number of available work days for spraying is a function of many climatic factors, but a further consideration is field trafficability. This depends on the soil type and local climate and is part of the Ecomac data set. (See also section 2.4.3).

The soils at the IFS sites were classified into light, medium and heavy groups on the basis of their clay, sand, silt and available water capacity (AWC) as follows:

Table 2. The percentage of textural components in light medium and heavy soils

		clay	sand	silt + (2* clay)	AWC
LIGHT	Sand	<16		<31	<120
	Loamy Sand	<16		<31	>=120
MEDIUM	Sandy Loam	16-18	>50		
	Loam	<18	<50	>31	
HEAVY	Clay Loam	18-35			
	Clay	>35			

All values are percentages of the soil components in the top row occurring in the soils classified on the left hand side of the column. AWC is the plant available water content (mm) in the upper 90 cm of soil depth.

Further Notes and Additional Classifications

A Sandy Loam was LIGHT if over a Sand or Loamy Sand Subsoil and it was MEDIUM if over anything else. If soils were shallow (30-40 cm) over chalk or limestone, then they were classified MEDIUM, as were deep peat (>40 cm). Shallower peats were HEAVY if over clay, or MEDIUM if over sand.

2.3 Meteorological Station Selection - Rationale

The calculation of available work days for spraying requires hourly data on a daily basis. There are only fifteen meteorological stations in the UK which supply this information. The stations used to provide the regional data for the sites are shown below.

Table 3 **Matching IFS Sites Meteorological Sites:-**

IFS Site	Meteorological Station	Region Covered
Boxworth	Wyton	Eastern England - Heavy Soil
Sacrewell	Wyton	Eastern England - Light Soil
Manydown	Heathrow	Southern England
Lower Hope	Shawbury	West Midlands
High Mowthorpe	Leeming	Northern England
Path Head	Turnhouse	Southern Scotland

For eastern England Wyton, near Huntingdon, provided the data for both Boxworth and Sacrewell. The two IFS sites experience broadly similar weather and are in similar situations geographically, with no high hills or deep valleys to interfere with local climate.

For Manydown and southern England, the closest site was Heathrow. The west midland site at Lower Hope in Herefordshire is 40 miles south of Shawbury, but experiences similar weather, both sites being in the rainshadow of the Cambrian Mountains.

High Mowthorpe used data from RAF Leeming in the Vale of York. Despite the difference in altitude of the sites, no simple relationship exists which would prevent the Leeming data being valid for spray day calculations at High Mowthorpe, (Barrie, personal communication).

It is worth noting that the fifteen stations available from which to chose the data are those studied by Spackman and Barrie (1981) in earlier iterations of spray opportunity modelling.

The Model

The summary in table 4 shows the mean available spraying opportunities for 1986-1995 at each site for each month of the year and the annual total. Spraying opportunities increase from north to south. The number of opportunities in early spring appears very low apart from at Heathrow.

Table 4. Average Number of Spray Opportunities for Contact Herbicides at LGP 1986 -1995

	Jan	Feb.	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Turnhouse	1.5	0.6	1.7	7.5	15.4	26.0	20.2	22.7	17.6	9.5	2.6	1.2	126.5
Leeming	1.5	0.7	2.3	7.0	18.4	20.4	25.7	24.0	19.2	11.5	6.4	2.0	139.2
Shawbury	1.9	2.5	3.2	9.6	23.2	27.0	25.0	28.4	23.6	12.5	5.8	2.8	165.5
Wyton	2.7	3.0	4.8	9.8	22.7	27.0	25.2	25.2	21.7	14.0	8.1	4.2	168.3
Heathrow	4.0	5.1	8.6	18.2	33.0	34.3	35.0	37.9	30.8	20.5	10.8	5.4	243.6

Average values for sites around the Midlands and East Anglia are 230 to 250 spray opportunities annually.

For this study, data was limited to the ten years from 1986 to 1995 inclusive, although there was insufficient data from Wyton for 1995.

The individual sites are considered in Section 2.4.2.

2.4 Spray Machinery

2.4.1 Boom Size and Low Ground Pressure

The rotational influences of the conventional and IFS were considered within the two farm sizes to suggest typical sprayer selections.

Typically the 200 ha farm would have a sprayer with a 1000 litre spray tank fitted with a 12m wide boom, whilst the larger 350 ha farm would probably include a 2000 litre tank with a 20m boom. Although there are many possibilities for selection, any further variables were considered unnecessary complications (Basford unpublished).

Table 5. Effect of increases in sprayer boom width and tank capacity on work rates (ha/hr)

	Boom width (m)							
Tank Capacity (l)	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
% change	*100*	*117*	*133*	*150*	*167*	*183*	*200*	217
1000	**3.8**	**4.1**	**4.4**	**4.6**	**4.8**	**5**	**5.1**	**5.3**
100	*100*	*108*	*116*	*121*	*126*	*132*	*134*	139
1200	**4.2**	**4.5**	**4.9**	**5.1**	**5.4**	**5.6**	**5.8**	**5.9**
120	*111*	*118*	*129*	*134*	*142*	*147*	*153*	155
1400	**4.5**	**4.9**	**5.2**	**5.6**	**5.8**	**6.1**	**6.3**	**6.5**
140	*118*	*129*	*137*	*147*	*153*	*161*	*166*	171
1600	**4.7**	**5.2**	**5.6**	**6**	**6.3**	**6.6**	**6.8**	**7.1**
160	*124*	*137*	*147*	*158*	*166*	*174*	*179*	187
1800	**4.9**	**5.4**	**5.9**	**6.3**	**6.7**	**7**	**7.3**	**7.6**
180	*129*	*142*	*155*	*166*	*176*	*184*	*192*	200
2000	**5.1**	**5.7**	**6.1**	**6.6**	**7**	**7.4**	**7.7**	**8**
200	*134*	*150*	*161*	*174*	*184*	*195*	*203*	211
2200	**5.3**	**5.9**	**6.4**	**6.9**	**7.3**	**7.7**	**8.1**	**8.4**
220	*139*	*155*	*168*	*182*	*192*	*203*	*213*	221
2400	**5.4**	**6**	**6.6**	**7.1**	**7.6**	**8**	**8.4**	**8.8**
240	*142*	*158*	*174*	*187*	*200*	*211*	*221*	232

The above sprayer sizes were then included into the ADAS Sprayer Logistics program (ADAS, unpublished) developed to forecast sprayer work rates and system efficiencies. Both systems were assumed to be applying 200 l/ha as the water volume at a forward speed of 8 km/hour. Both systems were assumed to require the sprayer to return to a central filling point for tank replenishment, this single journey taking 15 minutes. Once at the refilling point, a further time of 12 minutes was allowed for mixing chemicals and refilling the tank. All these values can be varied within the program. The forward speed selected allows for stable boom function. Sophisticated boom suspension systems will allow higher speeds, though the distance and refilling times are often changed.

In this way, the work rates applying to reasonable operation of the 12m and 20m sprayers were calculated at 4 and 7 ha per hour respectively. The time required to cover the ground was the same on both farm sizes since the advantage of the larger equipment was used up by the increased acreage.

2.4.2 Spraying Time Available Using Low Ground Pressure

Acceptable meteorological conditions for spraying of contact herbicides have been published (Spackman and Barrie, 1981). Initially in the 1980's, these included conventional wheeled equipment and tyre pressures resulting in severe limitations in hours available, as the land was too wet to support imposed loads from higher tyre ground pressures. Since then the industry has switched to lower ground pressure equipment for working at critical soil moistures, typical of UK winters (Rutherford 1980). Thus forecasting of suitable conditions now includes "low ground pressure equipment" which considerably increases the number of winter days available. The available time for spraying has been published as the number of 'occasions' the requirements of which are described in section 2.1.

Spraying is limited by two groups of factors; atmospheric parameters like wind, rain and humidity and soil parameters like moisture content and mechanical strength. This contrast may be a significant factor where a spray needs to be applied and there is a weather opportunity to do so, but the land is too wet. This happened during the spring of 1999, where spraying was delayed due to very wet conditions and some farmers were forced to apply sprays on wet soil, leaving ruts in many fields. In such cases, the risk of damage to the land must be weighed against the risk of delayed or missed sprays. This is considered in section five.

It should also be noted that soil trafficability is not just one of supporting the load. There is often a marginal trafficability period on some unstable soils (silts and silty clays) when a moist greasy surface will preclude spraying due to tyre pick up of soil and young plants. Additionally, when soil conditions are difficult, failure to maintain a uniform forward speed can result overdosing the crop with pesticide.

Spraying Opportunities For Each Site

Spraying opportunities for each month, year and site within the study are shown in Appendicix 2. There is clearly a significant rise from April onwards at all sites. In addition, climatic requirements for contact herbicides are unlikely to be limiting from April onwards. The critical period for the application of contact herbicides is therefore early spring from January to March. Table 6 shows that there is a large annual variation in the number of 5 hour opportunity periods, so during this period spraying opportunities may be limiting, and the inability to apply a spray may have a significant effect. (Table 1).

At Turnhouse (Pathhead), the average number of opportunities is 3.8, totalling 19 hours (3.8 x 5 hrs) of potential spraying time. Over the ten years, the average ranged from zero to eleven in one exceptional year. Leeming (High Mowthorpe) shows a similar variation and Wyton has a minimum of five opportunities in the nine years of data available with a maximum of sixteen. There is a similar range for the data from Shawbury (Rosemaund) and Heathrow (Manydown).

Table 6. Available spraying opportunities between January and March at each of the six IFS sites over a ten year period

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	Ave
Turnhouse/ Path Head	0	5	4	4	2	11	4	5	3	0	3.8
Leeming/ Mowthorpe	2	2	0	9	8	10	5	5	1	3	4.5
Wyton/ Sacrewell	6	9	8	12	10	11	17	16	5	No data	9.4
Wyton/ Boxworth	6	9	8	12	10	11	17	16	5	No data	9.4
Heathrow/ Manydown	8	10	12	19	19	19	25	24	15	17	16.8
Shawbury/ Rosemaund	3	7	7	10	7	10	11	14	5	2	7.6

2.4.3 Spraying Time Required

The spraying opportunities available depend on the local climate as described in section 2.1 and the spraying opportunities required depend on the rotation. Clearly, where there is no requirement for a spray there is no problem, but as the number of hectares requiring treatment rises, the requirement for spraying opportunities rises and completing the task becomes difficult where requirements outweigh the time available.

The minimum number of spraying opportunities required was taken as the time for one application of a contact herbicide to winter wheat and winter oilseed rape during early spring. This was calculated by applying the work rates in section 2.4.1 to the acreages of winter wheat and winter oilseed rape in the rotations on the two model farm sizes for each site's weather data. The number of spraying opportunities required was found by dividing the spraying hours by five.

Comparing the average time available with the time required indicated a surplus or deficit of time for conventional and IFS at each site. Where there was a deficit of time, this constituted a 'bad year'.

Table 7 below shows the comparison of time required for each rotation and the number of bad years out of ten during 1986-1995. If more than one spray was required, the amount of time increased significantly. There is a difference in the opportunities required depending on the rotation. The requirements to apply one contact herbicide to IFS are equal to, or lower than the conventional regime.

Table 7. Early Spring spraying opportunity requirement of each site and no. of 'bad years'

Site		Opportunities Required Conventional	IFS
Turnhouse	Pathhead	6.75	4.50
Bad years		9	7
Leeming	High Mowthorpe	6.75	4.50
Bad years		7	5
Wyton	Sacrewell	4.50	4.50
Bad years		0	0
Wyton	Boxworth	8.00	6.00
Bad years		2	1
Heathrow	Manydown	6.00	6.00
Bad years		0	0
Shawbury	Rosemaund	6.75	4.5
Bad years		3	2

Pathhead had the highest number of bad years with nine and seven for conventional and IFS respectively and for High Mowthorpe, the figure was seven and five. However, Sacrewell and Boxworth differed even though they had the same meteorological data because they had different rotations and different soils. At Sacrewell, there were no bad years, but Boxworth, with a preponderance of autumn crops, had two for Conventional and only one for IFS.

Manydown experienced no bad years and the lowest number of spraying opportunities was eight in 1986. At Rosemaund, the number of bad years was low with three and two for Conventional and IFS respectively.

Table 8. Total herbicide applications per month 1993 - 1997[1] on Integrated and Conventional farming systems. Mean application date per month

			Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Boxworth	Integrated	No. sprays	6	1	6	14	6	4	2	0	1	4	5	0
		Mean date	15-Jan	20-Feb	21-Mar	15-Apr	16-Oct	8-Jun	12-Jul	0-Jan	13-Sep	15-Oct	13-Nov	0.00
	Conventional	No. sprays	0	6	1	6	6	0	0	0	1	2	12	6
		Mean date	0.00	11-Feb	3-Mar	21-Apr	9-May	0.00	0.00	0.00	23-Sep	14-Oct	17-Nov	14-Dec
H Mowthorpe	Integrated	No. sprays	2	2	5	5	12	1	1	12	8	1	2	0
		Mean date	25-Jan	18-Feb	12-Mar	19-Apr	15-May	6-Jun	29-Jul	13-Aug	13-Sep	31-Oct	15-Nov	0
	Conventional	No. sprays	2	0	0	1	9	4	1	14	6	5	4	0
		Mean date	25-Jan	0.00	0.00	29-Apr	9-May	4-Jun	29-Jul	15-Aug	10-Sep	21-Oct	15-Nov	0
Rosemaund	Integrated	No. sprays	0	3	4	6	2	3	1	2	1	1	2	0
		Mean date	0.00	3-Feb	15-Mar	21-Apr	11-May	3-Jun	30-Jul	19-Aug	8-Sep	15-Oct	19-Nov	0
	Conventional	No sprays	1	4	2	7	7	4	3	1	5	3	3	0
		Mean date	26-Jan	9-Feb	13-Mar	20-Apr	17-May	13-Jun	17-Jul	0.00	16-Sep	13-Oct	18-Nov	0.00
Manydown	Integrated	No. sprays	2	1	5	8	13	8	0	3	3	2	2	1
		Mean date	16-Jan	28-Feb	12-Mar	22-Apr	11-May	9-Jun	0.00	28-Aug	21-Sep	23-Oct	3-Nov	18-Dec
	Conventional	No sprays	3	0	3	12	15	6	0	3	3	5	4	4
		Mean date	16-Jan	0.00	12-Mar	19-Apr	10-May	12-Jun	0.00	28-Aug	21-Sep	20-Oct	3-Nov	9-Dec
Sacrewell [1] 1994-97	Integrated	No. sprays	1	0	1	10	10	5	3	4	1	0	2	2
		Mean date	20-Jan	0.00	25-Mar	18-Apr	14-May	12-Jun	25-Jul	8-Aug	27-Sep	0.00	22-Nov	0.00
	Conventional	No sprays	0	0	5	9	17	4	2	2	3	2	6	2
		Mean date	0	0.00	16-Mar	26-Apr	14-May	12-Jun	25-Jul	11-Aug	8-Sep	15-Oct	6-Nov	9-Dec
Pathhead	Integrated	No. sprays	0	0	0	10	9	4	1	5	1	1	0	0
		Mean date	0.00	0.00	0.00	14-Apr	18-May	15-Jun	25-Jul	22-Aug	3-Sep	8-Oct	0.00	0.00
	Conventional	No. sprays	0	1	2	4	7	5	1	4	4	5	3	0
		Mean date	0	0.00	26-Mar	10-Apr	15-May	15-Jun	25-Jul	18-Aug	10-Sep	27-Oct	15-Nov	0.00
Integrated -Mean spray no.			1.83	1.17	3.50	8.83	8.50	4.17	1.33	4.33	2.50	1.50	2.17	0.50
Integrated - Mean date			19-Jan	17-Feb	17-Mar	18-Apr	13-May	9-Jun	24-Jul	18-Aug	14-Sep	18-Oct	14-Nov	18-Dec
Conventional - Mean spray no.			1.0	1.83	2.17	6.50	10.17	3.83	1.17	4.00	3.67	3.67	5.33	2.00
Conventional - Mean date			22-Jan	10-Feb	14-Mar	21-Apr	12-May	11-Jun	24-Jul	18-Aug	14-Sep	18-Oct	12-Nov	11-Dec

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3. IFS RESULTS

3.1 Spray Applications Per Site

Table 8 shows the number of herbicide sprays applied per crop per site per month totalled over the 5 years of the trial. In determining the logistical and environmental constraints of IFS and conventional systems, it is important that the number of spraying operations are analysed on the basis of their distribution within years, and particularly the distribution within periods of the year when application is difficult and when the consequences of delay are high. Hitherto, analyses of data from this trial series have not looked at the distribution within such periods in the year, for the different crops and sites

In tabulating the data in table 10, if there were two spraying occasions of the same products on two dates very close together, on any one of the crops in the rotation, those episodes were counted functionally as one application. The layout of fields, the time of day the job was initially started, and the weather are all factors that can demand the job was split. But, for the purpose of this analysis, it is the single functional treatment that counts as one spray application. With 1000 hectares of each crop several days would be required, but the application would be a single functional treatment. The effects of the size of crop area were standardized in the model farm analysis of effects of sprayer size.

3.2 Spray Applications Per Function

Each of the individual crop species sown in the rotations at all sites have the same basic herbicide requirement at their various growth stages i.e. for the crop to be free of grass and broad leaved weeds (BLW). The active ingredients listed in table 9, are all those applied for the occasions listed in table 8 between 1993 and 1997 at all sites. Also shown is the basic function and target group of weeds. The balance of individual species varies from site to site, the selection of both broad-spectrum products and those with more specific targets means treatments can easily be tailored to any requirement. Spring crops offer scope for much simpler weed control programmes because there is not the protracted germination period that is a feature of autumn sown crops, and rapidly growing crops can quickly produce a very effective weed suppressing canopy. Additionally spring cropping may allow the fuller use of glyphosate and other non-selective products for the clearance of weeds before planting.

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Table 9. Active ingredients applied to individual crops in rotations at all sites

Cereals		
Active ingredients applied	**Function** [a]	**Weeds** [a] **(major target first)**
Benazolin (with HBN)	Contact	BLW
Bromoxynil+ Ioxynil (HBN[3])	Contact	BLW
Clodinafop-propargyl	Contact	Grasses
Difenzoquat	Contact	Grasses
Diflufenican*	Residual	BLW and grasses
Fenoxaprop-ethyl	Contact	Grasses
Flamprop-m-isopropyl	Contact	Grasses
Fluroxypyr	Contact	*Galium aparine* and other BLW
Glyphosate	Contact	Non-selective
Isoproturon	Residual and contact	Grasses[1] and BLW
Mecoprop	Contact	BLW
Metsulfuron-methyl	Contact and residual	BLW
Pendimethalin	Residual	BLW and grasses
Simazine (with IPU)	Residual	BLW and grasses
Trifluralin	Residual	BLW and grasses
Triasulfuron[2]	Contact and residual	BLW
Thifensulfuron-methyl[2]	Contact and residual	BLW

[1] Grasses includes volunteer cereals and wild oats for some products.
[2] Spring barley.
[3] HydroxyBenzoNitriles

Oilseed rape		
Active ingredients applied	**Function**	**Weeds**
Benazolin+ clopyralid	Contact	BLW
Cyanazine	Contact and residual	BLW and grasses
Cycloxydim	Contact	Grasses
Diquat	Contact	Desiccant (non-selective)
Fluasifop-p-butyl	Contact	Grasses
Glufosinate	Contact	Desiccant (non-selective)
Metazachlor	Residual	BLW and grasses
Propaquizafop	Contact	Grasses
Propyzamide	Residual	BLW and grasses
Pyridate	Contact	BLW
Trifluralin	Residual	BLW and grasses

Beans		
Active ingredients applied	**Function**	**Weeds**
Bentazone	Contact	BLW
Cycloxydim	Contact	Grasses
Diquat	Contact	Desiccant (non-selective)
Fluasifop-p-butyl	Contact	Grasses
Fomesafen	Contact and residual	BLW
Glufosinate	Contact	Desiccant (non-selective)
Glyphosate	Contact	Desiccant (non-selective)
Pendimethalin	Residual	BLW and grasses
Prometryn	Contact and residual	BLW and grasses
Simazine	Residual	BLW and grasses
Terbutryn	Residual	BLW

Peas		
Active ingredients applied	**Function**	**Weeds**
Bentazone+ MCPB	Contact	BLW
Cyanazine	Contact and residual	BLW and grasses
Cycloxydim	Contact	Grasses
Glyphosate	Contact	Desiccant (non-selective)
Isoxaben+ Terbuthylazine	Residual	BLW BLW and grasses
Pendimethalin	Residual	BLW and grasses
Simazine + Trietazine	Residual	BLW and grasses BLW
Terbuthylazine+ Terbutryn	Residual	BLW and grasses BLW

Linseed		
Active ingredients applied	**Function**	**Weeds**
Metsulfuron-methyl	Contact and residual	BLW
Glyphosate	Contact	Desiccant (non-selective)
Cycloxydim	Contact	Grasses
Fluasifop-p-butyl	Contact	Grasses
Diquat	Contact	Desiccant (non-selective)

Potatoes		
Active ingredients applied	**Function**	**Weeds**
Bentazone	Contact	BLW
Cycloxydim	Contact	Grasses
Diquat	Contact	Desiccant (non-selective)
Glufosinate	Contact	Desiccant (non-selective)
Glyphosate	Contact	Desiccant (non-selective)
Linuron	Residual and contact	BLW and grasses
Metribuzin	Contact and residual	BLW and grasses
Monolinuron	Residual	BLW and grasses
Paraquat	Contact	Non-selective
Sulphuric acid	Commodity chemical	Desiccant

a) UK Pesticide Guide 1999

There is a wide range of possible spray applications per weed group. Forty separate active ingredients were used on the above seven crops (2 cereal types). Cycloxydim (graminicide) and glyphosate (non-selective herbicide or desiccant) were the most widely used. Because of the large number of products that are both contact and residual, and the frequent tank mixing of individual contact and residual products, analysis of safe spraying days has been done on the basis of contact acting products (section 2).

The number of applications are ultimately a reflection of the number of functions that need to be carried out. Tank mixing two or more products with different functions allows the number of application operations to be combined, but in some situations incompatibility of products limit the range of mixable products or enforces a separation interval between products. Some idea of the range of tank mixes used is shown in table 10. Certain mixes like isoproturon (IPU) + fenoxaprop-ethyl, and metsulfuron-ethyl + fluroxypyr are common at several of the sites. The former mix represents one of the commonest and most reliable mixes for the control grass weeds and some broad-leafed weeds. It is a mix of residual (IPU) and contact products and can be used from autumn after the crop has emerged until early spring. Fenoxaprop is particularly active against black-grass (*Alopercurus mysuroides*). The second mix is of two contact broad-leafed weed herbicides; the metsulfuron-methyl has activity against a wide range of weeds, whilst fluroxypyr is a more targeted product with very high activity against cleavers (*Galium aparine*). These two examples show how, using mixtures of products, the function of residual and contact weed control can be combined with both a general and targeted approach to various weed species.

Selecting the right product for the target weed; the correct dose rates for the weed size; applying the spray in favourable weather, and at the correct weed growth stage are all important in maintaining efficacy. Failure in any one aspect reduces efficacy, and failure on several counts may well require follow up treatments. It is important however, to distinguish between follow up treatments dictated by the emergence of weeds at different times of the year (e.g. autumn IPU to control grass and some broad-leafed weeds, and spring applied tank mix of contact graminicides and broad-leafed weed herbicide), and follow up treatments because of failure of the first treatment to provide normal levels of control. The latter cases have been few in this trial (*italics* in table 10). It is of note that for an herbicide to have sufficient active persistence to cope with weeds all the way through the open canopy phase of an autumn sown crop (September - April), would require an ability to persist that could cause problems with acceptance by the registration authorities.

3.3 Variation Within Sites in Spray Application

Table 10 shows the products used from January to April for the conventional and integrated systems and the variation within that period in the timing of product use. The products used in the January-March period of the spray opportunity model are shown in bold type. In years with no treatments shown, autumn sprays may have been timely and adequate for full weed control, or sprays were applied later, during May and June. Products like metsulfuron-methyl are described in the comments section as 'contact' products even though they have some residual activity, on the basis that they are deployed in weather and timing terms, as contact products.

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Table 10. The herbicide active ingredients used on all crops at all sites during January - April and their dates of application

Boxworth

	C/I	Active ingredient	Comment
WW1	C	**IPU+Diflufenican- 15 Feb 1993** Mecoprop+HBN - 13 Apr 1993 Mecoprop 19 Apr 1994 Mecoprop+HBN - 22 Apr 1997	The IPU/DFF treatment would normally be applied in the autumn, but here and below autumn treatments are frequently carried over to winter/spring due to poor spraying conditions in the autumn. The April sprays here and below are typical spring BLW treatment.
WW1	I	Mecoprop+Metsulfuron-methyl - 13 Apr 1993 Mecoprop+HBN - 13 Apr 1993 Mecoprop+HBN - 30 Apr 1994 **IPU+Fenoxaprop-ethyl 13 March 1995** Mecoprop+HBN - 8 Apr 1995 **IPU+Pendimethalin 15 Jan1996** **IPU+Pendimethalin 16 Jan1997** HBN + Mecoprop/fluroxypyr - 7 Apr 1997	Mecoprop + partner product are typical spring BLW treatments, the switch from metsulfuron-methyl to HBN or fluroxypyr reflecting a change in weed population pressures. Under a non-IFS regime IPU + pendimethalin would normally be applied prophylatically in the autumn.
WW2	C	**IPU Diflufenican - 16 Feb 1993** **IPU+Diflufenican- 10 Feb 1994** Fenoxaprop-ethyl - 28 April 1995 Fluroxypyr 26 Apr 1996	Late IPU/DFF treatment as for WW1. Fenoxaprop needed for second flush of grasses and wild oats. As a second wheat BLW will tend to be reduced by herbicides on WW1, but cleavers need treatment with spring fluroxypyr
WW2	I	HBN+Fluroxypyr - 30 Apr 1993 **IPU+Fenoxaprop-ethyl - 26 March 1994** **IPU+Fenoxaprop-ethyl - 13 March 1995** Mecoprop + HBN - 8 April 1995 *Fenoxaprop-ethyl - 28 April 1995* **IPU+Pendimethalin 15 Jan 1996** **IPU+ Pendimethalin 16 Jan 1997** Fluroxypyr 7 Apr 1997	The use of glyphosate in the autumn in the first three years of the trial allowed spraying to be delayed until the spring. The 1996 and 1997 treatments would normally have been applied in the autumn. The re-treatment with 3.0 l/ha Fenoxaprop-ethyl on 28 April 1995 after treatment with 0.751 /ha is one of the few occasions when using an early low rate of product proved inadequate for effective control.
WOSR	C	***Cycloxydim 3 Mar 1997***	The only spring treatment need was a follow up graminicide after a low-rate late September treatment proved inadequate
Linseed (*winter crop in 1996 & 97)*	I	**Glyphosate - 20 Feb 1993** Metsulfuron-methyl - 4 Apr 1997 *Cycloxydim - 18 Apr 1997*	Pre-sowing glyphosate controlled most early weeds pre-drilling, and all crops not listed here had treatments (Fluasifop-P-butyl or Metsulfuron-methyl +/- cycloxydim) later in the spring (May - July).

Boxworth (cont.)

WW1	C	**IPU Diflufenican - 21 Feb 1993** **IPU Diflufenican - 10 Feb 1994**	Most treatments autumn applied. Some late BLW control of cleavers in May
WW1	I	Mecoprop + HBN - 13 Apr 1993 **IPU + Fenoxaprop-ethyl - 23 Mar 1994** HBN + Fluroxypyr - 30 Apr 1994 Metsulfuron-methyl - 26 Apr 1996 Mecoprop + HBN - 7 Apr 1997	Similar treatments to WW1 after Beans at the start of the rotation
W Beans	C	Cycloxydim - 21 Apr 1993	1993 was the only year not to receive autumn applied Simazine
W Beans	I	Cycloxydim - 21 Apr 1995 **Cycloxydim - 31 Mar 1996**	In 1993 autumn glyphosate, and in 1997 autumn simazine were applied. In 1995 Cycloxydim was needed in May. Some residual herbicide with graminicidal properties appeared necessary for beans

High Mowthorpe

	C/I	Active ingredient	Comment
WW1	C	Mecoprop +HBN - 29 Apr 1993 **IPU + Diflufenican - 25 Jan 1995**	The more northerly situation and higher altitude of this site reduced pressure from weeds; grass weed pressure is notably less than on the clay soils at Boxworth. In 1996 and 1997 pre-harvest glyphosate was used to ensure all weeds and green crop material were dead at combining on both the C and I treatments
WW1	I	Mecoprop +HBN - 29 Apr 1993 **IPU + Diflufenican - 25 Jan 1995** Fluroxypyr - 30 Apr 1996 Fluroxypyr - 6 Apr 1997	The C and I treatments were very similar at this site except in 1996 when an autumn IPU + diflufenican treatment was used on the C regime, and fluroxypyr was used on the I regime in 1994 (1 May) and 1996
Set-aside	C		Glyphosate was used in June on the C regime, but not on the I regime.
Set-aside	I		
WOSR	C		All treatments were autumn applied and proved adequate for the whole season
S Beans	I	Pendimethalin + Prometryn - 11 Apr 1994 **Glyphosate - 9 Mar 1995** Fomesafen+Terbutryn - 24 Apr 1996 **Fomesafen+Terbutryn - 25 March 1997**	Pre-harvest desiccation of crop and weeds was needed in all years except 1995
WW1	C	**IPU + Diflufencian - 25 Jan 1995**	Autumn residual applied in all years except 1993. Late treatment in January 1995
WW1	I	**IPU + Diflufencian - 25 Jan 1995** Fluroxypyr - 30 Apr 1996	Autumn residual only applied in 1997, but spring contact herbicides were applied each year. The later spring at this site resulted in most treatments being applied in May.
Seed pots	C		All treatments to both I and C applied during May and later.
Seed pots	I		

Rosemaund

	C/I	Active ingredient	Comment
WW1	C	Metsulfuron-methyl+Fluroxypyr - 28 Apr 1995 Metsulfuron-methyl+Fluroxypyr - 24 Apr 1996 **IPU - 3 Feb 1997** Metsulfuron-methyl+Fluroxypyr - 21 Apr 1997	Very commonly used spring BLW herbicide treatment, also used in May in 1994, and without Fluroxypyr in 1993, following mechanical weeder on 12 March. No 'autumn residuals' used on either regime except for the IPU treatments shown.
WW1	I	**IPU + Diflufenican - 16 Jan 1993** Metsulfuron-methyl+Fluroxypyr - 28 Apr 1995 Metsulfuron-methyl+Fluroxypyr - 25 Apr 1996 **IPU+Diflufenican - 3 Feb 1997** Fluroxypyr - 21 Apr 1997	Treatment show slight variation from C regime. Mechanical weeder used in May 1994 and 1995
Set-aside	C		Glyphosate only used 1994 -97 on the C regime during the May - July
Set-aside	I		
WOSR	C	**Propyzamide - 26 Jan 1993** **Clopyralid - 16 Feb 1993** **Propaquizafop - 6 Mar 1997**	Autumn residuals used every year except 1993. Additional spring graminicide needed in 1997
S Beans	I	**Glyphosate - 13 Mar 1995** **Glyphosate - 6 Mar 1996** **Glyphosate - 14 Mar 1997**	All treatments applied pre-sowing
WW1	C	**IPU +Diflufencian - 17 Feb 1993** Fluroxypyr - 15 Apr 1993 **IPU + Diflufencian - 21 Mar 1994** Fluroxypyr - 15 Apr 1995 Mecoprop - 22 Apr 1996 **IPU + Diflufencian - 3 Feb 1997** Metsulfuron-methyl+Fluroxypyr - 21 Apr 1997	1995 and 1996 had IPU+Diflufenican applied in the autumn. The programme was therefore relatively consistent from year to year varying in the timing
WW1	I	Fluroxypyr - 15 Apr 1993 Mecoprop - 16 Apr 1994 **IPU - 3 Feb 1997** Fluroxypyr - 21 Apr 1997	Mechanical weeding was used in March and May 1993, April 1994, May 1995, but not in 1996 and 1997. No residuals were used in 1993-1995, but were autumn applied in 1996 and as shown in 1997
Potatoes	C		All treatments except as shown, were applied from May onwards
Potatoes	I	**Glyphosate 30 Mar 1995**	

Manydown

	C/I	Active ingredient	Comment
WW1	C	Fenoxaprop-ethyl - 14 Apr 1993 Metsulfuron-methyl - 21 Apr 1993 IPU + Metsulfuron-methyl - 28 Apr 1994 **IPU + Metsulfuron-methyl - 20 Mar 1995** Fenoxaprop-ethyl - 16 Jan 1996	Autumn residuals only were used in 1997 on both C and I regimes. Fluroxypyr applied in May to both regimes
WW1	I	Fenoxaprop-ethyl - 14 Apr 1993 Metsulfuron-methyl - 21 Apr 1993 **IPU +Metsulfuron-methyl - 15 Mar 1994** **Metsulfuron-methyl - 21 Mar 1995** Fenoxaprop-ethyl - 27 Apr 1995 **Fenoxaprop-ethyl - 16 Jan 1996** **Mecoprop - 7 March 1996 (*part area*)** Mecoprop+Metsulfuron-methyl - 20 Apr 1996	Similar treatments to the C regime, although less residual product used in 1995 and 1996. Dates of treatments match those on C regime except where additional treatments were applied in 1996.
WW2	C	Fenoxaprop-ethyl - 14 Apr 1993 Fluroxypyr - 29 Apr 1993 **Pendimethalin+ IPU+ Simazine +Mecoprop - 9 Mar 1994** Mecoprop+Metsulfuron methyl - 20 Apr 1994 Mecoprop+Metsulfuron methyl - 4 Apr 1995 Fenoxaprop-ethyl - 13 Apr 1995 **IPU+Pendimethalin+Mecoprop - 7 Mar 1996** **Fenoxaprop-ethyl - 16 Jan 1997**	Autumn applied residuals were applied in 1993 and 1997. 1995 was the only year when no residual was used. Fluroxypyr was applied later in May or June except as shown in Apr 1993.
WW2	I	Fenoxaprop-ethyl + Metsulfuron-methyl - 14 Apr 1993 Mecoprop+HBN - 28 Apr 1994 Fenoxaprop-ethyl - 13 Apr 1995 **Fenoxaprop-ethyl - 16 Jan 1996** **IPU+Pendimethalin+Mecoprop - 7 Mar 1996** **IPU+Pendimethalin+Mecoprop -15 Mar 1997**	All treatments were spring applied as shown, and followed by Fluroxypyr in May or June except in 1995. The only residuals used were those shown in 1996 and 1997.

Manydown (cont.)

S Barley	C	Mecoprop+Metsulfuron-methyl - 30 Apr 1993	The same treatment was used on both regimes in all years, but in other than 1993 it was applied later than the January - April. Tralkoxydim was applied in 1996 and 1997, but again later in May.
S Barley	I	Mecoprop+Metsulfuron-methyl - 30 Apr 1993	
Peas	C	Glyphosate - 15 Apr 1997	All residuals applied during May. Seedbed spraying off in autumn 1993 (for 1994), and as shown
Peas	I		
WOSR	C		All autumn applied residuals provided adequate season long control.
WOSR	I	**Cyanazine +** **Benazolin + Clopyralid - 29 Feb 1994**	

Sacrewell

	I/C	Active ingredient	Comment
Peas	C	**Terbuthylazine+Trietazine - 14 Mar 1994** **Terbuthylazine+Trietazine - 25 Mar 1995** **Terbuthylazine+Trietazine - 14 Mar 1996** **Cyanazine+Pendimethalin - 12 Mar 1997**	Contact herbicides used every year but applied in May and June. Desiccation pre-harvest in 1997
Peas	I		No residual herbicides used. Contact herbicides used every year but applied in May and June. Desiccation pre-harvest in 1997
WW1	C	Metsulfuron-methyl +Fenoxaprop-ethyl - 12 Apr 1994 Metsulfuron-methyl+Fluroxypyr - 29 Apr 1994 Metsulfuron-methyl+Fluroxypyr - 30 Apr 1995	Different treatments on two areas in 1994. Residual grass and BLW treatments applied each autumn. Autumn treatments only in 1996 and 1997
WW1	I	**Fenoxaprop-ethyl (*part area*)- 25 Mar 1994** Fluroxypyr +Thifensulfuron-methyl - 26 Apr 1994 Mecoprop+HBN - 14 Apr 1995 **IPU - 20 Jan 1996** Metsulfuron-methyl+Fluroxypyr - 26 Apr 1996 Metsulfuron-methyl+Fluroxypyr - 7 Apr 1997	Residuals applied in 1996 and in December 1997. Otherwise all contact products applied in the spring. Pre-harvest glyphosate used in 1994 and 1997.

Potatoes	C	**Terbuthylazine+Trietazine + Diquat+Paraquat - 23 Mar 1995** Metribuzin - 28 Apr 1996 Metribuzin - 30 Apr 1997	All treatments in May and June other than those shown
Potatoes	I	Paraquat - 19 Apr 1995 Nil - 1997	One of the lowest herbicide input crops in the whole trial series. Only pre-planting non-selective treatments in 1994 - 1996, and a late graminicide 1996.
WW1	C	**Fenoxaprop-ethyl - 18 Mar 1994** Mecoprop+Metsulfuron-methyl - 26 Apr 1994 Benazolin+HBN - 27 Apr 1994 Metsulfuron-methyl+Fluroxypyr - 29 Apr 1994 Metsulfuron-methyl+Fluroxypyr - 30 Apr 1995	Range of different BLW treatments applied in 1994 depending on field - only spring contact herbicides used. Autumn residuals used in 1995-1997, and late spring (May) contact herbicides in 1997.
WW1	I	Mecoprop (*patch*) - 26 Apr 1994 Benazolin+HBN - 27 Apr 1994 Fluroxypyr - 29 Apr 1994 Mecoprop+HBN - 14 Apr 1995 Fenoxaprop-ethyl - 16 Apr 1995 Mecoprop+HBN - 25 Apr 1996 Metsulfuron-methyl+Fluroxypyr - 7 Apr 1997	As with C regime, range of different BLW treatments applied in 1994 depending on field - only spring contact herbicides used. Autumn residuals applied for 1996 and 1997
Set-aside	C		Glyphosate used every year after the January -April period.
Set-aside	I		

Pathhead

	C/I	Active ingredient	Comment
WOSR	C	**Benazolin +Clopyralid - 27 Mar 1993** Cycloxydim - 8 Apr 1997	Autumn applied residuals were used in all years except 1993.
SOSR	I	Metazachlor - 27 Apr 1994 Matazachlor - 15 Apr 1995 Metazachlor - 6 Apr 1996 Metazachlor - 3 Apr 1997	Metazachlor was applied in early May in 1993. Pre-harvest desiccation was needed in all years except 1995
WW1	C		Autumn residuals were used in 1995 - 1997, and contact herbicides were applied in all years except 1997. The relative lateness of crops at this site delayed all contact use until May and June
WW1	I	Mecoprop+Metsulfuron-methyl - 24 Apr 1993 Mecoprop+Metsulfuron-methyl - 12 Apr 1995 Mecoprop+Amidosulfuron - 11 Apr 1997	No residuals were used, and as a result contact herbicides were deployed earlier in the spring. 1994 and 1996 treatments were applied in May and June
Set-aside	C	Glyphosate - 29 Apr 1996	Glyphosate was applied in all other years in the June- August period.
Set-aside	I	Glyphosate - 29 Apr 1996	
WW1	C	**IPU+Diflufenican +Metsulfuron-methyl+Mecoprop - 26 Mar 1993** Metsulfuron-methyl +HBN+Mecoprop - 2 Apr 1997	Late contact herbicides were used in 1994 and 1996, and autumn residuals in 1995
WW1	I	Mecoprop - 23 Apr 1993 Mecoprop+Metsulfuron-methyl - 12 Apr 1995 Benazolin+HBN+Fluroxypyr - 12 Apr 1995 Metsulfuron-methyl +HBN+Mecoprop - 10 Apr 1997	No herbicide treatment was needed on the 1994 crop. Two different combinations of products used in 1995 to cater for different fields.
W.Barley	C	**IPU+Diflufenican +Metsulfuron-methyl - 24 Feb 1993** Benazolin+HBN+Mecoprop+IPU - 4 Apr 1997	(1993 - mix of winter and spring barleys). Autumn residual used in 1995 and 1996. Late applied contacts used in 1993, 1994, and 1996
S.Barley	I		Only late contact herbicides applied in May, or early June (1994)

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3.4 The Effects of Product Choice

The impact of product choice on spraying programmes is through the effects on spray timing dictated by the growth stage of the crop and the weeds. Thus it is the weeds and the crop growth stage that dictate the time of spraying, and the choice of pre- or post- emergence products for both spring and autumn sown crops. Where weather and ground conditions delay spraying, it is the changes in the crop and weed growth stage that may necessitate changes in products. The differences in the crops growth stages between southern England and Scotland account for some of the differences between residual and contact herbicide use shown in table 11.

3.4.1 Mode of Action

During the autumn and winter period when residual herbicides are applied, weeds are small or germinating and emerging. There is little need for foliar rainfastness as product is taken up by the roots or hypocotyl. Indeed soil moisture is needed for herbicides to be at their most active. The majority of residual products applied to autumn sown cereals were applied in the autumn and of those carried over into the January-April period of this study, the majority were January, February and early March applied. Only in Scotland was IPU applied to winter barley in early April.

Spring sown crops use largely contact or contact and residual materials. The choice of mode of action and pre- or post-emergence timings are some of the major decisions in herbicide selection for crops like peas and potatoes. In warm wet seasons like 1999 pre-emergence residual products effectively control early flushes of weeds, and in changeable weather give more leeway for the timing of later contact treatments, many of which are applied after the end of April when spraying opportunities become more frequent. In seasons when pre-emergence activity is reduced by the dry soil, weed germination emergence is also delayed. Occasionally an early flush of weeds follows planting, and then a much later flush occurs when pre-emergence residual activity is much diminished. The timing of post-emergence contact sprays is crucial to the success of these treatments, but again these later applications to spring sown crops are generally in May or June when spray opportunities are not limiting.

Table 11. Total number of sprays January - March, and April period for all crops from 1993-1997. Percentage of applications with residual activity

Site	Conventional				Integrated			
	Jan-Mar	% Res	April	% Res	Jan-Mar	% Res	Apr	% Res
Boxworth	6	100	6	0	10	80	16	0
H. Mowthorpe	2	100	1	0	4	75	6	0
Rosemaund	7	86	7	0	7	43	6	0
Manydown	4	75	11	9	8	38	8	0
Sacrewell	6	83	9	22	2	50	12	0
Path Head	3	66	4	25	0	-	12	25
Mean	4	72.86	5.43	8	4.43	57.2	8.57	3.57

[1] *Mode of action of mixtures is residual if a primarily residual product is used in mix*

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The major difference between conventional and integrated farming systems occurs when the latter regime adopts spring crops, or deliberately avoids autumn residuals and seeks to obtain weed control through spring treatments. The table above shows, as a sum for the total trial period, how the total number of sprays varied in the January - March, and April periods. It also lists the percentage of applications with marked residual activity.

As the figures in table 11 are the total for 1993 -1997, the number of sprays applied per annum at each site are relatively small and thus between years there is considerable scope for variation. The various scenarios can be summarised by the programmes at Boxworth and Pathhead. The other sites are variations between these two extremes. On the chalky boulder clays at Boxworth where autumn planting predominates (and spring cultivations can be difficult), across the rotation there is a reliance on herbicides with residual activity all through winter. Once the warmer drier spring weather arrives, there is a wholesale adoption of contact herbicides. In contrast, the later development of crops and weeds in Scotland at Pathhead and a lower total number of spraying opportunities, produced an increase in the percentage of later sprays that contained residual materials.

The annual number of spray applications between January and March derived from table 11 show virtually no correlation at all with the number of spraying opportunities in the conventional farming systems (r = -0.08). In the IFS however the correlation between the number of spraying opportunities and the number of applications is 0.78. In the absence of an empirical causal link such a relationship is tenuous, but the degree of difference does suggest that on IFS spraying is more linked to the availability of opportunities. On conventional regimes the greater amount of residual use in the autumn reduces the need to seize opportunities.

3.4.2 Environmental Impact

The environmental impact of herbicides and the risks of spraying in adverse conditions are taken into account by MAFF's recent publications on Local Environmental Risk Assessments for Pesticides (LERAPS) (MAFF 1999). Previous guidelines on best practice for spraying were contained in the Code of Practice for the Safe Use of Pesticides on Farms and Holdings (MAFF/HSE 1990) and the program used to define the frequency of safe spraying intervals took into account the necessary safe conditions with respect to wind speed and freedom from rain after spraying (see General Criteria, section 2.1)

If safe spraying conditions are complied with, the main environmental impact arises from the movement of residual herbicides to water courses (White *et al.* 1997). Various studies have shown IPU to be one of the main sources of water contamination by herbicides (Harris, Bailey and Mason 1991) and of that contamination the vast majority arises from point sources such as sprayer filling and spillages. The spraying conditions being studied here between January and March will not differ in this respect from operations at any other time of the year. The difference in the relative usage of residuals and contact products between Conventional and Integrated systems, although marked in some years varies from year to year as shown in table 10, but more importantly there is considerable variation between sites. Overall, however, the bias towards contact products is more marked on the Integrated regimes.

The more stringent requirements for applying contact herbicides (section 2.1) mean that the integrated programmes with a higher usage of contact herbicides put a greater load on the spraying logistics than do the conventional regimes.

4. MACHINERY COMPLEMENT

Relating sprayer size to any area to be treated is a relatively simple but detailed process. Most businesses will be able to predict the number of spray treatments required within a system for each crop and relate these to the areas grown.

Calculation of sprayer work rates is possible simply, or by using such aids as the ADAS Sprayer Logistics program (ADAS 1999). Any parameter within the computation can be varied and the significance of altering tank size, speed of field travel, boom width, application rate, travelling and refilling times can be tested.

Alongside such calculations the opportunity "window" for spray treatment can also be considered. This relates to the time available for completion of the spray treatment to ensure effective treatment. This time will vary dependent on pest, disease or weed build up and on crop development. For instance for a cereal crop it is considered that any spray treatment should be completed within 25 spraying hours from the time when the decision to treat was made. These hours may be within a 2 -3 day period after which time conditions of either target or crop will be considered to have changed significantly, possibly requiring a reconsidered treatment or product.

Thus knowing the largest area to be treated and the potential work rates for any size of sprayer system, the sprayer work rate needed can be calculated.

The annual and operational costs can vary widely since more than one solution to any area can be produced because support system provision and function are of major influence (Bailey and Graham unpub.). Sprayer selection must be related to the work rate and system but also to tramline widths, treatment constraints, local climatic conditions (particularly exposure to wind) and economics (Barrett unpub.).

For the two sizes of sprayer considered there are likely to be changes in tractor size and hence costs included as below:

200 ha Farm, 12 m boom and 1000 litre tank. Mounted on 80 hp 2 wheel drive tractor.

350 ha Farm. 20 m boom and 2000 litre tank. Trailer sprayer pulled by 95 hp 4 wheel drive tractor

Table 12: Operating costs per hour and per ha for spray treatments

	Farm size	
	200 ha	350 ha
Tractor	4.54	7.87
Sprayer	5.59	6.97
Labour	6.00	6.00
Costs per hour (£)	16.13	20.84
Cost per hectare (£)	4.03	2.98

The lower operating costs for the larger sprayer on the larger holding are to be expected for both the sprayer and tractor would be operated for a greater number of hours. This use would not be expected to increase dramatically the wear rates on either machine (Basford unpub.).

Under the model farm conditions in table 7 there is possibly less spraying to be done with the IFS approach thus possibly increasing the hourly per hectare charge. Though this has not been conclusively demonstrated to date; it does suggest lower annual costs may be possible through extending the service life of a sprayer thus incurring a lower depreciation figure.

5. DISCUSSION

5.1 The Effects of Weather: IFS v Conventional

Overall, the differences between Integrated and Conventional rotations have been small. In some instances, the management can be seen to have evolved in the integrated regime, as it became clear that certain operations in the conventional armoury were perhaps more benign that the planned integrated options. For example, at Rosemaund the mechanical weeding of wheat after spring beans was replaced in the last two years of the trial with an autumn/winter residual herbicide. At Sacrewell autumn/winter residual herbicides were introduced in the wheat crop for the last two years of the trial.

The use of residuals reduces the demand for timely use of contact herbicides. Clearly the reduction does not remove the need for timeliness, but having some residual activity slowing weed development adds some flexibility to the spraying dates. Also, as the residual activity of autumn/winter applications degrades in the spring, so the number of available spray days makes timeliness easier.

In spring sown crops, there is very little difference between integrated and conventional systems. Weeds and crops develop together and weeds must be controlled early if crops are to establish well. Winter cereals on the other hand, can tolerate weed competition, provided it is not too aggressive, until the start of stem extension in March and April. If a residual herbicide is used in the autumn or winter there is possibly more leeway in the timing of the spring contact 'stem-extension' herbicide. Viewed in this light the 'spring only' strategy is 'high risk', as failure to get the first contact herbicide applied at the right time can lead to higher doses to treat larger plants, incomplete control, or the need for repeated spraying (See table 1); all features which are the antithesis of integrated farming operations.

The recent increase in the popularity of early September sown autumn cereals means that the early stem extension stage of first and second node can occur in March and early April. As this analysis shows, spraying opportunities increase after this time. If integrated farming plans to use early sowing of autumn cereals to spread the burden of field operations, this risk of applying herbicides to crops at later growth stages pushes growers to using products like metsulfuron-methyl, thifensulfuron-methyl, fluroxypr, fenoxaprop-ethyl and clodinafop-propargyl. These enable the grower to apply herbicide as late as flag leaf emerges - but the penalty for such delays are that weeds can have an effect on yield.

If the recent spell of mild winters becomes the norm, the risk of overwinter weed growth in early sown crops would mean spring applied contact herbicides would more often be too late to avoid yield loss from competitive weeds

5.2 Variation Between Modes of Action

Herbicides have a wide range of biochemical modes of action, from the prevention of protein formation, to the more direct effects like the prevention of photosynthesis by destroying chlorophyll. However, in reviewing the limits to herbicide use in Integrated and conventional farming systems, it is the physical attributes of the modes of action that are of more importance.

The solubility and volatility of residual herbicides are important determinants of their performance, and therefore of their weather requirements. The arylureas (IPU on cereals and linuron and monolinuron on potatoes) are absorbed from the soil by plant roots and therefore need moisture to ensure they work. Too much moisture means they can be moved through the soil, and heavy rain after the application of IPU can move it out of the rooting zone of young weed seedlings, markedly reducing its efficacy. The criteria used in modelling suitable spraying intervals for both residual and contact materials do not take into account weather in the days immediately following application.

Similarly the days and weeks before a product is used are not taken into account. Dinitroaniline herbicides (pendimethalin and trifluralin) are either incorporated or surface applied products that have some action derived from their volatility. Seedbed quality is thus important for such compounds and labels carry information on sowing depth and depth of incorporation. Their mode of action therefore relies to some extent on the weather before drilling and its effect on the quality of seedbeds that can be produced. Good seedbed quality -fine, firm and flat- is a general requirement of all residual products.

The above points show how the mode of action of residual products is affected by the weather outside the immediate period used by the model for calculating spraying opportunities.

The mode of action of contact herbicides are also affected by the weather outside the immediate spraying period used by the model, but only because it affects the growth of the weeds and crop. Warm moist weather in the period prior to spraying will produce 'soft' sensitive growth in both weeds and crop. This increases the sensitivity of the weeds to herbicides, and at the same time makes the crops more vulnerable to side effects like scorch or transient discoloration. Although the model has a frost limit built in (no frozen ground at 12 noon), frosty weather in the period prior to spraying causes disruption to the protective layer of leaf wax on crops, and for some products a period for the recuperation of wax cover is recommended. Some products even suggest the use of solvent based dyes to check there is adequate wax cover. Windy weather which rubs leaves together also produces the same symptoms and again can lead to a period for recovery of leaf wax before spraying. Some products can be applied "on the frost", notably the graminicides used in cereals for grass weed control. This procedure allows tractors to run on frozen ground and apply herbicides, provided the crop foliage is free from frost which on thawing would drain away along with the herbicide.

Rainfastness in the immediate spraying window is taken into account by the model. However, unlike residuals, heavy rain in the days following application will not affect product efficacy as the material is then in the plant.

The mode of action of contact herbicides is also affected by the overall growing conditions. The weather and nutrient status of the soil can affect the nature of the leaf surface (this has already been mentioned in relation to soft growth), and on weeds with leaf hairs or surface roughness these features can vary from site to site as growing conditions vary. Rougher or hairier leaves can make spray adhesion more difficult. The other attribute of weeds that vary with growing condition is their size. Where spray has to hit the leaves of the target weeds, larger leaves intercept more spray. Arguably this is of little extra benefit as larger weeds are harder to kill.

The above resume of the physical aspects of modes of action show that even with a satisfactory number of spraying opportunities there are other factors occurring before and after the immediate spraying interval that will affect product efficacy, and possibly the need for further treatment.

5.3 Rotational Effects on Spray Programmes

There are two main areas where the rotation affects spray programmes. The first is that the species of crops chosen determine the types of sprays which can be used. The choice of crop ultimately arises from decisions about profitability. This in turn is based on assumptions about yield and selling price of the produce, and the costs of production. There is such a wide range of products available for most crops (table 9), that decisions about production costs based on agrochemical inputs are usually of a general nature e.g. Sugar beet can incur high herbicide costs; spring barley can have low or zero herbicide costs; crops grown on high organic soils like Fen peats face a predictable challenge from high levels of weeds and need a good programme of contact herbicides. At the planning stage example programmes can be priced, but changes in growing and spraying conditions can force a change of product. The sort of modelling done in this report can provide useful guidance about how herbicide programmes should be put together, but only on a general basis. Thus the figures in Table 6 suggest that at Pathhead and High Mowthorpe the low level of spraying opportunities in the January- March period implies either a need for residual autumn herbicides on autumn sown crops, or an increase in spring sown crops.

The other consideration of rotational effects are those arising from the restrictions on the following crops which may be grown using certain herbicides. Table 13 shows some of the commoner restrictions

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Table 13. The effect of herbicide use on subsequent cropping and field operations.

Active ingredient	Restriction
Metsulfuron-methyl	Only cereals, oilseed rape, field beans or grass may be sown in the same calendar year. Only cereals should be planted within 16 months of use in a linseed crop
Metribuzin	Do not sow lettuce or radish in the following year
Linuron/monolinuron	Do not sow with lettuce in the following year
Simazine	Allow at least 7 months before drilling or planting other crops
Trifluralin	Minimum interval between application and drilling or planting may be up to 12 months
Pendimethalin	In the event of crop failure specified crops may be sown after at least 2 months following ploughing to 150 mm.
Terbuthylazine + terbutryn	Subsequent crops may be planted 12 weeks after original use
Terbutryn + trietazine	Plough or cultivate to 15 cm before sowing or planting another crop. Any crop may be sown or planted after 12 weeks (14 wk for brassicas)

Some restrictions are for periods of 12 months or more, whilst others simply restrict the choice of replacement crops within the same year. In horticultural areas lettuce after the potato crop is problematic with both metribuzin and linuron/monolinuron carrying restrictions. However this has a minor impact on most production systems compared with the restriction applying after metsulfuron-methyl. But it is of note that this is one of the most widely used spring herbicides, and was commonly used in this trial series. So although the restrictions exist they have little impact in practice. Those growers wishing to follow their cereals with a sensitive crop like sugar beet use alternative products.

Herbicide resistance is an increasing problem amongst intensive cereal growers with high levels of black-grass infestations, (Orson and Harris 1997). Although not commonplace, it occurs frequently enough to be on the 'check-lists' of reasons for failure when herbicides fail to work. Its occurrence and treatment have been well publicised by the Weed Resistance Action Group (HGCA 1997). Changing the rotation and modifying products used on various crops, along with adopting a 'best practice' cultivation programme are significant tools in overcoming the problem. There are two type of resistance, enhanced metabolism and target site resistance, the former is often associated with residual products like IPU, whilst the latter - which produces a complete failure of herbicides, rather than a marked reduction in efficacy- is linked to the contact graminicides (so-called -fops and -dims). At sites where the number of spraying opportunities are limited, herbicides will be at a higher risk of use in suboptimal conditions (see table 1). Reduced efficacy and the need to repeat treatments are some of the reasons why resistance increases in weed populations. Where effective spray planning and integrated farming methods avoid these conditions they will make a significant contribution towards reducing the spread of herbicide resistance.

5.4 The Impact of 'Contact' and 'Residual' Weather Windows

5.4.1 The Selection of Products

Theoretically, where the weather windows of opportunity are wide, and there are adequate spraying opportunities there is scope for the deployment of contact based herbicides. The timing can meet the crop and weed growth criteria and efficacy is maintained. Where windows narrow and the risks of failure increase, the need is for the more sustained activity obtained from residual products.

However, the treatments listed in table 10 show that the residuals were invariably followed later in the season by contact herbicides. For example, at Sacrewell peas received a pre-emergence residual herbicide each year, and were always followed by post-emergence contact herbicides to deal with later emerging weeds. These were applied in May and June when spraying opportunities for contact herbicides were not limiting. At Pathhead where the date spread of treatments was foreshortened residual and contact herbicides were applied together.

While looking at the impact of weather windows in the January-March period on the selection of products it should be remembered that product selection is affected probably more by what has been used earlier in the season, and what will be used later. This holistic approach reduces the apparent risks arising from an inability to spray during the winter months. The autumn 1998/99 has been an exemplary season for showing the risks of failure to spray at the right time. Many crops were not sprayed at all in the autumn and very limited herbicide spraying was possible in the January - March period; the last two weeks of March saw a very large area of crops sprayed with higher rates of herbicide than would have been required earlier in the season. Yet despite these delays growers have caught up with weed control by killing weeds at later than normal growth stages. Failure to apply herbicides in the limited windows of opportunity between January and March does not represent a critical failure risk for herbicide programmes in either conventional or Integrated farming operations.

5.4.2 Environmental Problems

The IFS spray programmes include more contact spray chemicals. This may dictate a greater reliance on sprays to be applied by nozzles within the "fine" BCPC nozzle classification. This requires a greater level of attention to drift limitation. Recent developments of drift reducing nozzles and drift control systems may therefore be more important with the IFS approach in order that spray opportunities are not missed, particularly in sensitive locations (Young 1991).

Conversely a greater reliance on residual action chemicals within the conventional approach may lessen the drift risks within assessments and allow spray opportunities to be taken more easily without the need to include changes to the application system.

Spray Drift

Spray drift is the most significant environmental risk factor within any pesticide application system. The loss of spray outside the target area constitutes both an environmental nuisance and a financial waste. Selecting a correct opportunity to enable spraying to commence will heavily depend on wind speed and to some extent on application equipment. This latter factor only relates to nozzle selection and use in relation to wind speeds quoted in the MAFF Code of Practice (1998).

Within this study the wind speed limits are those measured by the Meteorological Office at 10 m from the ground. The actual wind speed at boom height (critical for drift) is deemed to be roughly half the figure used, thus fitting the codes recommendation for spraying conditions.

New systems of spray drift control i.e. air entrainment or air assistance have not been considered within this study as the Code of Practice does not currently permit differentiation in wind speeds for such systems (Miller, 1991), (Taylor, 1991). The ability of spraying systems to apply sprays with reduced drift will, however, be one of the factors that will be taken into account in assessing local environmental risk (LERAPS, PSD 1999). Their contribution is considered to be one of reducing drift under normal conditions rather than extending working hours. There is no doubt that with proven data resulting in spraying being possible at higher wind speed, a greater number of spray occasions will be possible and thus increase the potential output from any one sprayer.

Spray Run Off

Spray run off from the target normally occurs when high volumes of water are applied. The application volume of 200 l / ha is considered conventional within this study with little recorded evidence of run off problems. Within combinable crops this volume is unlikely to be exceeded other than for desiccation of oilseed rape for example. Higher volumes are used e.g. up to 400 l/ha to ensure correct contact action but large leaf canopies normally justify this volume and do not normally lead to excess of spray being lost. A contributory factor to drift when desiccants are applied would be the use of higher nozzle working pressures , e.g. around 3.5 bar rather than 2 -3 bar for other treatments. This higher pressure is necessary for small droplet production for contact action, thus attention to windspeeds is again critical.

5.5 Risk Implications of IFS v Conventional

One of the main objectives of this report was to consider whether the spraying requirement of an IFS approach involved more risk than conventional. However, when considering risk, there are always a number of factors to choose from and reducing one risk often raises others.

5.5.1 Production Cost Risks

In most years from April onwards, weather was unlikely to be a limiting factor for spraying. However, for the period January to March, there was a lack of spraying opportunities. It was assumed that there would be a need to apply one contact herbicide during that period. The results are different where more than one application is necessary.

There was a greater lack of opportunities at more northerly sites, with the least available at Pathhead. Where winter wheat and winter oilseed rape are included, the model assumed a requirement for at least one early spring contact spray in the January to March period. Rotations with a high proportion of these crops will require the capacity to take account of it. At Pathhead, of the five courses in the Integrated rotation, only the two winter wheat crops required spring treatment. Rotations with spring crops avoid the early spring period and have a higher requirement for spraying opportunities in the later spring and summer.

In this context, the risks to production arise from:-

1) Failure to apply an early spring spray due to poor weather
2) Failure to apply an early spring spray due to insufficient machine capacity
3) Transferring the demand for spray opportunities to later spring and experiencing the same problems as 1 and 2 together higher treatment costs.

There will be various consequences of these, such as allowing black-grass to become established in wheat, resulting in substantially lower yield and difficult harvesting due to green material in the crop. It is for this reason that farmers have historically over invested in machinery capacity. Additionally other pesticides need to be applied during the January-March period, such as insecticides for the control of wheat bulb fly and fungicides for the control of light leaf spot and phoma on oilseed rape.

5.5.2 Model v Actual Requirements

The modelled requirements for the actual crops grown at the trial sites structures the rotations in an idealised format, see Appendix 3. In this format the systems are truly comparable; field areas and layout are equal, access times are equal and the inevitable daily operating problems are all equal between the conventional and Integrated systems. In this model state, the IFS has a lower requirement for a single spray opportunity (5 five hour occasions per annum *cf.* 6.45 for conventional - Table 7). In reality, however, the Integrated systems needed more 'opportunities' to apply slightly more sprays (Table 11), 4.43 sprays over 5 years compared to 4 on the conventional systems. The small differences highlight the problems of trying to look at statistically valid subsets of data drawn from multi-year system comparisons, and would probably be non-significant if valid comparisons could be made.

Because of the small differences and variability in the experimental data, more objective comparisons are available from the model. This suggests that due to rotational differences, IFS is a lower risk option in spite of a higher use of contact sprays that the conventional system.

The rate of contact sprays used by the two systems expressed in terms of IFS: conventional was 1.3:1 in the experiment and 1:1.3 in the model. The reasons for this reverse are the management in the experiment and rotations in the model. That is more contact sprays were used on IFS in the experiment, although the rotation requirement was greater in conventional.

5.5.3 Environmental Risks

The environmental risks arising from drift and run-off are unlikely to occur within the model parameters of the spraying opportunities. However, this is a prediction based on probabilities and for each operation it is always uncertain whether wind strengths will build up during operations or if rain will begin once spraying has started or shortly after completion before the product is reinvest.

As with production risks, the fact that IFS rotations had a lower requirement for spraying opportunities means that they are inherently less risky than conventional.

The occurrence of 'bad years' shows that where spraying opportunities are limiting, an operation may have been started and left incomplete due to wind or rain inevitably increasing the environmnetal risk.

Extent of the Project

This project was limited to the IFS sites and soil types. Further extension of the study to cover all of England and Wales would provide an assessment of the advantages of IFS in all relevant farm situations nationally

IFS has begun to be promoted nationally both directly and as a result of such schemes as ACCS and the appearance of LERAPS and no spray zones.

Looking at the results of the IFS project, it is clear that there was often little difference between conventional v IFS approaches. It has been acknowledged elsewhere that IFS was not a fixed system and much of it had to be learnt as the project developed. Larger differences between IFS and conventional regimes would have produced larger differences in the results of this project.

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Residual Spray and LGP Vehicles

Temperature must be greater than 1°C whilst spraying

Hourly rain must be less than 1.0mm

*********** General criteria ********************

Daylight but not outside normal working day (06-20)

Visibility greater than 100m whilst spraying

No standing water,glaze,or frozen ground at 1200hrs

Wind limit 1:

Not greater than 9kt but always above 1kt

Wind limit 2:

Not greater than 13kt but always above 1kt

Suitable conditions must prevail for 5 consecutive hrs

APPENDIX 2

Site Data

TURNHOUSE

Average Number of Spray Occasions
LGP Vehicles - Contact Herbicide

Wind Speed		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	Spring	Bad Years (Conv)	Bad Years (IFS)
0<OR= 9 KNTS	1986	0	0	0	3	3	19	12	23	13	5	1	0	79	0	1	1
0<OR= 9 KNTS	1987	2	2	1	17	12	28	29	34	15	5	5	1	151	5	1	0
0<OR= 9 KNTS	1988	1	1	2	12	17	44	10	19	13	13	2	3	137	4	1	1
0<OR= 9 KNTS	1989	2	1	1	5	19	33	34	12	21	12	3	2	145	4	1	1
0<OR= 9 KNTS	1990	1	0	1	10	36	27	24	18	20	8	2	1	148	2	1	1
0<OR= 9 KNTS	1991	4	0	7	1	19	26	19	24	23	15	1	1	140	11	0	0
0<OR= 9 KNTS	1992	3	1	0	10	12	28	20	14	17	11	1	0	117	4	1	1
0<OR= 9 KNTS	1993	1	1	3	10	19	22	13	22	18	5	2	0	116	5	1	0
0<OR= 9 KNTS	1994	1	0	2	2	7	11	22	34	14	13	5	2	113	3	1	1
0<OR= 9 KNTS	1995	0	0	0	5	10	22	19	27	22	8	4	2	119	0	1	1
	Mean	1.5	0.6	1.7	7.5	15.4	26	20.2	22.7	17.6	9.5	2.6	1.2	126.5	3.8	9	7

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Site Data

LEEMING

Average Number of Spray
Occasions
LGP Vehicles - Contact Herbicides

Wind Speed		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	Spring	Con Bad Years	IFS Bad Years
0<OR= 9 KNTS	1986	0	0	2	3	8	28	15	22	22	17	4	1	122	2	1	1
0<OR= 9 KNTS	1987	0	0	2	23	11	11	30	29	18	12	6	1	143	2	1	1
0<OR= 9 KNTS	1988	0	0	0	9				15	15	7	0	1	47	0	1	1
0<OR= 9 KNTS	1989	5	1	3	2	29	26	33	18	21	14	11	6	169	9	0	0
0<OR= 9 KNTS	1990	4	1	3	7	39	21	32	19	19	11	6	2	164	8	0	0
0<OR= 9 KNTS	1991	0	2	8	7	21	15	25	36	23	18	4	6	165	10	0	0
0<OR= 9 KNTS	1992	2	1	2	8	20	35	22	13	21	3	2	1	130	5	1	0
0<OR= 9 KNTS	1993	2	2	1	7	15	25	12	28	20	8	9	0	129	5	1	0
0<OR= 9 KNTS	1994	1	0	0	1	13	15	42	22	10	17	10	0	131	1	1	1
0<OR= 9 KNTS	1995	1	0	2	3	10	8	20	38	23	8	12	2	127	3	1	1
	Means	1.50	0.70	2.30	7.00	18.44	20.44	25.67	24.00	19.20	11.50	6.40	2.00	139.16	4.5	7	5

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APPENDIX 2

Site Data

SHAWBURY

Average Number of Spray Occasions
LGP Vehicles - Contact Herbicides

Wind Speed		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	Spring	Conv Bad Years	IFS Bad Years
0<OR= 9 KNTS	1986	1	0	2	4	9	32	26	29	37	15	1	2	158	3	1	1
0<OR= 9 KNTS	1987	3	1	3	29	19	21	27	29	22	14	10	5	183	7	0	0
0<OR= 9 KNTS	1988	3	1	3	10		39	12	27	16	17	2	4	134	7	0	0
0<OR= 9 KNTS	1989	3	2	5	5	35	34	38	19	27	14	7	7	196	10	0	0
0<OR= 9 KNTS	1990	1	1	5	9	41	23	30	24	17	10	6	0	167	7	0	0
0<OR= 9 KNTS	1991	0	1	9	2	22	11	23	36	31	16	3	3	157	10	0	0
0<OR= 9 KNTS	1992	3	5	3	11	23	34	19	16	17	3	3	2	139	11	0	0
0<OR= 9 KNTS	1993	2	10	2	14	18	36	16	31	22	9	6	0	166	14	0	0
0<OR= 9 KNTS	1994	2	3	0	2	24	16	34	30	21	15	12	2	161	5	1	0
0<OR= 9 KNTS	1995	1	1	0	10	18	24	25	43	26	12	8	3	171	2	1	1
	Mean	1.90	2.50	3.20	9.60	23.22	27.00	25.00	28.40	23.60	12.50	5.80	2.80	165.52	7.6	3	2

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APPENDIX 2

Site Data

WYTON

Average Number of Spray Periods
LGP Vehicles - Contact Herbicides

Conv IFS

Wind Speed		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual	Spring	Bad Years	Bad Years
0<OR= 9 KNTS	1986	2	0	4	4	9	27	25	24	27	18	6	2	148	6	1	0
0<OR= 9 KNTS	1987	3	5	1	26	21	30	32	32	21	16	10	5	202	9	0	0
0<OR= 9 KNTS	1988	1	3	4	13	19	29	5	26	17	20	6	13	156	8	0	0
0<OR= 9 KNTS	1989	3	1	8	7	33	27	33	18	27	15	6	7	185	12	0	0
0<OR= 9 KNTS	1990	3	0	7	8	42	24	30	33	24	9	11	2	193	10	0	0
0<OR= 9 KNTS	1991	1	1	9	6	29	16	31	33	25	19	9	5	184	11	0	0
0<OR= 9 KNTS	1992	5	6	6	11	25	32	28	15	16	6	2	1	153	17	0	0
0<OR= 9 KNTS	1993	4	9	3	11	12	38	13	24	23	7	7	1	152	16	0	0
0<OR= 9 KNTS	1994	2	2	1	2	14	20	30	22	15	16	16	2	174	5	1	1
	Mean	2.67	3.00	4.78	9.78	22.67	27.00	25.22	25.22	21.67	14.00	8.11	4.22	172	10.44	2	1

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APPENDIX 2

Site Data

HEATHROW

Average Number of Spray Periods
LGP Vehicles - Contact Herbicides

Conv IFS

Wind Speed		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total	Spring	Bad Years	Bad Years
0<OR= 9 KNTS	1986	3	0	5	10	14	35	39	35	35	23	8	0	207	8	0	0
0<OR= 9 KNTS	1987	4	4	2	25	28	26	36	42	30	18	8	8	231	10	0	0
0<OR= 9 KNTS	1988	3	3	6	15	28	33	9	31	24	25	6	14	197	12	0	0
0<OR= 9 KNTS	1989	6		13	16	40	36	44	36	38	23	10	9	271	19	0	0
0<OR= 9 KNTS	1990	5	2	12	9	39	28	36	45	32	12	16	1	237	19	0	0
0<OR= 9 KNTS	1991	3	3	13	11	37	22	30	44	36	25	11	5	240	19	0	0
0<OR= 9 KNTS	1992	5	10	10	22	37	40	38	24	29	13	9	5	242	25	0	0
0<OR= 9 KNTS	1993		12	12	29	38	40	33	42	26	8	7	3	250	24	0	0
0<OR= 9 KNTS	1994	6	7	2	11	30	38	45	31	29	24	18	3	244	15	0	0
0<OR= 9 KNTS	1995	1	5	11	34	39	45	40	49	29	34	15	6	308	17	0	0
	TOTAL	4.0	5.1	8.6	18.2	33.0	34.3	35.0	37.9	30.8	20.5	10.8	5.4	243.6	16.8	0	0

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APPENDIX 3

200 Hectare Farm showing Conventional and IFS rotations

200 Site	HM		RM		MD		PH		SC		BX	
Crops	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int
W W	45	45	45	45	40	40	45	45	45	45	40	40
SAS	20	20	20	20			20	20	20	20		
WOSR	45		45		40	40	45				40	
WW	45	45	45	45	40	40	45	45	45	45	80	80
Seed P	45	45										
Spring Beans		45		45								
Potatoes			45	45					45	45		
Spring barley					40	40		45				
Peas					40	40			45	45		
W Barley							45					
S OSR								45				
W Beans											40	40
Linseed												40
possible applications												
Jan - Mar												
W W	45	45	45	45	40	40	45	45	45	45	40	40
WOSR	45		45		40	40	45				40	
WW	45	45	45	45	40	40	45	45	45	45	80	80
Total ha	135	90	135	90	120	120	135	90	90	90	160	120
Hours @ 4ha/h	33.75	22.5	33.75	22.5	30	30	33.75	22.5	22.5	22.5	40	30
no of spray occs	6.75	4.5	6.75	4.5	6	6	6.75	4.5	4.5	4.5	8	6
Ecospray actual occs	4.5	4.5	7.6	7.6	16.8	16.8	3.8	3.8	9.4	9.4	9.4	9.4
Margin %	-50.0	0.0	11.2	40.8	64.3	64.3	-77.6	-18.4	52.1	52.1	14.9	36.2

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APPENDIX 3

300 Hectare Farm showing Conventional and IFS rotations

350 Site	HM		RM		MD		PH		SC		BX	
Crops	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int	Conv	Int
W W	78.75	78.75	78.75	78.75	70	70	78.75	78.75	78.75	78.75	70	70
SAS	35	35	35	35			35	35	35	35		
WOSR	78.75		78.75		70	70	78.75				70	
WW	78.75	78.75	78.75	78.75	70	70	78.75	78.75	78.75	78.75	140	140
Seed P	78.75	78.75										
Spring Beans		78.75		78.75								
Potatoes			78.75	78.75					78.75	78.75		
Spring barley					70	70		78.75				
Peas					70	70			78.75	78.75		
W Barley							78.75					
S OSR								78.75				
W Beans											70	70
Linseed												70
W W	78.75	78.75	78.75	78.75	70	70	78.75	78.75	78.75	78.75	70	70
WOSR	78.75		78.75		70		78.75				70	
WW	78.75	78.75	78.75	78.75	70	70	78.75	78.75	78.75	78.75	140	140
	236.25	157.5	236.25	157.5	210	140	236.25	157.5	157.5	157.5	280	210
Hours @ 7 ha/h	33.75	22.5	33.75	22.5	30	20	33.75	22.5	22.5	22.5	40	30
no of spray occs	6.75	4.5	6.75	4.5	6	4	6.75	4.5	4.5	4.5	8	6
Ecospray occs	4.5	4.5	7.6	7.6	16.8	16.8	3.8	3.8	9.4	9.4	9.4	9.4
Margin %	-50.0	0.0	11.2	40.8	64.3	76.2	-77.6	-18.4	52.1	52.1	14.9	36.2

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