Integrated Pest Management Portfolios in UK Arable Farming: Results of a Farmer Survey

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Abstract

BACKGROUND. Farmers are faced with a wide range of pest management (PM) options which can be adopted in isolation or alongside complement or substitute strategies. This paper presents the results of a survey of UK cereal producers focusing on the character and diversity of PM strategies currently used by, or available to, farmers. In addition, the survey asked various questions pertaining to agricultural policy participation, attitude toward environmental issues, sources of PM advice and information and the important characteristics of PM technologies.

RESULTS. The results indicate that many farmers do make use of a suite of PM techniques and that their choice of integrated PM (IPM) portfolio appears to be jointly dictated by farm characteristics and Government policy. Results also indicate that portfolio choice does affect the number of subsequent insecticide applications per crop.

CONCLUSIONS. These results help to identify the type of IPM portfolios considered adoptable by farmers and highlight the importance of substitution in IPM portfolios. As such, these results will help to direct R&D effort toward the realisation of more sustainable PM approaches and aid the identification of potential portfolio adopters. These findings highlight the opportunity a revised agri-environmental policy design could generate in terms of by enhancing coherent IPM portfolio adoption.

Key Words: Pest management, pesticide alternatives, technology and portfolio approaches.

1. INTRODUCTION

The aim of the work described in this paper is to first assess the current commercial adoption of a range of alternative pest management techniques in UK arable agriculture. Secondly, to investigate whether these techniques, if used, are employed in IPM portfolios or in isolation and if portfolios exist, to discover the range of portfolio approaches adopted. Here, the objective is to discover which techniques combine to form IPM portfolios so that further scientific effort can address portfolio interactions among techniques and so to improve the impact of further science funding. The work also addresses economic drivers for, and other determinants of, commercial IPM adoption and considers the potential for IPM to produce gains in terms of pesticide use reductions on farms.

Pest management scientists have long realised that ecological approaches to pest management are necessary to ensure the sustainability of food supplies, the natural environment and other natural resource systems (see Kogan[1] for a review of the history and drivers of modern IPM approaches). Some scientists argue that reliance upon chemical pesticide toxicants produces an extreme form of ecological disturbance which enhances system imbalances, resurgence occurrences and may see reduced efficacy in the longer run (Trumper and Holt[2], Lewis *et al*[3], Thomas[4]). Others argue that pesticide resistance is an inevitable consequence of an over-reliance on the pesticide approach (Devonshire *et al*[5], McCaffery[6], Bata[7] and Hoy[8]) and that increased registration requirements ensure that new chemical products and modes of action will become prohibitively expensive to deliver (Chandler *et al*[9]). Chandler *et al*[9] argue that the problem of pesticide scarcity is already emerging in the case of minority specialist crops in both Europe and the US. Both of these schools of thought argue that farmers cannot expect to rely on toxicant pest control technology in the long-run and that there may be a strong argument that this technology, at least when used alone, has already run its course.

Bio-control might be an attractive alternative and much research has been done on a range of options including the introductions of beneficial organisms, conservation bio-control, sterile release strategies and pheromone induced behavioural management approaches (Waage and Mills[10]). However, in isolation, their efficacy to cost ratios appear less attractive than that of chemical control. Both Thomas[4] and Lewis *et al*[3] caution against the search for 'silver bullets' and suggest that combined, or integrated, systems approaches are required while Stiling and Cornelissen[11] find that efficacy improves with an increased number of bio-control options. The notion of Integrated Pest Management (IPM) has become a dominant paradigm in minority crop or high value systems in order to cope with pesticide resistance problems or zero pesticide residue tolerance at the marketing stage. However, the viability of IPM in arable systems will likely require farmers to consider the effect of pesticide use on bio-control mechanisms, future pest events and the erosion of pesticide efficacy (Thomas[4]). As Chandler *et al*[9] point out, chemical pesticides should be treated as a precious resource, subject to erosion by biological resistance and under attack from regulatory processes[i],which need to be managed through sparing use. Biological and cultural alternatives have a role to play here. However, pesticide resistance, and possibly bio-control performance, is affected by the collective action of all farmers. Individually each farmer cannot hope to capture all of, or to exclude others from, the benefits (or costs) of their own actions to preserve (or over exploit) pesticide effectiveness. As such, individual farmers incentives to change their practices will be blunted.

IPM portfolios will include a number of PM methods that may be complements to each other, or substitute for each other. Here, complementarity between techniques would result in an increased efficacy of each pest control technique. PM techniques might complement each other by enhancing control at specific sites; across space, either from field margin to field centre or from ground level to crop canopy; or across time, from early to late season activity, when used in combination. Stiling and Cornelissen[11] and Holland and Oakley[12] both discuss empirical research which has found some support for this functional relationship between techniques. Furthermore, the use of techniques which can substitute for one another[ii], by building in resilience

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[i] These may also take the form of informal regulation enforced via sales contracts instigated by retailers or other actors further up the food supply chain as well as via the action of the Pesticide Safety Directorate in the UK and the EU under directive 91(414).

[ii] Functional substitutes are often, rather derogatively, referred to as functional redundance in the applied ecological literature.

into systems, could prove highly effective at controlling the variance of the pest control function (Fonseca and Ganade[13]). Griffiths *et al*[14] also argue that it is important to consider the way in which IPM efficacy changes as IPM adoption increases in scale beyond the single farm and toward the wider landscape of neighbouring farms. Therefore, the evaluation of PM technologies needs to be considered at both a portfolio level and at a range of adoption scales.

Despite the potential for pesticide use to reduce the effectiveness of alternative pest management strategies Holland and Oakley[12] argue that these chemicals will remain an important component of the pest management tool kit. However, they recognise that lower doses may well be required to ensure that various technologies are not antagonistic. Despite the realisation of the fact that certain types of pest management strategies can be beneficial, if practiced in particular ways, very little is know about the actual portfolio of techniques currently adopted on farms. Lohr and Park[15] considered how the mix of PM technologies adopted by organic apple farmers in the US is influenced by various farm specific characteristics, but this is a rare example reported in the literature to date.

This paper reports the findings of a survey of UK cereal producers, concentrating on the adoptions of pest management techniques on commercial farms. Farmers were asked a series of questions aimed to discover what 'attributes' of PM technologies they considered as desirable and their attitudes and preferences toward pest management techniques. They were asked about the number and type of pest management techniques they currently use, have trialled but no longer use, or might use in future. The results allow an investigation into the range of pest management strategies used, and an assessment of which techniques combine to form IPM systems within a commercial farming context. Thus, unlike much of the existing literature on pest management and pesticide use, the work reported here is less concerned about the adoption of a new technology *per se* but rather the mix of technologies adopted in an effort to control pests in cereal crops.

The structure of this paper is as follows. An overview of the current important agricultural policy influences on the use and adoption of land use and farm practices for pest management in arable systems is given (Section 2). The development of the survey instrument is discussed (Section 3) and the sample characteristics and the key variables collected are described (Section 4). The results are analysed and conclusions are drawn in the final sections.

2. PEST MANAGEMENT AND AGRICULTURAL POLICY

If well targeted, both agricultural and agri-envionmental policy (AEP) can give rise to landscapes that support a large number of arthropods including pests and their natural enemies. Holland and Oakley[12] note that well-managed hedgerows which include substantial shrubby components plus a two metre floristically diverse hedge-base and beetle banks, all of which are promoted within AEP, provide the best potential habitat for enhanced populations of beneficial insects. AEP could play a key role in the IPM adoption process. As Cowen and Gunby[16] point out, in the competition between technologies which perform similar roles, the choices made by early innovative producers will likely influence the technology adoption decisions of those who follow. This is especially so if the technologies involved exhibit increasing returns to scale. These scale economies could stem from 'learning by doing', falling information costs, scale economies in product manufacture and scale effects in the pest control process itself. If so then the 'first' technology to be adopted (in this case chemical control) will likely become cheaper and more effective to use for both current and new adopters, even if the alternative (IPM) is potentially superior. Subsequently, technology choice will likely be 'path dependant' and chemical control may remain 'locked-in' simply because it generates more benefit to the user than the alternative could at its' current scale of adoption. AEP may then help to improve the financial return of IPM to farmers if a sufficient scale of IPM land use adoption can be primed in by financial policy incentives[iii].

Currently, there are a number of strong agricultural policy drivers for farmers to adopt a range of different PM strategies, both consciously and unconsciously. The Environmental Stewardship (ES) scheme was introduced in England in 2005 following the closure of the Countryside Stewardship Scheme (CSS) to new applicants. The ES is composed of Entry Level Stewardship scheme (ELS), Organic Entry Level Stewardship scheme (OELS) and the Higher Level Stewardship scheme (HLS). Parallel programmes exist for Wales, Scotland and Northern Ireland managed by the devolved administrations.

ELS and OELS are highly relevant and can potentially influence PM. The ELS scheme is open to all land managers in England. Applicants select a number of environmental commitments each of which earn a prescribed number of points toward a threshold of 30 points per hectare which guarantees entry. ELS contracts are initially for 5 years extendable to 10 years. Currently, the ELS payment is set at £30/ha per annum. For the organic sector, the OELS is very similar in terms of how it operates albeit with slightly modified objectives, management options and a higher payment rate of £60/ha per annum.

The Voluntary Initiative (VI) on pesticides was introduced to bring about best practice in pesticide use by initiating research, training, communication and stewardship[17]. The VI introduced Crop Protection Management Plans (CPMPs), a self audit of farm level crop protection activities. CPMP considerations include the storage, handling and application of pesticides and emphasise the integration of cultural options such as crop rotations, cultivation regimes, resistant varieties and practices to promote natural predators, eg beetle banks and unsprayed field margins. CPMPs are at present estimated to cover some 1.5 million hectares in England, and 39.5% of all farms in the ELS. They attract 2 points per hectare toward the ELS threshold.

The options farmers undertake within the ELS can, to some degree, be used to see what farmers are currently doing with respect to pest management. Boatman *et al*[18] report that 16% of English farmers covering 3.5 million hectares participate in the various ES schemes with the highest proportion being in Eastern regions. Arable farmers are the largest group of participants both in terms of number and area and they have adopted the largest number of options in the ELS per farm. Boatman *et al*[18] found that the most popular options include hedge and ditch management, field corner management and 4m and 6m buffer strips on cultivated land. Those options which

[iii] Primary production assurance schemes and some retailer schemes may also provide farmers with incentives to adopt IPM approaches.

proved less popular include the use of wild bird seed mix or pollen and nectar mix on set aside, beetle banks, skylark plots, conservation headlands and uncropped cultivated margins on arable land, and all options to encourage a broader range of crop types on farms. For the organic sector, some 167,000 hectares were entered into the OELS mostly in the South West. The percentage of arable farms entering the scheme is very low, although cereal farmers have enrolled the largest total area. It is also noted that very few organic farmers adopted either beetle banks or skylark plot options.

Boatman *et al*[18] note that the main reason given by farmers for the adoption of particular options in both the ELS and OELS was the points gained and therefore choice has been motivated by financial concerns.

Therefore, it is clear that AEP has produced real change in farm practices which could have PM implications. However, little is known about the impact of AEP on the adoption of IPM portfolio combinations or the effect of portfolio choice on pest control and chemical pesticide use. The remainder of this paper is devoted to addressing these questions with the help of a survey of commercial farmer practice.

3. SURVEY DESIGN AND DISTRIBUTION

3.1. Survey Design

A pilot study was employed to provide preliminary evidence regarding the adoption of a portfolio of strategies and to aid the design of the main survey instrument. It was distributed to 152 farmers and a 25% response rate was obtained. These returns helped to establish the mix of qualitative and quantitative content of the final questionnaire and to ensure that the content of the final questionnaire was grounded in a reality familiar to respondents.

3.2. Survey Distribution

In order to reach a large sample of UK cereal producers it was necessary to obtain an industry specific mailing list. This was achieved by distributing the questionnaire using the UK's Home Grown Cereals Authority newsletter mailing list. The mailing list contains the name and address of 30,000 British cereal growers. The survey instrument was sent out to 7,500 randomly selected names on the mailing list.

For reasons of cost, a single mail out strategy with no follow-up was employed. The size of the mail-out was determined by prior expectation of the likely response rate which was anticipated to be 10% based on previous survey work in this area (ADAS[19])[iv].

3.3. Survey Returns and Response Rate

From the 7,500 surveys distributed 645 were returned. There are likely three main reasons why the response rate was low. Firstly, it was a single mail-out survey with no follow-up or media campaign to support the survey. Secondly, a number of returns indicated that the quality of the mail-out was at times poor with no survey instrument included in the materials dispatched. Thirdly, several of the addressees to were either not, or were no longer, farmers. Therefore, the size of the return can be considered reasonable. However, following the screening of returns for non-participation, or incomplete responses, the sample fell to 571 useable observations. Overall, the total number of returns compares reasonably favourably with that of ADAS[19].

4. SURVEY DATA

4.1. Reliability of the Sample

Survey respondents were asked to classify their type of farming operation. Of the 571 useable returns 39% were from arable farms, 7% from livestock and 52% from mixed farms. The average farm size was 295 hectares including an average of 177 hectares owned by the farmer. The main arable crops grown were wheat (435 growers) and barley (428 growers).

The survey returns can be benchmarked for reliability in several ways. First, following ADAS[19], the proportion of respondents registered as organic can be

[iv] ADAS[19] employed a mail survey with reminder letters and their survey was also given publicity in the media.

considered. ADAS had 4% of their sample for cereals compared against 3.2% from Soil Association 2001 statistics. The sample used for this research can be broken down into 92.6%, conventional farms, 5.4% organic and a further 1.9% farms with both conventional and organic activity which is in keeping with the percentages reported by ADAS[19].

The majority, of the respondents were farm owners, 69%. Tenant farmers comprised 22% and 9% were farm managers. Less than 1% of the returns were completed by 'engaged' or consulting agronomists. Therefore, the majority of the returns were completed by those responsible for developing and implementing farming practice. With respect to the type of business operation 83% were full-time farms, 11% were part-time farms, 2% were part of large agri-businesses and 3% uncategorised. Land area devoted to production and yields can also be considered. DEFRA[20] report that the average area used to grow cereals in 2005 was 51.7 hectares but this corresponds to an average for all farm types. Data from this survey reports that the average area of wheat grown is 94 hectares and the average area of barley grown is 44 hectares. In terms of production DEFRA[20] report that the mean yield for wheat is 8 tonnes per hectare and for barley is 5.9 tonnes per hectare. The survey respondents report a mean yield for milling wheat of 8.6 tonnes per hectare, for feed wheat of 8.8 tonnes per hectare, for malting barley of 6.7 tonnes per hectare and feed barley of 8.4 tonnes per hectare. Thus, the sample figures are once again comparable with the population statistics.

4.2. Pesticide Application Advice

Respondents were asked to identify all of their sources of insecticide application advice, allowing for multiple responses from individual farmers, and to indicate their most important source of advice. These results are summarised in Figure 1 which details the proportion of respondents ranking each source as 'most important' and the proportion of all responses using each source in total.

{Approximate Position of Figure 1}

Figure 1 shows that the majority of farmers rely upon the advice of an independent adviser/agronomist when it comes to decisions regarding the use of insecticide. These results are in keeping with the literature. The DEFRA Pesticide Usage Survey (Garthwaite *et al*[21]) and ADAS[19] both confirm that most arable farmers rely on the advice of agronomists'. None of the respondents who claimed to be agronomists reported use of any additional information sources.

Very few farmers claim to consult either, decision support systems, other farmers or government bodies for pesticide use advice. When considering all of the information used by farmers, the first point worth noting is that about 41% of the sample report that they use multiple sources and that 11% of the sample consulted 3 or more advices sources when formulating their pest control programmes. Furthermore, it is clear that, while much weight is given to the advice of independent advisors or agronomists, these advisors do appear to be supported, in no small measure, by a wide range of other professionals, acquaintances and their own experience.

4.3. Attitudes Toward Pest Management Technologies

Farmers were next asked about their attitudes toward a range of attributes of new pest management strategies. Respondents ranked the desirability (rank 1=high to 9=low) of a range of attributes that new pest management technologies could possess. The attributes chosen span the spheres of safety, environmental impact and on farm resource use. Figure 2, records the % of respondents reporting a high importance (<5) and the mean importance score for each attribute.

{Approximate Position of Figure 2}

Figure 2 shows that farmers' rate "Be Effective" very highly but also consider environmental safety to be a very important attribute. These two attributes also received a very high proportion of rank 1 scores. These results bear out those previously reported by ADAS[19]. "Operator Safety" is also important with more than 60% of respondents ranking this attribute highly. Only half of the respondents were concerned with attributes regarding crop quality and simplicity of use of new technologies. Of least importance are those attributes concerning the use of on-farm resources of land, labour and machinery. This suggests that farmers may be willing to consider adopting technologies which require the diversion of land from production (beetle banks for example), or the use of labour for careful monitoring (pheromone control for example) or the understanding of complex pest-prey ecology (the introduction of parasites/predators of insect pests for example).

4.4. Agricultural and Agri-environmental Policy Participation

Given the potential for government policy to induce adoption of practices conducive to IPM an investigation of AEP participation by members of sample may shed light on adoption patterns. These results are reported in Figure 3.

{Approximate Position of Figure 3}

Figure 3 shows that of the six schemes considered, the ELS has the highest rate of participation at approximately 55% of survey respondents. By comparison, the results reported in Boatman *et al*[18] report that almost 20% of farmers participate in the ES generally. This finding would suggest that this survey may yield an over representation of particular pest management activities which attract a financial incentives as part of the ELS. There is also quite a division between those participating in the VI and those not.

4.5. Pest Control Methods

Respondents were asked to report the extent and mix of pest, disease and weed control technologies adopted on their farms from a prescribed list of technologies. Respondents were asked to indicate whether each technology 1. is currently used, 2. has been discontinued, 3. would not be considered or 4. may be considered for future use. The results of this question for the 17 pesticide alternative practices are reported in Figure 4.

{Approximate Position of Figure 4}

The results reported in Figure 4 show a clear divide between a group of pest management practices that are widely adopted and a group that are far less prevalent. Many of these results are as would be expected *a priori*. The relatively large number of farmers using improvements in field margins and can be explained by the fact that these attract AEP initiatives and are a marginal addition to a land management practice required for receipt of the Single Farm Payment (SFP). The results of this survey indicate 53% of farmers actively choose cultivars based on resistance to the pest and disease problems they face. ADAS[19] estimated that 88% cereal growers claimed to be using (always or mostly) resistant varieties. However, DEFRA research, quoted in ADAS, indicates closer to 40%, so the discrepancy with the result of ADAS is likely a result of the wording of the respective questions.

Few of the technologies appear to have been discontinued following a trial phase. The highest response is 14%. This would suggest that, if farmers do trial a technique, they are highly likely to adopt it. There would appear to be some reticence to trying some of the technologies, although only for 2 technologies would more than 40% of farmers never consider adoption (mixed varieties and trap crops). As such, all of the technologies considered here have the potential to be tried, and adopted, by the majority the survey respondents.

While this raw data does suggest that farmers are using quite a wide range of technologies to protect their crops, further analysis is required to investigate the relationships between individual technologies in detail.

5. DATA ANAYSIS

5.1. Pest Management Portfolios

This section presents the results of analysis conducted to discover the mix, or portfolios, of pest management strategies adopted by farmers. Principal Component Analysis (PCA) is applied to the adoption data discussed in Section 4.5 in order to summarise that raw data into coherent aggregates or latent factors. This approach is valid in this case since there is little or no theory which can guide the specific modelling of potential complementarity, or substitution, relationships between the PM techniques considered here. In this analysis the original data used are binary variables recording the current, and likelihood of future, adoption of a technology. For each technology, the corresponding dummy takes value 1 if the technique is either currently adopted or considered for trial in the near future, and 0 otherwise. The analysis will reveal a set of latent factors, which allow the characterisation of potentially heterogeneous pest management techniques into more homogeneous aggregate approaches. By examining the techniques which appear important in each latent factor, information is gained about the types of techniques which appear to work best together, address farm specific problems or fit best within a farming system, as distinct portfolio practices.

Before commencing the PCA itself an examination of the variables in questions in terms of the degree of interdependence between them is performed.[v] Both tests indicate that PCA is appropriate in the case of the adoption data used here. Next, the number of factors which best describe the data are considered. Only those factors which describe a significantly large amount of variation in the original data are retained[vi]. Table 1 presents the rotated factor matrix of the resulting four PM factors. Only the factor loading scores greater than of 0.36, showing important association, are reported in Table 1. Double asterisks in Table 1 are used to mark those factor loadings with values less than zero, showing clear disassociation between an individual technology and a PM factor.

{Approximate Position of Table 1}

As shown in Table 1, the data suggest that 4 factors best summarise the raw data. For each factor, or portfolio a mutually exclusive subset of the distinct pest management techniques can be identified. From this statistical association inference can be made about the types of techniques which form a separable pest management portfolio. Table 1 includes a characterisation of each of the portfolios. These portfolio names relate to the potential motivation farmers might have considered when deciding on what approach to take. Clearly, this process is somewhat arbitrary and one might think up many alternative characterisations of these groups.

Portfolio 4 appears to characterise the approach likely taken by farmers who face significant weed problems. This cluster of techniques includes the adjustment of timing of planting and field operations in combination with rotating crop types and cultivation practices, all of which should be potentially beneficial in the control of many important arable weeds, including black grass and wild oats. While crop rotations are often used to promote soil fertility and to limit fungal disease or other soil-bourn problems, rotation can also widen the fallow window which provides the opportunity to employ cultural weed control practices. In addition, hand rogueing of these weeds maybe associated with important or localised infestations. Both treated seeds and rotating pesticide classes are negatively associated with this portfolio.

Farmers adopting Portfolio 2 might potentially be, but not exclusively, concerned about the prevalence of fungal plant diseases. In particular, the use of seed treatments, the selection of resistant varieties and using a number of distinct crop varieties all might help reduce crop disease problems. In addition, given the relative importance of fungal disease (in terms of the number of pesticide applications per crop) the importance of rotating pesticide classes in the face of potential pesticide resistance could explain its importance in this factor. Beetle banks, hand rogueing and the use of mixed crop varieties are negatively associated here although the latter could be beneficial in fungal disease control.

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[v] This is typically done by employing Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. The Bartlett test statistics reported here is 1660.6, distributed as χ^2, which has a p value $p<0.000$ and the KMO statistic for the data is reported at 0.804 and therefore is greater than 0.6, a minimum level for this type of analysis. Bartlett's test indicates

[vi] This is performed by selecting only those factors for which the corresponding eigenvalue exceeds unity. An eigenvalue is computed for each component and provides an objective measure of the amount in variation in the original data explained by that component or factor. Selecting only those components with an eigenvalue greater than 1 limits the analysis to only important explanations of variability.

The motivation for adopting each of the two remaining approaches appears likely based upon the management of insect pests. Portfolio 1 appears to include the forms of techniques which can be conducted within (but not exclusively) a single crop, while those constituting Portfolio 3 appear to be activities conducted external to the crop. More fundamentally, the techniques included in Portfolio 3 are those designed to enhance the population of control agents, whereas those in Portfolio 1 appear to be those designed to make best use of existing (and enhanced) background populations of beneficial species. As for the technologies which appear to be negatively associated with these portfolios, using cultivation practices to suppress weeds is not associated with Portfolio 3 while spot spraying and hand rogueing are not associated with Portfolio 1. Overall, there appears to be a fundamental split in bio-control approaches between conservation bio-control, as described by Portfolio 1, and bio-control manipulation, exemplified in Portfolio 3.

5.2. Explaining Portfolio Choice

The next step is to attempt to explain portfolio choice using data on farm characteristics recorded in the survey. Linear regression is used to detect association between the set of farm characteristics and the factor scores derived from the PCA performed on currently adopted pest management practice data only. Four separate regressions have been performed, one for each set of factor scores from the PCA, as dependent variables. Table 2 summarises the results of the 4 regression equations performed. Each model includes the same set of farm characteristics.

{Approximate Position of Table 2}

This analysis sheds very little light on Portfolio 1, the ‘Intra Crop Bio-controlers’. However, there do appear to be some significant relationships in the other three cases. Portfolio 2, (Chemical "Users" / Conservers) does appear to be associated with increasing cropped areas (larger arable operations), a higher frequency of insecticide application, and membership of the ESA and the VI. Organic status, perhaps not surprisingly, is negatively related to this portfolio approach.

For Portfolio 3 (Extra Crop Conservation Bio-controllers) there appears to be a statistically significant negative relationship with the number of insecticide applications per crop and positive relationships with the proportion of land with tenant rights and membership of the VI. Certainly, the absence of tenant rights would likely form a barrier to the adoption of habitat manipulations which require some significant investment, beetle banks for example.

Finally, Table 2 reports that there are four statistically significant relationships between farm characteristics and Portfolio 4, (Weed Focused Farmers). Here, livestock farms with high levels of tenant rights and those engaged in the HLS are less likely, while organic farms are more likely, to adopt Portfolio 4.

5.3. Portfolio influence on Insecticide Spray Regimes

The factor scores used in Section 5.2 can also be employed in regression models as independent variables. In this section, the four factor score variables are used, alongside a range of farm characteristics, to explain differential rates of insecticide application intensity (number of insecticide applications per crop) across farms. Only those farms classified as either conventional or part conventional are included in this analysis. All organic-only farms have been excluded. The results of this analysis are presented in Table 3.

{Approximate Position of Table 3}

The results a in Table 3 suggest that farmers who adhere closer to Portfolio 1 (Intra Crop Bio-controllers) do apply chemical insecticides less intensively than their peers. The two statistically significant coefficients for Portfolios 1 and 2 do conform to prior expectation in terms of sign. Trap crops, pheromones mixed varieties and introductions, at least when used together, do appear to reduce reliance and intensity of use of chemical insecticides on commercial arable farms.

The results also suggest that arable farmers who derive their spray advice from independent crop consultants, are members of the ELS and who have adopted Portfolio 2 (Chemical Users / Conservers) tend to spray for insect pests more frequently than there peers.

No statistically significant affect on insecticide use could be detected for Portfolio 3 (Extra Crop Bio-controllers) even though many of the technologies included in this portfolio are expected to effect pest populations either directly or indirectly. Therefore, this analysis finds no statistical support for the proposition that field margins, beetle banks and floral strips reduce farmers' reliance on chemical insect control. The technologies included in Portfolio 4 are unlikely to affect insect pest populations and so it was anticipated that this portfolio would have no affect in insecticide use.

It is interesting to note that the membership of the ELS, with its focus on environmental land-use change and CPMPs, is counter-intuitively correlated with a greater intensity of insecticide application. Although statistical power was lacking, the positive sign on the coefficient for the VI is also striking and suggests that further work to uncover the impact of the VI on pesticide use is warranted.

6. DISCUSSION AND CONCLUSIONS

Much research effort has been directed toward the development and evaluation of individual components of IPM over recent decades. The scientific literature on IPM and bio-control often offers an optimistic picture of the commercial potential of these techniques to reduce, if not supplant, pesticide use in agriculture. However, what little research has been done to date on the adoption of IPM in the commercial setting presents a more cautious view. With world-wide penetration of bio-control use in all agriculture estimated at less than 1% in sales terms, and even when recognising that much of IPM activity cannot be represented in formal sales, a far less successful, or integrated, picture emerges.

The results presented here indicate that UK arable farmers are already using a range of techniques to control pest, disease and weed problems on their farms and indeed, very few of the respondents to this survey appear to rely solely on chemical pesticides. As such, some degree of IPM approach appears to characterise control strategies on these farms. The choice of IPM portfolio differs across the sample and appears to be conditioned by farm type, land tenure and AES engagement. However, other, unobserved characteristics such as background ecology and landscape heterogeneity and complexity, and the pest problems prevalent on specific farms also likely play an important role.

Although there are sound theoretical arguments why rational farmers might not adopt a potentially superior IPM strategy public policy, in the form of AEP as implemented in England, does appear to have promoted the adoption of innovative alternative PM strategies. However, results from the regression analysis reported in Table 3 suggest that membership of the ELS tends to promote an increased number of insecticide applications per crop, a result which may be of some concern to DEFRA. Perhaps some of the options within the ELS tend to promote the abundance of some key pest species or form an attraction for bio-control agents ensuring they remain outside the cropped area and thus neutralise their conservation bio-control (CBC) impact? More large scale systems based scientific effort is needed to understand these complex push and pull forces in detail and to develop optimal landscape ecology with pest control in mind. Subsequently, it is likely that AEP will require some fine-tuning of incentive structures in order to promote those practices which can be shown to enhance PM function while recognising the importance of portfolio composition in IPM systems as demonstrated here.

The results presented in Table 3 importantly show that the adoption of practices which modify the cropped environment, those included in to Portfolio 1, appear to produce a statistically significant reduction in the need to apply chemical insecticides. The lack of statistical support for a similar affect from practices conducted predominantly outside the cropped area, as included in Portfolio 3, will be of some concern to CBC researchers and practitioners.

Recently the potential scaling impacts of IPM and biodiversity have been considered by the scientific (Griffiths *et al*[13]) and policy making (Franks and McGloin[22]) communities. The potential for farmers to create, at least local, network external benefits in the provision of bio-control and other conservation goals are now being considered. To this end, coordinated or cooperative bids submitted by groups of neighbouring farmers for collective AEP funding could provide the key to gaining otherwise elusive scale benefits in agro-ecosystem services.

Finally, the results presented in this paper will prove useful to the scientific community in designing large integrated PM research programmes. An important implication of these findings is that there is a pressing need to consider the way in which combinations of pest control techniques interact. Thus, intensive research, evaluation and development work is needed to discover which PM practices complement each other, and boost overall pest control function, and which PM techniques are functional substitutes, and can help to control the variance of pest management efficacy. This information is vital to enhance the design of IPM portfolios and to encourage the wider adoption of IPM. Perhaps the portfolios of pest control techniques identified here could provide an initial indication of potential combinations of techniques for such work. Extension agents and farm advisors will also find these results useful for the identification of potential early adopters of novel pest management techniques and to help tailor targeted advice to farmers considering the adoption of coherent IPM portfolio practices and AEP scheme applications.

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Table 1: Rescaled, Rotated Component or Factor Matrix

	Factor			
	1	2	3	4
	'Intra Crop Bio-controllers'	'Chemical "Users" / Conservers'	'Extra Crop Conservation Bio-controllers'	'Weed Focused Farmers'
Trap Crops	0.787			
Mixed Varieties	0.707	**		
Introductions	0.685			
Pheromones	0.634			
Different Varieties		0.425		
Resistant Varieties		0.470		
Spot Spraying	**	0.644		
Treated Seeds		0.656		**
Rotate Pesticide Classes		0.732		**
Field Margins			0.497	
Floral Strips			0.788	
Beetle Bank		**	0.814	
Cultivate Weeds			**	0.747
Crop Rotation				0.387
Timing of Operations				0.536
Hand Rogueing	**	**		0.582

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
Rotation converged in 6 iterations.
** denotes negative association between technology and portfolio.

The 4 factors explain 51.1% of the variance in the original data. Since 21% of the pair-wise correlation coefficients, available from the authors on request, for the pest management techniques are statistically significant fewer that 9% of these (3% in all) are greater than 0.65. So there is a reasonable degree of association within portfolio.

Table 2: Regression Results; Explaining 'Technology Currently Adopted' Factor Scores

Dependent Var / Independent Var	Factor Score 1 'Intra Crop Bio-controllers' Beta	*t*	Factor Score 2 'Chemical "Users" / Conservers' Beta	*t*	Factor Score 3 'Extra Crop Conservation Bio-controllers' Beta	*t*	Factor Score 4 'Weed Focused Farmers' Beta	*t*
Constant	-0.218	*-0.576*	**-0.761**	*-2.276*	-0.397	*-1.083*	0.261	*0.741*
Cropping Area	0.571	*1.000*	**0.860**	*1.702*	0.829	*1.496*	-0.246	*-0.462*
Insecticides/Crop	0.117	*1.221*	**0.331**	*3.901*	**-0.223**	*-2.389*	-0.055	*-0.612*
%Tenure	0.296	*1.171*	0.185	*0.830*	**0.442**	*1.804*	**-0.592**	*-2.516*
Arable	0.036	*0.249*	-0.028	*-0.219*	0.090	*0.637*	-0.091	*-0.674*
Livestock	0.245	*0.633*	0.255	*0.747*	-0.040	*-0.107*	**-1.018**	*-2.831*
Organic	-0.270	*-0.929*	**-0.993**	*-3.865*	0.075	*0.266*	**1.136**	*4.197*
Commercial Advice	0.036	*0.152*	-0.160	*-0.757*	0.179	*0.772*	0.007	*0.032*
SFP	-0.196	*-0.698*	0.079	*0.318*	-0.088	*-0.324*	0.200	*0.762*
CSS	-0.031	*-0.203*	-0.077	*-0.576*	0.136	*0.933*	-0.160	*-1.139*
ELS	-0.149	*-1.031*	-0.034	*-0.269*	0.110	*0.785*	0.182	*1.349*
HLS	0.267	*0.905*	-0.283	*-1.087*	0.094	*0.329*	**-0.860**	*-3.134*
ESA	0.066	*0.310*	**0.495**	*2.613*	0.125	*0.603*	0.313	*1.571*
VI	0.120	*0.827*	**0.483**	*3.769*	**0.298**	*2.117*	0.113	*0.834*
R Square		0.045		0.29		0.078		0.188

Highlighted Parameter significantly different from zero at >90%

Table 3: Determinants of Insecticidal Application

Dependent Var / Independent Var		Spray Application/Crop Beta	t
(Constant)		**-1.33**	-2.07
FS1: 'Intra Crop Bio-controllers'		**-0.07**	-2.09
FS2: 'Chemical "Users" / Conservers'		**0.07**	2.25
FS3: 'Extra Crop Conservation Bio-controllers'		0.04	1.26
FS4: 'Weed Focused Farmers'		0.02	0.75
Membership of:	CSS	-0.06	-0.97
	ELS	**0.33**	5.05
	HLS	-0.08	-0.61
	VI	0.11	1.62
Proportion of farm 'Conventional'		0.97	1.52
Independent Advice		**0.11**	1.70
Arable		**0.22**	3.55
Durbin Watson			1.834
R Square			0.162

Highlighted Parameter significantly different from zero at >90%

n=412

Figure 1: Insecticide Advice

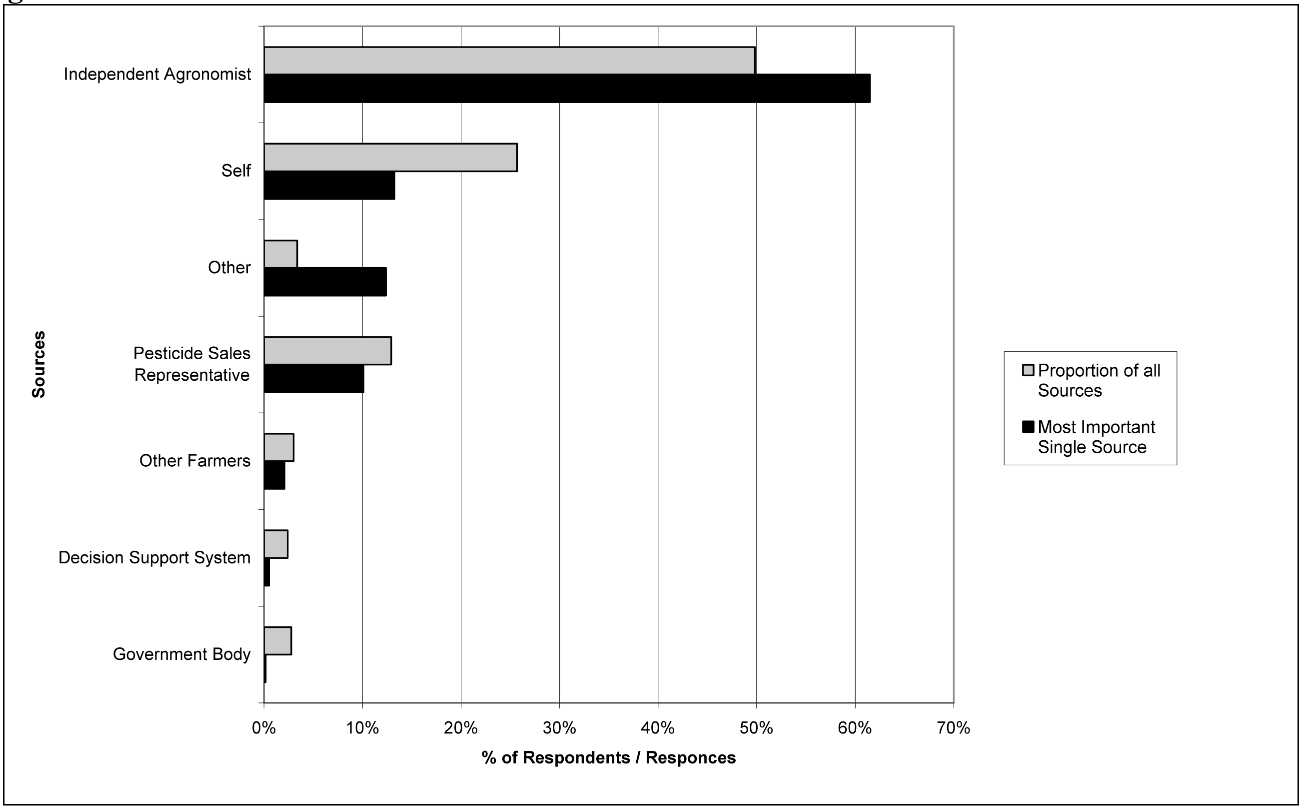

Figure 2: Attitudes to a New Pest Management Strategy/Technology

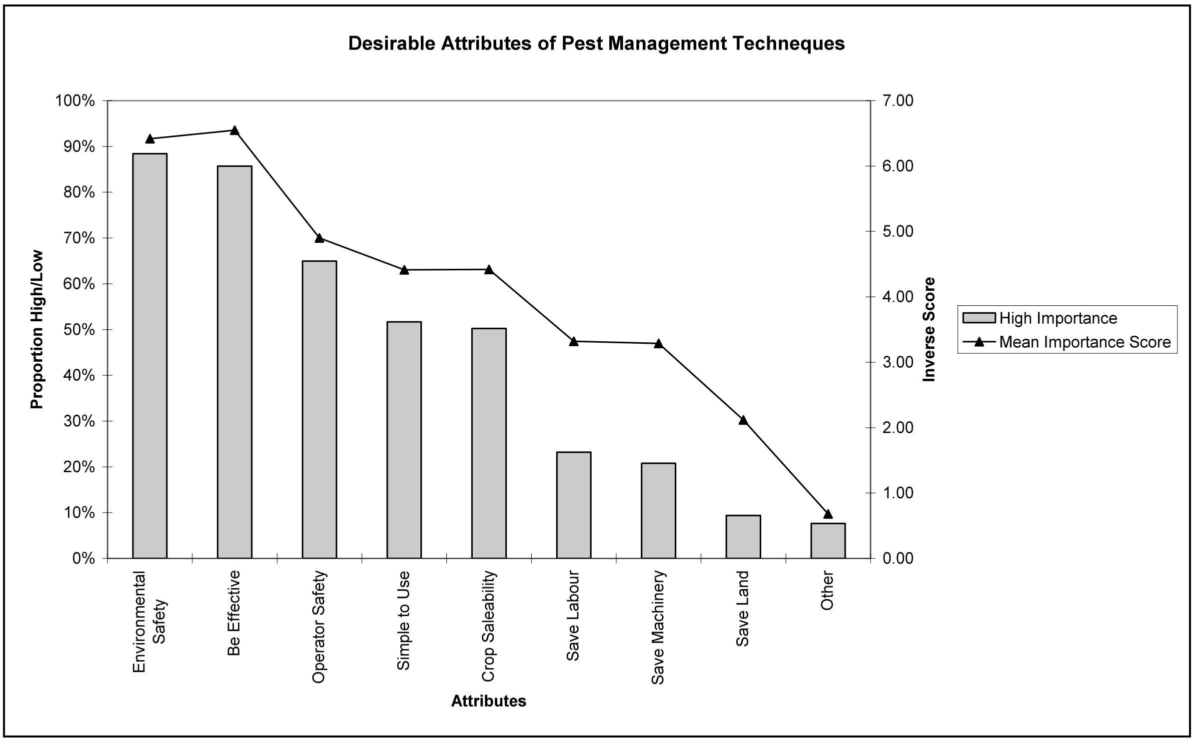

Figure 3: Agricultural Policy Participation

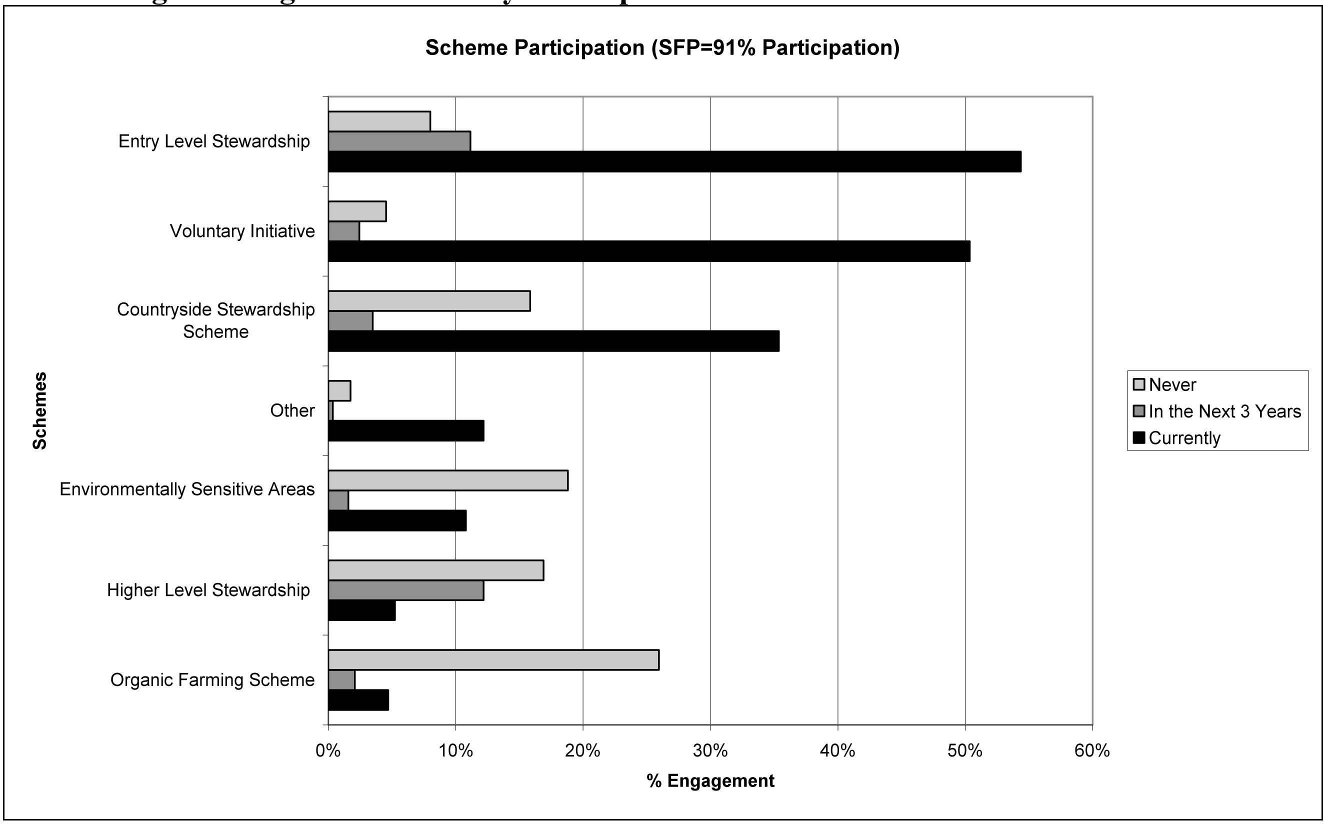

Figure 4: Adoption of Pest Control Methods (Percentages)