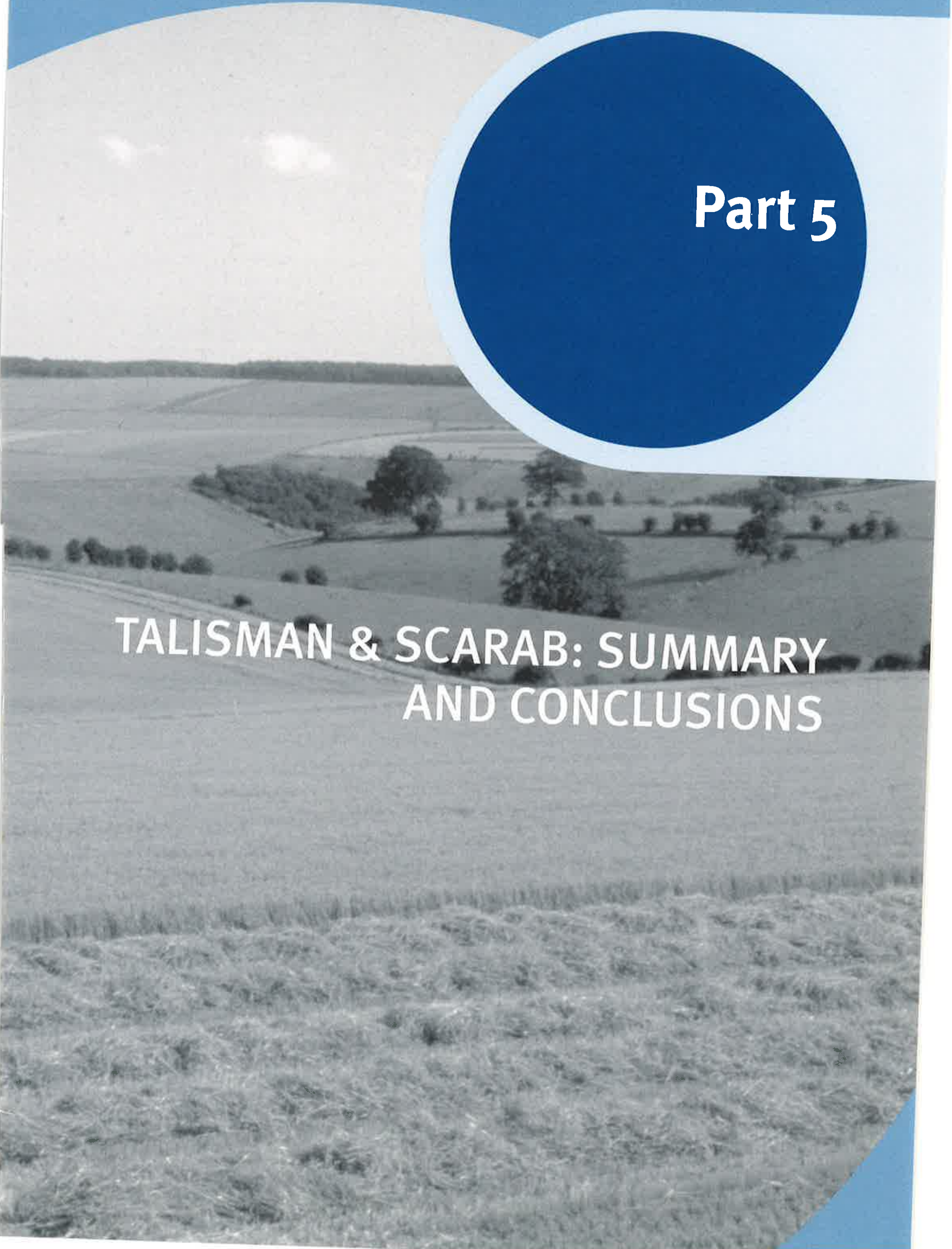
Part 5

TALISMAN & SCARAB: SUMMARY AND CONCLUSIONS



TALISMAN & SCARAB: SUMMARY AND CONCLUSIONS

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Introduction

The TALISMAN and SCARAB Projects have provided important benchmarks for the ecological, agronomic and economic impacts of reduced pesticide and nitrogen use on arable farms in England. As follow-on studies to the Boxworth Project, TALISMAN and SCARAB were unique in many respects. Both Projects were designed as long-term, multi-disciplinary, studies in a range of geographical locations and farming situations over a six-year period (Chapter 1.1). The RISC Project in Northern Ireland provided complementary data to support TALISMAN.

The difficulties of resolving the conflicting demands of ecological and agronomic investigations were acknowledged at the outset, giving rise to the two complementary Projects – TALISMAN with its focus on economics and agronomy and SCARAB which concentrated on ecological studies. A large group of scientists from a diverse range of disciplines (including agronomy, weed science, plant pathology, entomology, microbiology and soil science) collaborated on both Projects. Two basic farming systems lay at the core of each Project – a commercially representative or 'conventional' regime and a parallel low-input regime of pesticide and/or nitrogen use. Importantly, it was possible in these two Projects to carry out consecutive scientific observations to track cumulative developments in individual fields across complete, six-course, crop rotations.

Experimentation versus reality

TALISMAN and SCARAB strived to attain a balance between the strict demands of scientific experimentation and the need to realistically simulate low-input pesticide use within the bounds of 'conventional' arable farming practices. In such a situation, conflicts are bound to arise and compromises need to be struck in terms of experimental design and objectives, whilst maintaining studies that will remain meaningful to a wide audience, including farmers, environmentalists and policy makers. Within the Projects, decisions were taken to resolve these problems in a number of areas, which are discussed below.

Pesticide decisions

Great efforts were made to ensure that decisions on pesticide use accurately reflected typical on-farm crop protection practices. In commercial practice, pesticide decisions range from routine or 'insurance' applications, to those dictated by a more precise knowledge of the relationship between the crop, the pest organism and the expected cost-benefit of treatment (Chapter 2.1).

Reducing Agrochemical use on the Arable Farm: The TALISMAN and SCARAB Projects.

Young J E B, Griffin M J, Alford D V, Ogilvy S E. [eds] 2001. London: DEFRA.

In TALISMAN and SCARAB, a Technical Management Team, comprised of specialists with expertise in a range of crop protection disciplines, was responsible for recommending the use of pesticides. Their approach was to ensure that the rules governing the conventional and low-input regimes were adhered to. Decisions to apply pesticides were always governed by the demands of the conventional pesticide regimes and were invariably guided by crop monitoring and the assessment of weed, pest or disease incidence. Action thresholds were always applied if they were available for the problem in question. Pesticide product choice was normally dictated according to the most widely used active ingredients, as indicated by current information from the MAFF Pesticide Usage Surveys.

In most circumstances, pesticide use in TALISMAN and SCARAB reflected the decisions that would be taken at the forefront of commercial use on the most technically aware farms. However, the need to standardise the experimentation by applying the most commonly used active ingredients to both the conventional and low-input regimes, introduced a degree of inflexibility compared with the most technically competent farmers. For example, the broad-spectrum insecticide, dimethoate, was applied to control cereal aphids, whereas an environmentally aware farmer may have chosen a more selective insecticide such as pirimicarb. Similar limitations were accepted with respect to the manipulation of pesticide rates, which is discussed below.

Pesticide application rates

Against a background of continually evolving and changing arable farming practices, the design of the conventional pesticide regimes, used as standard treatments in the TALISMAN and SCARAB projects, was a hotly contested issue. Pesticides were always applied in the conventional regimes according to their full 'label-recommended' rates. However, it is well known that, during the 1990s, there was an increasing trend for farmers to apply pesticides at less than their label-recommended rates.

At the outset of the Projects, it was decided to follow manufacturers' label rates in the conventional regimes as, at that time, there was uncertainty in defining the scope and extent of rate-reducing practices. Furthermore, label rates were deemed to be the only reliable 'benchmark' against which comparisons relating to reducing pesticide use could be assessed.

The large reductions in pesticide use achieved in the Projects were mainly attained through rate reductions in the case of herbicides and fungicides, but mostly by the omission of applications in the case of insecticides and molluscicides. It has been important to examine the validity of the experimental regimes in view of an increasing commercial trend to apply certain pesticides at rates less than those recommended by their manufacturers.

Consequently, data from the MAFF Pesticide Usage Survey Reports were examined in an attempt to quantify the impact of rate-reducing practices on the commercial realism of the experimental regimes. This exercise revealed only limited evidence that insecticides and molluscicides were being applied at less than their label rates. However, in the case of herbicides and fungicides, there was greater evidence of low-rate usage. Nevertheless, it was concluded that the reduced rates of herbicides and fungicides applied in the low-input regimes continued to represent input levels below those used in average farm practice. The impact of this issue is discussed in greater detail in relation to TALISMAN in Chapters 2.3, 2.5 and 2.6, dealing with herbicide, fungicide and insecticide use respectively.

Reductions in nitrogen use

Although the consequences of adopting low-input pesticide use were the main driving force behind the Projects, reducing the use of nitrogen fertiliser was a subsidiary objective which was examined in TALISMAN only, where a deliberate reduction of 50% was imposed in the low-input regime, compared with the conventional regime. It could be said that such a large and inflexible reduction in nitrogen use was too extreme. Indeed, the 50% reduction in nitrogen use harmed crop yield and profitability by lowering yields by an average of 11% and gross margins by 9%.

However, at the outset of the Project, it was considered that such an arbitrary reduction in nitrogen use (in line with the target reduction in pesticide use), was necessary to 'force' the extremes required between the experimental treatments. Under these conditions, although it was accepted that such a reduction might be untenable to a farming business, it would create the contrasts necessary to detect potential interactions between nitrogen and pesticide use.

By the end of the Project, it was evident that very few meaningful interactions had occurred between nitrogen and pesticide use in TALISMAN. One of the best examples was found in a crop of winter wheat at High Mowthorpe (Chapter 2.6), where greater numbers of cereal aphids developed in association with full-rate nitrogen.

Crop rotations

The design of TALISMAN was enhanced by the inclusion of the contrasting Standard and Alternative Rotations. The Alternative Rotation was included as a deliberate attempt to design a crop rotation with an inherently lower demand for nitrogen and pesticide inputs and, therefore, departed from what might be considered as a typical arable rotation of the 1990s. As such, the Alternative Rotation contained a large proportion of spring-sown crops, compared with the winter-crop-dominated Standard Rotation.

The agronomic and economic performance of rotations based on spring crops also merited investigation as the shift to winter cropping over the past thirty years has been implicated in the decline of certain species of farmland birds (Campbell & Cooke, 1997). The loss of winter stubbles due to increased winter cropping is a likely contribution to the decline of birds which feed on arable weed species. To improve farmland for birds, it is necessary to develop economically and agronomically acceptable farming practices which allow increased spring cropping (Jones *et al.*, 1997).

Reduced rates and resistance

The development of pesticide resistance in weeds, pests and diseases is now a world-wide problem. The incidence of resistance to insecticides increased rapidly after 1950 following an upsurge in the use of newly discovered organochlorine and organophosphorus insecticides (Georghiou, 1986). Fungicide resistance increased after 1960 (Dekker & Georgopoulos, 1982), whereas the first case of herbicide resistance did not appear until 1968 (Clarke *et al.*, 1997). The use of reduced-rate applications of pesticides in TALISMAN and SCARAB has often raised the question of whether or not this approach might lead to an increased risk of resistance.

Manufacturers' label-recommended rates are invariably developed to achieve a consistently high standard of control in a wide range of cropping situations and, as such, these rates need to be robust enough for general use (Finney, 1993). TALISMAN achieved its aim of reducing pesticide use by 50%, largely through reductions in pesticide rates (Chapter 2.1). Since the inception of TALISMAN in 1990, it has become an increasingly common on-farm practice to apply pesticides at less than their label rates (Thomas *et al.*, 1997).

In the majority of cases in TALISMAN, commercially acceptable levels of control were obtained with the low-input rates. However, there were instances where full rates were required even in the low-input regime, e.g. to maintain adequate control of black-grass at Boxworth. In practice, if the pressure from weed, pest or disease populations is excessive, inadequate control is likely to result from a reduced rate of a pesticide, which could lead to a greater proportion of the target organism population surviving treatment. For example, the control of cereal aphids with low-rate insecticides may be inadequate when the crop is subjected to abnormally severe attacks (Oakley *et al.*, 2001).

Arguments can be constructed as to why high or low dose rates of pesticide might influence the development of resistance. For example, low doses may select for resistant biotypes or, on the other hand, they may permit survival of a mixed population containing an unaltered proportion of resistant and susceptible organisms. Clarke *et al.* (1997) considered that focusing on dose as a cause of resistance has proved to be a distraction, whereas concentration on selection pressure is more relevant. There does not appear to be a simple answer to the question of the effect of dose rates on the development of resistance. Clearly, each case should be considered on its individual circumstances. The majority of the low-rate pesticide applications in TALISMAN were generally applied as isolated, single treatments as opposed to a repeated, sequential, series of low-rate applications against the same target. In the extreme, the latter practice could select for resistance in some circumstances, particularly if targeted against a multi-generation pest or disease. However, there was no evidence that the low-rate strategy adopted in TALISMAN contributed to the development of resistance. Clearly, the reduced-rate application of pesticides is a valuable strategy to minimise pesticide use but practitioners must remain vigilant to the risks of resistance, especially where resistance is already known to occur.

Constraints and demands of the ecological studies

It has been emphasised how the differing priorities and objectives of TALISMAN and SCARAB dictated the design of these studies, and how both Projects finally fitted together and complemented each other in the quality of data they generated (Chapter 1.1). SCARAB was governed primarily by the demands of the various ecological studies on non-target arthropods, soil microbiology and earthworms. The mobility of many of the arthropod species in question called for a large-plot design utilising whole fields (Chapter 3.1). Compared with TALISMAN, the low-input regime in SCARAB was disadvantaged in several respects owing to the ecological demands of the study. In order to ensure the provision of treated versus nil-treatment comparisons, no insecticides, molluscicides or nematicides were permitted in the low-input regime of SCARAB, and this resulted in an immediate commercial disadvantage (Chapter 3.6). Furthermore, if an insecticide application to the conventional regime was not triggered by the naturally occurring populations of invertebrate pests, it was necessary, for the ecological purposes of the study, to apply a single insecticide to each crop (with the exception of the grass crops). When this was required, a treatment was applied for the most commonly occurring pest in the relevant crop and locality. It was accepted that these constraints would need to be taken into account when assessing the economic and agronomic performance of the low-input regime of SCARAB.

A contrasting situation was true for TALISMAN in relation to the non-target arthropod studies (Chapter 2.7). The main theme of TALISMAN was to investigate the agronomic and economic consequences of pesticide use and, as such, the study demanded a traditional small-plot, randomised block design to deliver data which could be subjected to robust statistical analysis. It was appreciated, at the outset, that the monitoring of pesticide effects on non-target arthropods in the relatively small plots of TALISMAN would be compromised by the migration of the more mobile arthropod species. Nevertheless, the arthropod data generated in TALISMAN has been of value in supporting and complementing that of the more ecologically-focused SCARAB Project.

The potential influence of previous farm management on the arthropod populations of the study fields in SCARAB has also been questioned (Chapter 3.2). It was only at Drayton that the introduction of both the conventional and low-input regimes resulted in an increase in pesticide inputs relative to previous practice because the rotation was dominated by grass at this site prior to the study (**Appendix Tables 3.1.12 & 13**). At the other two SCARAB sites (Gleadthorpe and High Mowthorpe), the most obvious change from previous practice was a reduction in pesticide usage under the low-input regime, as previous cropping and pesticide use was similar to that used in the conventional regime in the Project. Therefore, the low-input regime at Gleadthorpe and High Mowthorpe may be viewed as providing an opportunity for recovery of any arthropods whose populations may have been adversely affected by the previous conventional pesticide use. However, with few exceptions, there were no indications of long-term increases in arthropod abundance under the low-input regime. These exceptions included an increased incidence of some species of springtails (*Lepidocyrtus* spp. at High Mowthorpe and *Entomobyra multifasciata* at Gleadthorpe), but it was not possible to say if these changes were related to pesticide use.

TALISMAN

TALISMAN has provided evidence that low-input pesticide policies do not automatically result in financial losses and, if managed successfully, can be financially profitable. However, the results have shown that low-input pesticide use strategies are not suitable for all sites and all crops. Developing the right combination is essential to success and this may mean modifying rotations at the local level to find the right mix of crops best suited to low-input pesticide use. Ultimately, to reap the rewards, local knowledge and management skill remain a vital factor in determining the scope, extent and financial viability of reducing pesticide use in arable crops.

Crop rotations in TALISMAN

The Alternative Rotation met with mixed success in achieving a reduction in demand for nitrogen and pesticide inputs. As expected, in the conventional regime overall nitrogen use was 29% lower and pesticide use was 18% lower than that used in the Standard Rotation. However, the lower pesticide use achieved in the Alternative Rotation was not shared evenly between pesticide groups (Chapter 2.1). In the case of herbicides and insecticides, the reductions were marginal (4% and 6% respectively) in the Alternative Rotation, compared with the Standard Rotation. In contrast, fungicide use was 46% lower in the Alternative Rotation than the Standard Rotation. These differences reflected the lower disease pressure experienced in some of the Alternative Rotation crops, and also the difficulties in maintaining control of certain weeds and invertebrate pests in the Alternative Rotation (Chapters 2.1, 2.3 & 2.5). For example, aphid attacks occurred in the spring beans and spring oats, and the inclusion of winter triticale at Drayton resulted in slug problems.

In financial terms, in both the conventional and low-input pesticide regimes, the Alternative Rotation was less profitable than the Standard Rotation, owing to the lower-yielding and lower output value of the spring-sown crops. The average gross margin from the Alternative Rotation was 15% (£109/ha) less than that from the Standard Rotation. Currently available cultivars of spring crops are inherently lower yielding than the equivalent winter crops. Under the present economic conditions, this factor makes the adoption of low-input rotations based on spring crops economically unviable for the majority of arable farmers. However, spring cropping remains a desirable objective from the viewpoint of aiding the survival of certain species of farmland birds (Jones *et al.*, 1997).

Nitrogen use in TALISMAN

The arbitrary 50% reduction in nitrogen use adopted in TALISMAN reduced yields and was unprofitable (Chapter 2.2). Yields were reduced, on average, by 11% where low-input nitrogen rates were used and the associated losses in gross margins averaged 9% overall. A more flexible and field-specific approach to reducing nitrogen use may have minimised such losses. In TALISMAN, low-input nitrogen use reduced the apparent nitrogen balance in the soil and may also lead to lower leaching losses of nitrogen to the environment. However, in the RISC Project in

Northern Ireland, no reductions in nitrogen leaching were observed. Nevertheless, caution is required as, in the longer-term, low-input nitrogen use may well lead to a loss of soil organic matter and a reduction in soil fertility (Bhogal *et al.*, 1997).

A more accurate approach is required in predicting the optimum nitrogen fertiliser requirements of crops at individual field level. It is in these situations that some of the new prediction techniques (e.g. 'canopy management' systems) may prove valuable (Sylvester-Bradley *et al.*, 1997).

Cutting nitrogen rates will help reduce nitrogen losses to the environment but the arbitrary 50% cuts adopted in TALISMAN were, by design, too imprecise and harmed crop yield and profitability. However, it must be appreciated that TALISMAN did not set out to redefine the optimum levels of nitrogen use in terms of maintaining the balance between nitrogen availability, utilisation and wastage. TALISMAN has proved useful in showing that nitrogen fertiliser is an essential input to maintain crop incomes. Therefore, policy-driven measures designed to limit such inputs need to be carefully considered against this background.

Pesticide use in TALISMAN

Pesticide use was defined according to pesticide units, where one unit is equal to one full-rate application of a single active ingredient. TALISMAN succeeded in reducing overall pesticide use by 58% in the low-input compared with the conventional regime. Larger reductions in pesticide use were possible in the break crops (65% reduction) than in cereals (56% reduction). An average of 6.1 pesticide units was applied in the conventional regime, compared with 2.6 in the low-input regime, across all crops. Of the three sites, Drayton was the highest user of pesticides, mainly due to the higher demand for herbicides and molluscicides on this heavy-land site (Chapter 2.1).

As discussed, reductions in pesticide consumption were obtained primarily through rate reductions, rather than through omitting applications altogether. This was particularly true for herbicides and fungicides, although in the case of insecticides and molluscicides, a greater proportion of applications were omitted from the low-input regime (Chapter 2.1).

Weed control and weed seedbanks in TALISMAN

In general, the build-up of weed populations has not been an insurmountable problem in TALISMAN (Chapter 2.3). Reducing herbicide use in a low-input regime was shown to be cost-effective. There is potential to improve the gross margins of certain crops through savings in herbicide costs, depending on local circumstances. However, it is clear that greater management skill and knowledge are called for in retaining long-term control of problem weeds at critical periods in the crop rotation. Current knowledge of weed management was used to good effect in dealing with the most injurious weeds (black-grass and wild-oats) and the timely use of full-rate herbicides was deemed essential to maintain control of problem weeds (e.g. black-grass) at critical times.

Reductions in herbicide use in the TALISMAN low-input regime were achieved primarily by reducing rates by 50% below full label-recommended rates, and the study demonstrated that this approach can be successful in agronomic and economic terms, if managed appropriately. However, caution must be exercised in containing weed populations at acceptable levels, as TALISMAN indicated that weed numbers can increase in association with low-input herbicide use in certain site-specific circumstances. This was also demonstrated in the RISC Project (Chapter 4.1). Aggressive weeds, such as poppy and cleavers, which were not adequately controlled, flourished and exploited the low-input crops. The subsequent and continued use of low-rate herbicides made these problem weeds difficult to control. However, in practice, the well-timed and judicious use of full-rate herbicides would be possible to prevent such weed populations from becoming unmanageable.

Break crops and spring-sown crops were the most susceptible to yield loss when herbicide rates were reduced. The low-input herbicide regime decreased yields by a small percentage (1%) in winter wheat but by greater amounts in break crops (3–41%) and spring-sown cereals (5–11%). The break crop least affected was winter beans in which reductions in herbicide use resulted in yield increases (up to 4%). However, gross margins were not penalised by the various yield decreases observed, owing to savings made in herbicide costs. Overall, low-input herbicide use resulted in a gross margin gain of 2% (£11/ha), compared with the conventional regime but there were differences between the sites which were due to different approaches to reducing herbicide use. At Boxworth and High Mowthorpe, herbicide use was arguably at an optimal level in the conventional regime at the outset, whereas at Drayton, reductions were made from a higher starting point. As a consequence, at Drayton, the reductions in herbicide use had a lesser effect on yield but the benefits on gross margin were clearly seen (8% overall increase in gross margin of the Low Herbicide treatment). In contrast, at Boxworth and High Mowthorpe, gross margins over the rotations were unaffected.

Weed seedbank studies in TALISMAN (Chapter 2.4) showed that there was scope for reducing the number and dosage of herbicide applications without necessarily encouraging the seedbank to multiply, but only in rotations dominated by competitive winter cereals and where the number of herbicide units applied was already high (e.g. at Drayton). Attempts to reduce herbicide use by introducing spring-sown crops were unsuccessful at two sites (Boxworth and High Mowthorpe) in terms of the very high weed seedbank populations that accumulated. There appeared a fine balance between suppression and enhancement of the seedbank, such that below a certain intensity of herbicide use, the seedbank amplified to very high populations of long-lived species.

Disease control in TALISMAN

Fungicide applications were made according to prevailing disease pressure, varietal resistance and environmental conditions and this policy rarely generated the opportunity to omit fungicide applications entirely from the low-input regime. However, the flexibility to reduce rates provided the opportunity to make significant financial savings in the low-input regime, without impinging too greatly on crop performance.

Lowering fungicide inputs rarely had a detrimental effect on yield and gave a modest overall improvement of 2% or £16/ha in average gross margins (Chapter 2.5). In winter wheat crops (n = 28), the low-input fungicide regime resulted in an improved benefit of 3% (£24/ha), compared with the conventional regime. In contrast, in the RISC Project, reducing fungicide inputs to wheat at the high rate of N resulted in significant yield and gross margin reductions of 13.6% and £42/ha respectively.

Poor disease control was occasionally associated with reduced-rate fungicides confirming that, under intense disease pressure, yield losses from reduced-rate applications could be expected to occur (e.g. control of *Septoria* spp. in winter wheat). There is clearly potential to reduce fungicide inputs safely and profitably provided the risk of yield loss can be predicted reliably (Paveley & Clark, 2000). These findings are consistent with recent developments in other projects on appropriate fungicide dose (Paveley *et al.*, 1998) and Integrated Crop Management (Ogilvy, 2000; Cook *et al.*, 2000).

Invertebrate pest control in TALISMAN

Across all sites and years, the low-input use of insecticides and molluscicides resulted in a small increase of 1% (£5/ha) in the low-input gross margin, compared with the conventional regime (Chapter 2.6). Further, in 62 (94%) out of a total of 66 interventions with insecticides or molluscicides, there were no significant economic losses, even when certain insecticides were omitted altogether, thus creating the opportunity to improve profit margins. The four significant yield and economic losses were sustained from attacks of cereal aphids in three crops of winter wheat and from one attack by black bean aphid in a single crop of spring beans. Similar effects were found in the RISC Project, although the frequency of use of insecticides was much lower on the Northern Ireland sites (Chapter 4.1).

The relatively low cost of many insecticides means that the potential savings from reducing insecticide use are not as great as with fungicides or herbicides. Nevertheless, small but consistent savings may be gained from minimising insecticide and molluscicide use in combinable crops and this should be exploited within the industry. However, careful management of inputs is essential, as omitting insecticides could lead to significant and costly yield losses if pest pressure, for example, from cereal aphids in high-risk summers, is high (Oakley *et al*., 2000).

Monitoring non-target arthropods and soil nematodes in TALISMAN

The invertebrate monitoring in TALISMAN revealed very few effects of pesticides on non-target arthropods. In total, 66 insecticide or molluscicide applications were used in TALISMAN throughout the life of the study and only on seven occasions was there any evidence of an apparent effect on pitfall trap catches. These results need to be considered in context with the small-plot design of TALISMAN, which was not ideal for invertebrate monitoring (Chapter 2.7).

In most instances, the apparent effect of pesticide application was to reduce pitfall trap catches, although numbers recovered within three months. These effects were noted with the molluscicide methiocarb, and with synthetic pyrethroids and dimethoate applied for aphid control. Furthermore, there was some evidence from Drayton that the effects of methiocarb were more persistent than those of other pesticide treatments.

Results suggest that the adoption of low-input pesticide use was less damaging to some invertebrates on some occasions but the effects were transitory and populations recovered. In general, years and rotations appeared to have a greater effect on the invertebrate fauna than pesticide applications, which was also noted in the larger-scale SCARAB Project (Chapter 3.2).

Multivariate analysis confirmed that arthropod abundance was most significantly affected by year-to-year differences. As might be expected, crop rotation also affected arthropod abundance, and there were individual year effects of pesticide use at Drayton and High Mowthorpe but these were not consistent across years or across sites.

Neither low-input nitrogen nor herbicide use had any effect on the plant-parasitic nematode population or on the structure of the nematode community, compared with conventional practice. Therefore, crop disorders associated with plant-parasitic nematodes were unlikely to increase or decrease and the well being of the soil, as measured by nematode community structure, was generally unaffected (Chapter 2.7).

The economics of low-input pesticide use in TALISMAN

Crop yields were generally reduced by the low-input pesticide regime, e.g. by -6% in winter wheat. However, gross margins were generally slightly higher in the low-input than the conventional regime, e.g. +1% (£9/ha) in winter wheat. Across all crops grown in TALISMAN, the average gross margin of the low-input regime was 2% (£12/ha) greater than the conventional regime. Utilising a low-input approach to reduce pesticide use could, therefore, provide growers with the opportunity to maximise financial returns from arable cropping (Chapter 2.8).

The following crops appeared to be suitable for use with low-input pesticide use strategies: winter wheat, winter triticale, spring barley, spring oilseed rape, winter beans, spring beans and spring linseed. However, spring wheat, spring oats and, notably, winter oilseed rape were apparently more responsive to certain pesticide inputs and would seem to be vulnerable to arbitrary reductions in pesticide use.

However, there were site-related differences in response to pesticide use. High Mowthorpe produced the highest gross margins (average £807/ha) and Drayton the lowest (average £559/ha). Drayton benefited the most from adopting the low-input pesticide regime (+9%, £50/ha) and High Mowthorpe the least (-2%, £15/ha). As discussed above, Drayton experienced more weed and pest problems than the other sites and, consequently, used and spent more on pesticides and the crops there were generally less responsive to pesticides. On average, Drayton used approximately two pesticide units per crop more than Boxworth or High Mowthorpe. Consequently, relatively greater financial savings were made in the low-input regime at Drayton than at Boxworth or High Mowthorpe (Chapter 2.8).

Taken overall, TALISMAN has shown that there is scope to increase profitability from lower pesticide use. The results suggest there is greatest potential to achieve this with fungicides, followed by herbicides and, to a lesser extent, insecticides. Overall, low-input fungicide use resulted in a gain of £16/ha, herbicides £11/ha and insecticides £5/ha, compared with the conventional regime. Adding these values together would suggest a combined benefit of £32/ha from the individual pesticide group effects, although, in reality, the 'All Low' treatment (in which all categories of pesticide use were restricted) only gave a benefit of £13/ha. This apparent difference is likely to have arisen from the adverse cumulative effects and interactions of reducing all categories of pesticide use in a single treatment, which ultimately limited crop yields and gross margins more so than where individual categories of pesticide were restricted in isolation.

The results have shown that not all sites and crops are always suitable for use in conjunction with low-input pesticide use strategies. This factor is linked to the starting point from which a farm embarks on a low-input strategy in terms of the performance of existing cropping, the local demands of weed, pest and disease control, and the current level of pesticide use. Looking to the future, the TALISMAN results remain highly relevant to the profitability of arable crops. Furthermore, the economic scenarios presented (Chapter 2.8) demonstrated how the financial incentives to adopt low-input pesticide use can improve under the more stringent financial conditions imposed by falling sale prices or increases in variable costs. To reap the rewards, local knowledge and management skills remain vital factors in determining the scope, extent and financial viability of reducing pesticide use in arable crops.

SCARAB

The reduction of pesticides and the omission of insecticides and nematicides in the SCARAB reduced-input treatment was used to create an ecological difference between the treatments to monitor the impact of commercial pesticide use. Therefore, the SCARAB crops faced an immediate commercial disadvantage because of the ecological demands of the project. In this respect, the aim of SCARAB was to quantify the ecological effect of pesticides on non-target populations of arthropods (primarily insects and spiders), earthworm populations and microbial activity and biomass in the soil.

Pesticide use in SCARAB

The type and frequency of pesticide applications used in SCARAB were comparable with those used on commercial crops, as indicated by comparison with the MAFF Pesticide Usage Surveys (Chapter 3.1). However, it is recognised that the dose rates of the pesticides applied in the conventional regime were likely to be higher than those applied commercially, where the use of reduced rates has become increasingly common, as discussed above. Pesticide use in the SCARAB conventional regime was similar to that of the Supervised treatment of the Boxworth Project, as both adopted frequent crop monitoring allied to a threshold-based approach to pesticide application decisions. The conventional pesticide regimes in SCARAB and TALISMAN were also broadly comparable, although insecticide use tended to be greater in SCARAB in order to create contrasting treatments (primarily for the sake of the non-target arthropod studies in SCARAB).

There was no call for the use of molluscicides in SCARAB, even on the heavy clay soils of Drayton which were troubled by slug attacks in TALISMAN. As discussed, no insecticide spray applications or nematicide treatments were used in the reduced-input regime. The insecticides used in the conventional regime were, in general, those most commonly used by commercial farmers e.g. cypermethrin for autumn aphids and dimethoate for summer aphids in winter wheat. Herbicide and fungicide product choices were more dependent on crop, target, soil type and local influences at each site but were still representative of commercial use.

Across all SCARAB crops, herbicide use was reduced by 43% and fungicide use by 52% in the reduced-input regime, compared with the conventional regime. Potatoes and sugar beet received the greatest number of active ingredient units in the conventional regime (14.9 and 11.7 units respectively), followed by winter wheat at 8.3 units per crop.

In relation to pesticide use prior to the start of the SCARAB Project, inputs were very similar to the conventional regime in SCARAB at Gleadthorpe and High Mowthorpe. RIA inputs were substantially lower and could be viewed as providing an opportunity for recovery for non-target species whose populations had been adversely affected by previous conventional pesticide use. In contrast, at Drayton, both the CFP and RIA pesticide regimes in SCARAB resulted in an increase in pesticide inputs relative to previous practice.

Non-target arthropod monitoring in SCARAB

Short-lived effects of insecticide applications within the conventional regime occurred among different groups of arthropods in all fields and years. In terms of long-term effects, SCARAB confirmed one of the findings of the Boxworth Project – that repeated use of organophosphorus insecticides in successive seasons can lead to long-term declines in abundance of certain arthropods. Springtails were the only group of arthropods to exhibit long-term adverse responses to the SCARAB pesticide regimes, though many other arthropod groups were temporarily affected by insecticide applications and subsequently recovered (Chapter 3.2). However, these long-term negative effects were observed in only one of the eight SCARAB study fields; this was 'Field 5' at Drayton which was under a grass and wheat rotation. The long-term effects in 'Field 5' were related to the repeated use of organophosphorus insecticides in consecutive seasons, namely chlorpyrifos in grass and dimethoate in wheat, which prevented the recovery of some species of springtails. However, consecutive use of these insecticides in a similar pattern is uncommon in UK agriculture.

The affected springtail species constituted a small proportion of all arthropod species monitored (< 3%), so it could be argued that arthropods in general would be unlikely to be affected adversely in the long term by regimes of pesticide use similar to those used in SCARAB. In terms of abundance, however, vulnerable species of springtails were important components of the overall arthropod fauna. For instance, springtails of the genus *Lepidocyrtus* spp. made up on average 26% of the total suction-sampled arthropod catch under the low-input regime of 'Field 5' (up to 83% of the total arthropod catch on some sampling occasions).

Unfortunately, it is difficult to predict the wider ecological significance of these observations without knowing the ecological importance of the species concerned. As springtails are important in the arthropod food web, and not all their predators were monitored during the SCARAB Project, a cautious interpretation would be to assume that effects of the conventional pesticide regime in 'Field 5' could be potentially serious if allowed to occur more widely in farmland. It is important, therefore, to consider the realism of the pesticide regime which led to the long-term effects in 'Field 5'.

Most short-term grassland, such as that typified by the grass/wheat rotation at Drayton, is less widespread than purely arable crop rotations. Furthermore, most short-term grassland is not treated with insecticides (Thomas & Garthwaite, 1994), so the use of insecticides in the conventional regime of 'Field 5' would appear to be representative only of a minority of agricultural situations. A reasonable conclusion would be that although the ecological consequences of the conventional pesticide regime in 'Field 5' are difficult to determine, such long-term effects would be unlikely to occur in UK arable agriculture, except in a minority of cropping scenarios where pest outbreaks and use of organophosphorus insecticides occur in consecutive seasons.

Soil microflora studies in SCARAB

The effects of pesticides on soil bacteria and fungi showed no clear-cut pattern and were highly dependent on soil type and soil condition at the time of application. As might be expected, effects were most often found with the more persistent types of pesticide. Weather and soil conditions also appeared to influence the effect of pesticides. The fungicides generally had a short-term negative effect on soil microbial activity and biomass; multiple applications of fungicide were often inhibitory to microbial activity. In contrast, the effect of herbicides and insecticides on soil microbes was variable, and both positive and negative short-term effects were observed.

For the first five years, the effects of conventional pesticide use on microbial populations were transient. Recovery of the microbial biomass to levels found under the low-input regime implied greater microbial population turnover under conventional treatments. However, in the sixth year of differential pesticide treatment, there was a tendency for average microbial biomass to be lower under the conventional regime, compared with low-input. At one site (High Mowthorpe), there was a suggestion that the potential for microbial re-cycling of organic matter was greater where reduced pesticide inputs were used. This may be an early indication of a site-specific reduction in soil fertility associated with conventional pesticide use. Two consequences could be envisaged if this trend were to continue. Either, detectable reductions in soil organic matter turnover may arise as a result of fluctuations in microbial biomass under conventional management, or greater fertiliser inputs may be required to balance the shortfall of microbially-processed nutrients in soil managed under conventional conditions. However, the longer-term implications of this initial observation need to be investigated before any firm conclusions can be made.

Earthworm studies in SCARAB

In SCARAB, earthworm populations showed considerable variability over time, but the reasons for this variability are not well understood and were not simply related to pesticide use. Unfortunately, there were no baseline assessments for these studies, as this part of the Project did not start until the third treatment year, so variability prior to the start of the pesticide regimes could not be determined. Some short-lived effects of pesticides were observed but these were small compared with natural variation found in the earthworm populations and were difficult to relate to pesticide use. These results were consistent with the known toxicity of the pesticides used in SCARAB to earthworms.

The data collected in this study allowed differential effects of the contrasting pesticide regimes on earthworm populations to be studied in great detail, in many cases down to separate age classes of individual species. Even then, there were no apparent long-term trends in earthworm populations, or individual species, which could be related to the particular pesticides applied in SCARAB.

Weed, pest and disease control in SCARAB

As already discussed, the large-scale, split-field design of SCARAB was implemented to satisfy the main ecological objectives of this Project. The limitations of this design meant that it was not possible to confirm the cause and effect of yield losses associated with the various weed, pest or disease problems encountered during the course of the Project. The following sections give an overview of those problems, together, where possible, with a view of their likely impact on the yield and economics of the crops concerned (Chapters 3.5 & 3.6).

Weeds

In virtually all instances, weed population densities were found to be higher under rotations receiving low-input herbicide treatments, compared with the conventional regime. Drayton, with grass-based rotations, was the least weedy; High Mowthorpe, with rotations based around conventional break crops, was the most weedy compared with the conventional regime. Weed populations increased over time. The difference in weed numbers in the low-input compared with the conventional regime changed from 5 per m^2 in 1992 to 35 per m^2 in 1995.

Weeds were implicated in yield losses experienced in the low-input regime in 18 out of 28 cereal crops and in eight out of 20 break crops. Notably, very high numbers of poppy, cleavers and wild oat populations in winter wheat at High Mowthorpe in 1995 were implicated in a yield loss of 1.91 t/ha in the low-input regime.

Low-input herbicide use led to an increase in weediness at all sites and, on occasions, large increases in site-specific weeds, such as poppy at High Mowthorpe. Low-input herbicide use, therefore, needs to be selectively targeted to prevent localised, long-term, increases in problem weeds. This observation mirrored similar findings in TALISMAN. The increased long-term weed problems would probably require remedial herbicide use in the future unless cultural measures were also adopted, as in an integrated farming system (Ogilvy, 2000).

Diseases

Disease was less prominent amongst break crops than amongst cereal crops. Disease was implicated in the yield reductions sustained in the low-input regime of only three crops of spring beans, out of a total of 20 break crops. In contrast, disease was implicated in yield losses experienced in the low-input regime in 13 out of 28 cereal crops. Septoria and powdery mildew were the most frequently observed disease problems in cereals, whilst chocolate spot and downy mildew were found in spring beans.

Existing information was used to estimate the scale of yield losses associated with the diseases encountered in winter wheat (Chapter 3.5). The incidence of *Septoria tritici* was found to be, on average, 6.9% greater on Leaf 2 in the low-input treatments of three winter wheat crops and is likely to have caused an estimated yield loss in the region of 2.9% or 0.25 t/ha. Similarly, a 4% greater incidence of powdery mildew found on Leaf 2 in the low-input treatments of two crops of winter barley could have resulted in an estimated potential reduction in yield of 1.4% or 0.1 t/ha.

Invertebrate pests

The design and objectives of SCARAB dictated the complete absence of insecticides and nematicides in the low-input regime. Subsequently, pest problems were frequently encountered and they were likely to have exerted unfair yield and economic penalties upon the performance of the low-input regime. Pests were implicated in yield reductions experienced in the low-input regime of 13 out of 28 cereal crops and 10 out of 20 break crops. In the majority of these cases (16 out of 23), aphids were deemed to be the only pest involved. However, migratory nematodes (e.g. *Trichodorus* spp.) were implicated in all three crops of sugar beet, silver y moth (*Autographa gamma*) in one crop of sugar beet, leatherjackets (*Tipula* spp.) in one grass crop, seed weevil (*Ceutorhynchus assimilis*) in one crop of winter oilseed rape, pea and bean weevil (*Sitona lineatus*) in one crop of spring beans and wheat bulb fly (*Delia coarctata*) in two crops of spring wheat.

Yield losses were difficult to predict from the observed pest populations. However, in the case of cereal aphids, the action threshold of more than 66% of tillers infested (from flowering onwards) was exceeded in the low-input treatment of four crops of spring wheat and two crops of winter wheat. Using information on the yield losses caused by cereal aphids (Chapter 3.5) suggested that, on each occasion, an estimated yield loss of at least 0.3 t/ha could have been expected where the aphid populations went untreated in the low-input regime.

Crop yields and economics in SCARAB

Results from SCARAB show that low-input pesticide use is not without economic risk. The enforced omission of insecticides and nematicides in the reduced input regime, to fulfil the ecological objectives of the study, gave an immediate commercial disadvantage. Uncontrolled pest problems, together with a build-up in weed populations, were the main factors associated with loss of revenue in SCARAB. However, as in TALISMAN, carefully managed reductions in fungicide use appeared to offer financial benefits without compromising yield or income. In practice, a more flexible and integrated approach than that used in SCARAB would be adopted to achieve reductions in pesticide use, without compromising farm profitability.

The overall effect of the low-input pesticide treatment was a mean reduction in yield of 12% (1.5 t/ha over all crops), and a range of responses from +1 t/ha to -14.3 t/ha. The largest yield reductions occurred in the sugar beet and potato crops (12.8 and 6.8 t/ha respectively). These effects appeared to be linked to the lack of nematicide and insecticide to control migratory nematodes and aphids on the sugar beet and potato crops respectively.

Wheat yields were reduced by 0.74 t/ha (9%) overall. Some of the yield losses could be attributed to specific problems such as aphids or weed competition. Disease levels were higher on some crops but did not appear to cause large yield losses. Yield losses on the other combinable crops were relatively small.

Gross margins were less affected than yields but there was still an overall reduction of 6% (£47/ha). Low-input pesticide use reduced gross margins in 52% of the comparisons, with responses ranging from +£128/ha to -£493/ha, with the majority of reductions between £0 and £150. The high-value sugar beet and potato crops were most affected by the low-input pesticide regime (-£286 and -£426/ha respectively). Wheat gross margins for the low-input regime were reduced by £35/ha (4%) overall, which was less than the yield difference of 9%. In practice, however, a more flexible approach to reducing pesticide use than that used in SCARAB would be adopted to prevent reductions in profitability.

Relevance to Integrated Crop Management

TALISMAN and SCARAB addressed specific questions related to pesticide use in representative arable rotations. The Projects could not attempt to answer all the issues raised by the Boxworth Project. Nevertheless, TALISMAN, in particular, has provided useful and scientifically robust information on the options for adopting lower inputs which will help farmers grow the crops we need both profitably and in a more environmentally benign way. Some of these issues, particularly the development of Integrated Crop Management (ICM), have been taken forward with industry support and involvement in separate studies in the UK and elsewhere in Europe (Holland *et al.*, 1994). For example, recent major projects in the UK have included LINK Integrated Farming Systems (Ogilvy, 2000) and LIFE (Less Intensive Farming and the Environment) (Jordan *et al.*, 1995).

ICM is increasingly being promoted as the best means of combining efficient, profitable production with greater environmental responsibility and safety at the farm level. In the UK, the Integrated Arable Crop Production Alliance (IACPA) was set up in 1994 to bring together various organisations working in the area of ICM in arable crops (Anon., 1998a). The definition of ICM adopted by IACPA is: "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".

Neither TALISMAN nor SCARAB was conceived or designed with an ICM remit. The Projects lacked many of the cultural and biological elements of weed, pest and disease control which are required in an ICM system. Nevertheless, TALISMAN and SCARAB share many common features with ICM, particularly in relation to achieving economically sustainable reductions in pesticide use. According to the classification of pest management defined by Tait (1987), both the conventional and low-input regimes tested in TALISMAN and SCARAB are in the 'Rational Reductionist' pest management group which requires that each pesticide application be justified on scientific, technical and/or economic grounds. Indeed, a large proportion of crop protection practitioners in the UK would probably claim to fall within this definition of optimised/selective pesticide use since the general move away from prophylactic or routine pesticide use during the last twenty years.

TALISMAN and SCARAB sought to minimise pesticide use through reducing application rates and the avoidance of routine use. Monitoring and, to a lesser extent, forecasting of pest, disease and weed problems were utilised together with use of treatment thresholds, where possible. Biological and 'novel' (e.g. mechanical weeding) methods of non-pesticidal control were not included. Although cultural control was not a high priority in the Projects, a major feature of the TALISMAN design in relation to ICM was the long-term study of six-year rotations with contrasting high- and low-input requirements. Observing cumulative rotational effects, such as those associated with disease and weed control and the overall response of the rotations to low inputs, has provided useful guidance on the implications of lower pesticide and nitrogen use within ICM systems.

The Projects confirmed that the principles of ICM entail a higher risk and lower safety margin in safeguarding the profitability of arable crops. It is likely that successful ICM systems of the future will be founded on a flexible approach, which will embrace the use of the most appropriate and environmentally benign inputs, and will undoubtedly demand high degrees of knowledge and management skill.

Government policy objectives and the future

During the life of the TALISMAN and SCARAB Projects, policy options surrounding the environmental impact of agriculture and pesticides have come under close scrutiny at an international level (Anon., 1997). However, pressures on UK farmers to reduce inputs of agrochemicals have generally been less than in some European countries, where particular problems associated with intensive pesticide use and nutrient leaching have had to be addressed over the past decade. Specifically, within the European Union (EU) Fifth Environmental Action Programme (FEAP) launched in 1992, targets were set for a significant reduction of pesticide use and conversion to methods of integrated farming, at least in all areas of importance for nature conservation (Reus *et al.*, 1997). National policies stemming from FEAP were set by individual member states, some of which defined plans to minimise pesticide use. However, only two countries, Denmark and the Netherlands, implemented pesticide use reduction plans backed by legislation which defined targets and timetables (Anon., 1997).

Although a 'pesticides tax' (Anon., 1999a) is currently under consideration by the UK Government, to date, the preference in the UK has been for regulation by responsibility and accountability, rather than by statutory control. The most recent example of this voluntary approach has been the formation of the Pesticides Forum, which was set up in 1996 and brings together a diverse range of organisations representing those with a practical interest in pesticide use. The Pesticides Forum is a co-ordinating rather than an executive body, so its success depends crucially on initiatives taken collectively or individually by its constituent organisations. The terms of reference of the Pesticides Forum are: "to bring together the views of those concerned with the use and effects of pesticides, to identify their common interests and to assist in the effective dissemination of best practice, advances in technology and research and development results and to advise Government on the promotion and implementation of its policy relating to the responsible use of pesticides" (Anon., 1998b).

It is Government policy that the amount of pesticides used should be limited to the minimum necessary for the effective control of pests, diseases and weeds (Anon., 2000). A key objective of this policy is to minimise the impact of pesticides on the environment, and to continue to ensure that there are no risks posed by approved products to human health. MAFF has recently published a pilot set of indicators for sustainable agriculture in the UK (Anon., 2000), which cover pesticides in rivers and groundwater, residues in food, quantity of pesticide active ingredients used and spray area treated with pesticides. Taken individually, the proposed indicators cannot provide a direct or comprehensive measure of the impact of pesticides on the environment or human health, but when assessed collectively, the indicators may provide an overview of the risk posed by pesticides. These issues are also being considered at an international level, and work is underway to develop an environmental pesticide risk classification system (Anon., 1999b).

At the end of the twentieth century, the continuing wide interest in the interaction of farming practices and the environment highlights the need for scientific research to guide an informed and rational assessment of the subject and to support government policy decisions. The TALISMAN and SCARAB Projects have been valuable milestones in improving our knowledge of some of the financial and ecological consequences of modern-day farming and they have provided important guidelines on how best to develop economically and environmentally acceptable farming systems in the new millennium.

References

Anon. 1997. *Agriculture, Pesticides and the Environment. Policy Options.* Paris: OECD Publications.

Anon. 1998a. *Integrated Farming. Agricultural Research Into Practice.* London: MAFF Publications.

Anon. 1998b. *Pesticides Forum Annual Report 1998.* London: Department of the Environment, Transport and the Regions.

Anon. 1999a. *Design of a Tax or Charge Scheme for Pesticides. A final report to the Department of the Environment, Transport and the Regions.* London: Department of the Environment, Transport and the Regions.

Anon. 1999b. *Environmental Indicators for Agriculture: Concepts and Framework, Volume 1.* Paris: OECD Publications.

Anon. 2000. *Towards Sustainable Agriculture. A Pilot Set of Indicators.* London: MAFF Publications.

Bhogal A, Young S D, Sylvester-Bradley R, O'Donnell F M, Ralph R L. 1997. Cumulative effects of nitrogen application to winter wheat at Ropsley, UK, from 1978-1990. *Journal of Agricultural Science* **129**, 1–12.

Campbell L H, Cooke A S. [*eds*] 1997. *The indirect effects of pesticides on birds.* Peterborough: Joint Nature Conservation Committee.

Clarke J H, Clark W S, Hancock M. 1997. Strategies for the prevention of development of pesticide resistance in the UK – lessons for and from the use of herbicides, fungicides and insecticides. *Pesticide Science* **51**, 391–397.

Cook S K, Turley D, Spink J, Drysdale A. 2000. LINK Integrated Farming Systems (a field-scale comparison of arable rotations) Volume II: The economic evaluation of input decisions. *HGCA Project Report No. 173.* London: HGCA.

Dekker J, Georgopoulos S G. [*eds*] 1982. *Fungicide resistance in crop protection.* Wageningen: Centre for Agricultural Publishing and Documentation.

Finney J. 1993. Risks and rewards from lower chemical inputs into agriculture. *Proceedings of the HGCA Cereals R&D Conference, Robinson College, Cambridge, 5-6 January 1993*, 144–158.

Georghiou G P. 1986. The magnitude of the resistance problem. In: *Pesticide resistance: strategies and tactics for management.* Washington D.C.: National Academy Press.

Holland J M, Frampton G K, Çilgi T, Wratten S D. 1994. Arable acronyms analysed – a review of integrated arable farming systems research in Western Europe. *Annals of Applied Biology* **125**, 399–438.

Jordan V W L, Hutcheon J A, Donaldson G V, Farmer D P. 1995. Research into and development of farming systems for less-intensive arable crop production: progress 1989-1994. *BCPC Symposium Proceedings* **63**, *Integrated Crop Protection: Towards Sustainability?*, 287–298.

Jones N E, Burn A J, Clarke J H. 1997. The effects of herbicide input level and rotation on winter seed availability for birds. *Brighton Crop Protection Conference – Weeds – 1997*, **3**, 1161–1166.

Oakley J N, Ellis S A, Watling M, Walters K F A, Young J E B. 2001. Responses of cereal aphid populations to reduced rate aphicide applications in large field plots of winter wheat. *Agriculture and Forest Entomology*, in press.

Ogilvy S E. 2000. LINK Integrated Farming Systems (a field-scale comparison of arable rotations) Volume I: Experimental Work. *HGCA Project Report No. 173.* London: HGCA.

Paveley N D, Clark W S. 2000. *The wheat disease management guide.* London: HGCA.

Paveley N D, Stevens D B, Hims M, Ainsley A E. 1998. Canopy, disease and fungicide use. *Proceedings of Sixth HGCA Conference on cereals and oilseeds 'Management through understanding research into practice'*, 9.1–9.17. London: HGCA.

Reus J A W A,Weckseler H J, Pak G A, van der Weijden W J. 1997. Towards a comprehensive crop protection policy in the European Union. *Proceedings of the Workshop on Pesticides, Concerted Action AIR3–CT93–1164, Policy Measures to Control Environmental Impacts from Agriculture, Wageningen 1995*. Wageningen: Wageningen Agricultural University, Dept. of Agricultural Economics and Policy.

Sylvester-Bradley R, Scott R K, Stokes D T, Clare R W. 1997. The significance of crop canopies for nitrogen nutrition. *Aspects of Applied Biology* **50**, *Optimising cereal inputs: its scientific basis*, 103–116.

Tait E J. 1987. Planning an integrated pest management system. In: Burn A J, Coaker T H, Jepson P C [*eds*] *Integrated Pest Management*. London: Academic Press, 189–207.

Thomas M R, Garthwaite D G. 1994. *Pesticide Usage Survey Report 119: Grassland and fodder crops in Great Britain 1993*. London: MAFF Publications.

Thomas M R, Garthwaite D G, Banham A R. 1997. *Pesticide Usage Survey Report 141: Arable Farm Crops in Great Britain 1996*. London: MAFF Publications.

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TALISMAN & SCARAB PUBLICATIONS

Boag B, Roger S J, Wright G McN, Neilson R, Hebden P, Squire G R, Lawson H M. 1998. Influence of reduced agrochemical input on plant-parasitic nematodes. *Annals of Applied Biology* **133,** 81–89.

Bowerman P, Young J E B, Cook S K, Jones A E, Green M. 1994. Economic results of farming with reduced levels of inputs: report on the first years of TALISMAN. *Aspects of Applied Biology* **40,** *Arable farming under CAP reform,* 69–76.

Bowerman P, Young J E B, Cook S K, Jones A E, Green M. 1995. Effects of reducing pesticide inputs in the first four years of TALISMAN, *BCPC Symposium Proceedings No. 63. Integrated crop production: Towards Sustainability,* pp. 305–312.

Bowerman P. 1993. Sequels to the Boxworth Project – Studies of environmental, agronomic and economic effects of reduced crop inputs. *Journal of RASE* **154,** 45–60.

Bowerman P. 1993. Strategy of two integrated farming systems experiments in the United Kingdom. *Proceedings of Integrated Arable Farming Systems Conference, Nitra, Slovakia,* pp. 52–59.

Çilgi T, Frampton G K. 1994. Arthropod populations under current and reduced-input pesticide regimes: results from the first four treatment years of the MAFF SCARAB project. *Brighton Crop Protection Conference – Pests and Diseases - 1994* **2,** 653–660.

Çilgi T, Frampton G K, Wratten S D. 1993. Long-term effects of current pesticide use on invertebrates in UK arable crops. *Pesticide Science* **39,** 359–360.

Çilgi T, Wratten S D, Frampton G K, Holland J M. 1993. The long-term effects of pesticides on beneficial invertebrates – lessons from the Boxworth Project. *Pesticide Outlook* **4** (4), 30–35.

Çilgi T, Holland J M, Turner D E, Frampton G K, Wratten S D, Jepson P C. 1994. Pesticide drift and the potential toxicity to beneficial carabids. In: Dedryver C A, [ed.] *Proceedings of IOBC/WPRS Working Group 'Integrated Control in Cereals'. IOBC/WPRS Bulletin* **17** (4), 220–236.

Clarke J H, Bowerman P, Young J E B, Cook S K, Jones A E, Groves S J, Green M. 1993. Effect of recommended and reduced rate herbicides on weed number, yield and gross margin in TALISMAN: report of the first two years. *Brighton Crop Protection Conference – Weeds – 1993,* **3,** 1009–1014.

Cook S K, Hill P E, Green M. 1996. The effect of a low-input regime on weed populations in contrasting rotations of the TALISMAN experiment. *Aspects of Applied Biology* **47,** *Rotations and cropping systems,* 203–210.

Cook S K, Jones A E, Green M. 1995. A comparison of input levels in oilseed rape. *Rapeseed today and tomorrow, 9th International Rapeseed Congress, Cambridge, UK, 1995* **1,** 238–240.

Cook S K, Clarke J H. 1997. The effects of six-years of reduced-rate herbicide use and rotation on weed levels, yields and profitability – TALISMAN results. *Brighton Crop Protection Conference – Weeds – 1997,* **2,** 705–710.

Cooper D A. 1990. Development of an experimental programme to pursue the results of the Boxworth Project. *Brighton Crop Protection Conference – Pests and Diseases –1990,* **1,** 153–162.

Frampton G K. 1997. Species spectrum, severity and persistence of pesticide side-effects on UK arable springtail populations. *Proceedings ANPP Fourth International Conference on Pests in Agriculture, Montpellier (Volume 1)*, pp. 129–136.

Frampton G K. 1997. Off-target effects of pesticides – are we targeting the right indicator species for risk assessment ? In: Haskell P T & McEwen P. [*eds*] *New Studies in Ecotoxicology*. Welsh Pest Management Forum, Cardiff. pp. 23–25.

Frampton G K. 1997. The MAFF SCARAB project: seven years of pesticide side-effects research on arthropods. In: Haskell P T, McEwen P [*eds*] *Ecotoxicology: Pesticides and Beneficial Organisms*. Dordrecht, The Netherlands: Kluwer Academic Publishers, pp. 292–300.

Frampton G K. 2000. Recovery responses of soil surface Collembola after spatial and temporal changes in long-term regimes of pesticide use. *Pedobiologia* **44**, 489–501.

Frampton G K. 2001. Large-scale monitoring of non-target pesticide effects on farmland arthropods in England. In: Johnston J J [*ed.*] *Pesticides and Wildlife. ACS Symposium Series 771*. Washington DC: American Chemical Society, pp. 54–67.

Frampton G K. 1997. The potential of Collembola as indicators of pesticide usage: evidence and methods from the UK arable ecosystem. *Pedobiologia* **41**, 179–184.

Frampton G K, Çilgi T. 1992. Long-term effects of pesticides on arthropods in UK arable crops: preliminary results from the 'SCARAB' project. *Aspects of Applied Biology*, **31**, *Interpretation of Pesticide Effects On Beneficial Arthropods*, 69–76.

Frampton G K, Çilgi T. 1993. Long-term effects of pesticides on Carabidae in U.K. farmland: some initial results from the 'SCARAB' Project. In: Desender K, Dufrêne M, Loreau M, Luff M L, Maelfait J-P, Desender K [*eds*] *Carabid beetles: ecology and evolution*. Dordrecht, The Netherlands: Kluwer Academic Publishers, pp. 433–438.

Frampton G K, Çilgi T. 1993. Boxworth and SCARAB: approaches to the long-term study of side effects of pesticide use on terrestrial invertebrates. *Proceedings of ANPP - BCPC Second International Symposium on Pesticide Application Techniques, Strasbourg*, pp. 399–406.

Frampton G K, Çilgi T. 1996. How do arable rotations influence pesticide side-effects on arthropods? *Aspects of Applied Biology* **47**, *Rotations and cropping systems*, 127–135.

Frampton G K, Çilgi T, Wratten S D. 1994. The MAFF 'SCARAB' Project: long-term consequences for farmland arthropods of pesticide use in the UK. In: Dedryver C A [*ed.*] *Proceedings of the IOBC/WPRS Working Group 'Integrated Control in Cereals'*. *IOBC/WPRS Bulletin* **17** (4), 245–257.

Green M R, Young J E B, Cook S K, Hill P. 1996. A comparison of the profitability of contrasting rotations in the TALISMAN experiment. *Aspects of Applied Biology* **47**, *Rotations and cropping systems*, 287–292.

Green M R, Ogilvy S E, Frampton G K, Çilgi T, Jones S, Tarrant K, Jones A. 1995. SCARAB: the environmental implications of reducing pesticide inputs. *SFS/BCPC Symposium Proceedings No. 63. Integrated Crop Protection: Towards Sustainability*, pp. 321–330.

Hancock M, Frampton G K, Çilgi T, Jones S E, Johnson D B. 1995. Ecological aspects of SCARAB and TALISMAN studies. In: Glen D M, Greaves M P, Anderson H M [*eds*] *Ecology and Integrated Farming Systems*. Chichester, UK: Wiley, pp. 289–386.

Holland J M, Frampton G K, Çilgi T, Wratten S D. 1994. Arable acronyms analysed - a review of integrated arable farming systems research in Europe. *Annals of Applied Biology* **125**, 399–438.

Jones S E, Johnson D B. 1994. The SCARAB Project : Pesticide application regimes and changes in soil microbial biomass. In: A. Copin *et al.* [*eds*] *Environmental Behaviour of Pesticides and Regulatory Aspects (COST ACTION 66).* Brussels: European Study Service, pp. 430–433.

Jones S E, Johnson D B. 1996. The effects of the insecticide dimethoate on soil bacteria in field and laboratory systems. In: Anderson J P E *et al.* [*eds*] *Pesticides, Soil Microbiology and Soil Quality.* SETAC: Europe, 24–25.

Jones S E, Jones A Ll, Johnson D B. 1992. Effects of differential pesticide inputs on the size and composition of soil microbial biomass: results from the Boxworth and SCARAB projects. *Proceedings of the International Symposium on Environmental Aspects of Pesticide Microbiology, Uppsala, Sweden*, pp. 30–36.

Merrett P, Powell D F, Maher H. 1993. A new species of *Centromerus* (Araneae, Linyphiidae) from arable farm land in eastern England. *Bulletin of the British Arachnological Society* **9** (6), 203–204.

Ogilvy S E. 1993. TALISMAN: Assessing the consequences of reduced inputs. *Proceedings of the HGCA Cereals Conference.* London: HGCA, 230–241

Ogilvy S E, Green M R, Mills A R. 1996. SCARAB - the effects of reduced herbicide inputs on floral density in two arable rotations. *Aspects of Applied Biology* **47**, *Rotations and cropping systems*, 211–214.

Ogilvy S E, Green M R, Groves S J, Jones A E. 1993. SCARAB - the impact of less intensive herbicide use on the diversity and distribution of weed species in three arable rotations. *Brighton Crop Protection Conference – Weeds – 1993*, **3**, 1241–1248.

Squire G R, Rodger S, Wright G. 2000. Community-scale seedbank responses to less intense rotations and reduced herbicide input at three sites. *Annals of Applied Biology* **136**, 47–57.

Tarrant K A, Field S A, Jones A, Langton S D, Hart A D M, McCoy C. 1994. The effects on earthworm populations of reducing pesticide use: part of the SCARAB Project. *Brighton Crop Protection Conference – Pests and Diseases – 1994*, **3**, 1289–1294.

Young J E B, Bowerman P, Cook S A, Green M R, Jones A E. 1994. The TALISMAN experiment - observations and implications for integrated pest and disease management of arable crops in the UK. *Brighton Crop Protection Conference – Pests and Diseases – 1994*, **1**, 125–134.

Young J E B, Cook S K, Green M R, Hill P E. 1996. Invertebrate pest control in low-input arable rotations: the TALISMAN experience. *Aspects of Applied Biology* **47**, *Rotations and cropping systems*, 137–144.

RISC publications

Easson D L. 1993. Reducing the input of agro-chemicals in cropping systems. *Agriculture in Northern Ireland* **7** (1), 20–21.

Easson D L. 1999. Making grass work for the arable farmer. *Forage Matters* **2**, 8-9.

Easson D L, Picton J. 1994. Reduced input system of cropping. *Agriculture in Northern Ireland* **8** (4), 14–15.

Easson D L, Picton J. 1996. The effects of reduced agro-chemical and fertilizer inputs on crops under differing rotational systems in the RISC project. *Proceedings Crop Protection in Northern Britain 1996* **1**, 9–14.

Easson D L, Courtney A D, Picton J. 1995. The effects of reduced rate fertilizer and herbicide input systems on the yield and performance of cereal crops. *BCPC Symposium Proceedings No. 63. Integrated crop production: Towards Sustainability*, pp. 313–320.

Easson D L, Picton J, Mellon R. 1996. The effects of rotation and reduced herbicide input on weed competition in the RISC project. *Aspects of Applied Biology* **47**, *Rotations and cropping systems*, 215–220.

Easson D L, Mercer P C, Bell A C, Christie P, Crawford A G S, Semple A M. 1998. A study of the effects of reduced agro-chemical and fertilizer inputs on yields, profitability and environmental impact of arable and mixed cropping systems. *Agricultural Research Institute for Northern Ireland Annual Report 1996-97*, pp. 35–51.

Semple A M, Easson D L, Christie P. 1996. Changes in soil mineral nitrogen in a reduced inputs system of cropping. In: Rotations and Cropping Systems. *Aspects of Applied Biology* **47**, 421–424.

Semple A M, Easson D L, Christie P. 1997. Overwinter changes in soil mineral nitrogen concentration in a reduced input system of cropping. *Irish Journal of Agricultural Research* **36**, 100.

GLOSSARY

Abiotic stress factors Inanimate stress factors such as drought or temperature that affect living organisms.

Acari (mites and ticks) A group (order) of Arachnida with diverse feeding habits; the head and abdomen are fused into a single compact carapace and the legs are usually short relative to body size. They are among the most abundant arthropods in agricultural fields.

Action threshold See *Threshold.*

Active ingredient (a.i.) That part(s) of a pesticide formulation which is active against, and toxic to, the target organism.

Admix To mix a pesticide, usually slug pellets, with the seed so that they are sown together.

Agrochemical A chemical intended for agricultural use.

Agromyzidae (leaf mining flies) A group (family) of herbivorous flies (Diptera) whose larvae eat out characteristic tunnels ('mines') in plant tissue.

Agronomic Relating to the management and productivity of land.

Aleocharinae A sub-family of staphylinid or rove beetles.

All High sub-treatment A TALISMAN sub-treatment in which all types of pesticide were applied according to CCP rules (Chapter 2.1).

All Low sub-treatment A TALISMAN sub-treatment in which all types of pesticide were applied according to LIA rules (Chapter 2.1).

Analysis of variance (ANOVA) A statistical analysis which estimates variation due to a range of factors and compares it with the general background variation.

Annual Area Payment See *Arable Area Payments.*

Aphicide A substance for killing aphids.

Aphid honeydew See *Honeydew.*

Aphididae (aphids) A group (family) of herbivorous bugs (Hemiptera: Homoptera), many species of which are considered important pests of field crops.

Aphids Small insects, commonly known as greenfly, that suck plant juices.

Apparent Nitrogen Balance A measure of the differences between N applied and N removed in crops; it does not include losses by leaching or volatilisation or additions by atmospheric deposition.

Arable Aid Payments See *Arable Area Payments.*

Arable Area Payments Annual payments, made at rates set by the European Union (EU), to arable farmers growing specified crops (including cereals, oilseeds and proteins) on eligible land. The rates vary from year-to-year and have also been different for each type of crop but by 2002, cereals and oilseeds will receive the same rate, with proteins being slightly higher. All payments are dependent on having an area (rate fixed annually) of set-aside, whereby land is taken out of crop production.

Arachnida A group (class) of Arthropoda that lacks wings, compound eyes and antennae; the body has at most two major divisions and, usually, four pairs of legs.

Araneae (spiders) A group (order) of predatory Arachnida in which the main strategies for prey capture involve silk webs, ambush or active pursuit. Distinguished from other arachnids by possession of abdominal silk glands and spinners.

Arthropods Large group (phylum Arthropoda) of invertebrate animals with jointed walking appendages; includes insects (Hexapoda, Insecta), spiders (Araneae), mites (Acari) and harvestmen (Opiliones).

Available P and K Results of soil tests for available nutrients which give a measure of the forms of phosphorous (P) and potassium (K) which plants take up as nutrients.

Bacteria Microscopic prokaryotic single-celled organisms.

Reducing Agrochemical use on the Arable Farm: The TALISMAN and SCARAB Projects.

Young J E B, Griffin M J, Alford D V, Ogilvy S E. [eds] 2001. London: DEFRA.

Bacterial PLFA Bacterial phospholipid fatty acid used as an indicator for bacterial community structure.

Bibionidae (March flies) A group (family) of predominantly herbivorous flies (Diptera), considered important as pollinators, although some species are occasionally injurious to field crops.

Bioavailability The ability of a compound (e.g. a pesticide) to induce environmental effect.

Biodiversity The existence of a wide variety of plant and animal species in their natural environment.

Biomass The quantity or weight of organisms (commonly microorganisms) in a given habitat (e.g. soil).

Biomass carbon A measure used to indicate the total microbial biomass in the soil.

Brackling Buckling or bending of the stems of cereal plants at a point one quarter or more up the stems from their base at soil level (see also *Lodging*).

Break crop A crop (e.g. beans or oilseed rape) commonly used to break a series of cereal crops in an arable rotation.

Broadcasting To scatter over the soil surface.

Broad-spectrum Describing a chemical (e.g. pesticide) that is toxic to a wide range of organisms, some of which may be non-target (non-pest) species.

Cantharidae (soldier beetles) A group (family) of predatory beetles (Coleoptera), adults of which are often seen on flowers, particularly umbellifers.

Carabidae (ground beetles) A group (family) of predominantly predatory ground-living beetles (Coleoptera) but with some herbivorous and omnivorous species. They are generally considered important natural enemies of crop pests.

Carbamate A group of insecticides based on a salt or ester of carbamic acid.

CCP Acronym for: Current Commercial Practice, a treatment in TALISMAN (Chapter 2.1).

Cecidomyiidae (gall midges, cecid midges) A group (family) of flies (Diptera) with diverse feeding habits that includes pests of field crops, e.g. orange wheat blossom midge (*Sitodiplosis mosellana*) and brassica pod midge (*Dasineura brassicae*).

CFP Acronym for: Current Farm Practice, a treatment in SCARAB (Chapter 3.1).

Chironomidae (non-biting midges) A group (family) of predominantly detritivorous flies (Diptera).

Chloropidae A group (family) of herbivorous flies (Diptera) that includes some pest species of field crops e.g. frit fly (*Oscinella frit*).

Chrysomelidae (leaf beetles) A group (family) of herbivorous beetles (Coleoptera) that are often found on plants, which they may damage; includes flea beetles.

Cicadellidae (leafhoppers) A group (family) of herbivorous bugs (Hemiptera: Homoptera).

Coccinellidae (ladybirds and relatives) A group (family) of beetles (Coleoptera) that includes both the familiar oval-shaped ladybirds whose adults and larvae predominantly prey upon aphids, and also fungivorous species.

Coleoptera (beetles) A group (order) of holometabolous insects with chewing mouthparts in which the adult forewings typically are modified as hard wing cases.

Collembola (springtails) A group (order) of small, wingless, insects (Hexapoda) not exceeding 6 mm in length which are often abundant in soils and on vegetation; an important prey resource for predatory arthropods. Sometimes considered as a distinct hexapod group (class Collembola), as they are morphologically unlike other insects.

Combinable crops Arable crops harvested with a combine-harvester e.g. cereals, pulses and oilseeds.

Common Agricultural Policy (CAP) The European Union operates a system of acreage/headage subsidies for agricultural enterprises, together with a system of surplus storage. All of these are subject to standard payments in terms of yield, exchange rates and area limitations. Due to changes in world trade agreements regarding production, payments under CAP are likely to focus increasingly on environmental and sustainable issues.

Contact herbicide A herbicide which is toxic to target weed species through direct contact of the active ingredient with the surface of the plant.

Correspondence analysis A statistical method for the analysis of multivariate data which attempts to identify relationships in the data and which is best represented graphically.

Crop canopy The light-intercepting leaf structure of a crop.

Crop equivalent The number of weeds present in a crop that will cause a 2% loss in yield.

Crop headland See *Headland.*

Crop rotation The sequence in which crops of various type are grown.

Cryptophagidae A group (family) of omnivorous and fungivorous beetles (Coleoptera) that includes pygmy beetles (*Atomaria* spp.).

Cultivar A genetically distinct line or variety of a given cultivated species of crop plant.

Curculionidae (weevils) A group (order) of herbivorous beetles (Coleoptera), adults of which often possess a long snout-like rostrum. Some species (e.g. the pea and bean weevil, *Sitona lineatus*) are pests of field crops.

DANI Department of Agriculture for Northern Ireland. This name changed in 1999 to Department of Agriculture and Rural Development (DARD).

DARD Department of Agriculture and Rural Development. Formerly Department of Agriculture for Northern Ireland (see *DANI*).

DEFRA Department for Environment, Food and Rural Affairs. A new UK Government Department created in June 2001 comprising of all functions of the former MAFF (see *MAFF*) and certain elements of the former DETR (Department of the Environment, Transport and the Regions).

Delphacidae A group (family) of herbivorous plant bugs (Hemiptera: Homoptera).

Detoxification Process by which an active ingredient in a pesticide or other poisonous compound is rendered harmless.

Detritivore An organism that feeds on fragmented particulate dead or decaying organic matter.

Diptera (true flies) A group (order) of holometabolous insects, adults of which have the hind wings modified as small club-shaped balance organs. Larvae and adults often have different feeding habits; in some species adults do not feed.

Diversity index A measure of the number of species and their relative abundance in a community; sometimes describes the absolute number of species (species richness).

Dolichopodidae A group (family) of predatory flies (Diptera).

Drosophilidae (fruit flies) A group (family) of flies (Diptera) that feed on decaying and fermenting plant material and on fungi.

DT_{50} Time taken for 50% disappearance of a compound (e.g. a pesticide) from soil.

Ear (of cereals) The fruiting head of a cereal plant, containing the grains.

Ecosystem A community of organisms, interacting with one another, plus the environment in which they live and with which they also interact.

Elateridae (click beetles) A group (family) of beetles (Coleoptera), many species of which are herbivores; adults, when overturned, can self-right with an audible click by flexing the thorax.

Empididae (dance flies) A group (family) of predominantly predatory flies (Diptera).

Ergosterol An exclusively fungal sterol, often a target site for many fungicides. Also a fungal biomarker.

Eukaryote A cell or organism having a unit membrane-enclosed (true) nucleus and usually other cell organelles (membrane-enclosed internal structures).

Fauna Animals of a particular habitat or region.

Fertiliser An inorganic (e.g. ammonium nitrate) or organic (e.g. animal manure) substance rich in elements and compounds essential for plant growth and development, applied to crops to stimulate growth and to maintain or improve crop yield. See also *Nitrogen*, *Phosphorus* and *Potassium*.

Field margin The uncropped zone at the edge or boundary of a field.

Fixed A sample (organism or part of an organism) which has undergone fixation, the first step in making permanent preparations for microscopic study.

Flag leaf The last and uppermost leaf to emerge on a cereal plant, such as wheat.

Flora Plants of a particular habitat or region.

Fumigation-extraction A method used to estimate soil microbial biomass, based on fumigation of soil with chloroform which lyses microbial cells and releases cytoplasm into the soil. Cell-derived material can then be extracted and measured chemically e.g. by dichromate oxidation or ninhydrin assay.

Fungi Eukaryotic microorganisms that obtain energy from the oxidation of organic compounds (non-photosynthetic) and that contain rigid cell walls.

Fungicide A type of pesticide used to control plant pathogenic fungi (e.g. rusts, mildews, blight).

Fungivorous Feeding upon fungi.

General Agreement on Tariffs and Trade (GATT) The system operated by the World Trade Organisation for trade including agricultural goods. The Agreement is updated every seven years and at the last round, there were substantial reductions of permitted production subsidies and export payments aimed at a level world market. This caused a major downward adjustment to the CAP which is expected to continue.

Gross margin The total income from a crop minus the variable costs attributed to that crop. This is a useful means of comparing enterprises without taking into account fixed costs such as machinery maintenance, depreciation, overheads and labour which cannot be attributed to a specific crop.

Gross output The sale proceeds of an enterprise or total business, for example the gross output of wheat will be its sale value, net of deductions for transport, moisture content and processing.

Hagberg Falling Number A measure of grain quality for milling wheats.

Headland The part of a crop at the edge of a field where farm machinery makes turning manoeuvres.

Hemimetabolous Lacking a distinct metamorphosis such that young instars (nymphs) are similar in appearance to adults, but smaller.

Hemiptera (true bugs) A group (order) of hemimetabolous insects with mouthparts modified for piercing and sucking. Includes aphids, leafhoppers and predatory bugs.

Herbicide A type of pesticide used to control weeds; a weedkiller.

Herbivorous Feeding predominantly on plant material.

Hexapoda An alternative name for Insecta (insects).

Holometabolous Possessing a distinct metamorphosis with well defined larval, pupal and adult stages.

Honeydew A sticky, sugary fluid excreted by aphids which often encourages the growth of sooty moulds on leaf surfaces.

Hydrophilidae A group (family) of beetles (Coleoptera) that includes both aquatic and terrestrial, mostly omnivorous, species.

Hymenoptera An order of insects icluding ants, bees, sawflies amd wasps.

Hyphae In many (mycelial) fungi and in some bacteria (e.g. actinomycetes): branched or unbranched filaments, many of which together constitute the vegetative form of the organism.

Indirect effects Pesticide effects on an organism which act via an intermediate mechanism e.g. by affecting the organism's food, or habitat quality.

Insecta (insects) A large group (class) of Arthropoda in which the adult body is typically divided into head, thorax and abdomen. The largest and most diverse of all classes of living organisms. Also referred to as Hexapoda.

Insecticide A type of pesticide used to control insect pests.

Insurance pesticide use See *Prophylactic pesticide use.*

Integrated management system A management system which incorporates a combination of chemical, biological, physical and cultural techniques with an overall aim of reducing pesticide inputs.

Invertebrate An animal without a backbone.

Labile extractable-C Soluble carbon (e.g. in soil) that can be easily degraded, usually by indigenous microorganisms.

Lathridiidae A group (family) of small (usually <3 mm long), principally fungivorous, beetles (Coleoptera).

Leachability The ability of a compound (e.g. a pesticide) to move downward through soil as a result of water movement.

Leiodidae (scavenger beetles) A group (family) of omnivorous and fungivorous beetles (Coleoptera).

LIA Acronym for: Low Input Approach, a treatment in TALISMAN (Chapter 2.1).

Linyphiidae (money spiders) A group (family) of spiders (Araneae) that predominantly capture prey using sheet silk webs. They are considered important natural enemies of some crop pests e.g. aphids.

Lodging Permanent displacement of cereal stems from the vertical, giving crops a leaning or flattened appearance. Most often occurring in tall, overly-dense or over-fertilised crops in conjunction with stem-base diseases and/or severe summer weather.

Lonchopteridae A group (family) of detritivorous and fungivorous flies (Diptera).

Long-term effect (of pesticide use) An effect of pesticide use (e.g. on insect abundance) that persists beyond the year in which the pesticide is applied, and hence can be detected in one or more following crops.

Low Fungicide sub-treatment A TALISMAN sub-treatment in which only fungicides were applied according to LIA rules and all other pesticides were applied according to CCP rules (Chapter 2.1).

Low Herbicide sub-treatment A TALISMAN sub-treatment in which only herbicides were applied according to LIA rules and all other pesticides were applied according to CCP rules (Chapter 2.1).

Low Insecticide sub-treatment A TALISMAN sub-treatment in which only insecticides (and molluscicides) were applied according to LIA rules and all other pesticides were applied according to CCP rules (Chapter 2.1).

Lycosidae (wolf spiders) A group (family) of spiders (Araneae) that actively hunt prey on the ground surface and on low vegetation.

MAFF Ministry of Agriculture, Fisheries and Food. Became part of DEFRA (see *DEFRA*) in June 2001.

Metabolism All biochemical reactions in a cell, both anabolic and catabolic.

Micrometer (μm) One-millionth of a meter, or 10^{-6} m, the unit used for measuring microorganisms.

Mineral nitrogen Nitrogen present in inorganic forms such as ammonium and nitrate ions.

Mineralisation The production of mineral (inorganic) nitrogen from organic matter by bacterial activity.

Miridae (capsids, leaf bugs) A group (family) of plant bugs (Hemiptera: Heteroptera) that is predominantly herbivorous but includes some predatory species.

Molluscicide A type of pesticide used to control plant-damaging molluscs, particularly slugs.

Multivariate analysis A method of statistical analysis in which effects of many variables are simultaneously tested or compared and often displayed graphically to summarise complex ecological data.

Mycelium A group or mass of discrete hyphae; the form of the vegetative thallus in many types of fungi and in certain bacteria.

Mycetophilidae (fungus gnats) A group (family) of predominantly fungivorous flies (Diptera).

Nabidae (damsel bugs) A group (family) of predatory bugs (Hemiptera: Heteroptera).

Nematicide A pesticide for killing harmful nematodes.

Nematode Small (0.5–5 mm long) multicellular worm-like organisms with an unsegmented, elongate, cylindrical body.

Nitidulidae A group (family) of beetles (Coleoptera) that, in agricultural fields, is principally represented by herbivorous pollen beetles (*Meligethes* spp.).

Nitrogen (N) An essential element for plant growth and development (see *Fertiliser*).

Non-target arthropods Arthropods which are not pests but which may be killed by the application of pesticides. This can include beneficial species such as predators or parasites of pests, pollinators such as bees, or other species which may be important in maintaining soil fertility such as collembola.

Omnivorous Having a mixed diet (e.g. being both herbivorous and fungivorous).

Opiliones (harvestmen) A group (order) of predatory Arachnida that resembles long-legged spiders (Araneae) but which lack a clear separation of the head and abdomen; legs are typically long relative to body size.

Opomyzidae (grass and cereal flies) A group (family) of herbivorous flies (Diptera) that includes species that are occasionally pests of field crops.

Order A group used for classifying organisms. Consists of a number of similar families.

Ordination A multivariate analysis technique that uses a two-dimensional graphical display (ordination diagram) to summarise the relative influence of different variables on complex data (e.g. ecological communities).

Ordination techniques A group of statistical methods, including correspondence analysis and principal coordinate analysis, which attempt to identify relationships within data sets.

Organophosphorus (OP) A type of pesticide (usually an insecticide) that is an organic ester of a phosphorus acid. These chemicals have broad-spectrum activity, being toxic to arachnids and vertebrates as well as insects.

Parasite An organism living in or on another organism (its host) from which it obtains its food.

Parasitoid An organism with a mode of life intermediate between parasitism and predation; usually a wasp whose larva feeds within the body of another animal, eventually killing it. Parasitoids can be important as natural enemies of pest species (e.g. aphids).

Penicillium A group of common soil fungi.

Pest threshold See *Threshold*.

Pesticide In crop production, a substance used to control the organisms that could cause reduced crop yields or post-harvest damage to stored crops.

Phalacridae A group (family) of oval, fungivorous beetles (Coleoptera).

Phoridae (scuttle flies, phorid flies) A group (family) of flies (Diptera) with diverse feeding habits that include detritivores and fungivores.

Phosphorus (P) An essential element for plant growth and development (see *Fertiliser*).

Phytotoxic Injurious or lethal to at least some plants.

Pitfall sampling A sampling method for capturing animals walking on the soil surface, using open collecting pots placed in the ground.

Pitfall trap A plastic or metal container buried so its rim is level with the soil surface, which acts as a trap.

Plant-parasitic nematode A nematode which feeds exclusively on plants.

Plate count technique A procedure using solid nutrient media (often agar-based) to grow and enumerate microorganisms.

Potassium (K) An essential element for plant growth and development (see *Fertiliser*).

Predator An animal that feeds on other animals i.e. is a secondary consumer but not a parasite (see *Parasite*).

Predicted Environmental Concentration (PEC) A calculation used in the risk assessment of pesticides to soil organisms. A PEC represents the maximum expected concentration of a pesticide in the soil environment and is calculated by assuming all of the pesticide reaches the soil and is evenly distributed in the top 5 cm.

Principal coordinate analysis See *Ordination* and *Ordination techniques*.

Prokaryote A cell or organism lacking a nucleus and other membrane-enclosed cell structures, usually having its DNA in a single circular molecule.

Prophylactic pesticide use Early or 'insurance' application of a pesticide aimed at preventing the establishment or outbreak of a pest organism.

Protozoa Unicellular eukaryotic microorganisms that lack cell walls.

Redundancy Analysis (RDA) A type of multivariate analysis that focuses on the variance in a data set that is attributed to specified variables.

Replication (in experiments) The technique of applying an experimental treatment to more than one experimental unit in order to obtain an estimate of variability.

Resistance (to pesticides) A change or shift in the susceptibility of a given weed, pest or disease so that the target population can no longer be fully controlled by a particular pesticide or group of pesticides.

Rhizodeposition Deposition of nutrients from the rhizosphere to the soil.

Rhizosphere The region immediately adjacent to plant roots.

RIA Acronym for: Reduced Input Approach, a treatment in SCARAB (Chapter 3.1).

RISC Acronym for: Reduced Input Systems of Cropping.

Saprophyte An organism which survives by obtaining its food from dead or decaying tissues of plants or animals.

SCARAB Acronym for: Seeking Confirmation About Results At Boxworth.

Sciaridae (sciarid flies, black fungus gnats) A group (family) of predominantly fungivorous flies (Diptera).

Seedbank See *Weed seedbank*.

Sepsidae A group (family) of predominantly detritivorous flies (Diptera).

Short-term effect (of pesticide use) An effect of pesticide use (e.g. on insect abundance) that does not persist beyond the year in which the pesticide is applied, and hence cannot be detected in following crops.

Similarity index Any of several different indices which show how similar two communities are in terms of the relative abundance of their constituent species. Usually expressed on a scale of zero (complete dissimilarity) to one (complete similarity).

Sodium Dodecyl Sulphate A measure of grain quality for milling wheats.

Soil Mineral Nitrogen The concentration of nitrate and ammonium nitrogen in the soil, usually expressed as kg/ha of N.

Soil respiration A measure of the metabolic activity of soil, quantified by measuring either CO_2 production or O_2 consumption.

Sphaeroceridae (lesser dung flies) A group (family) of detritivorous flies (Diptera) that includes some fungivorous species.

Spray round The application of a pesticide spray to a crop on an individual occasion.

Staphylinidae (rove beetles) A group (family) of mostly elongate beetles (Coleoptera) with characteristic short wing cases. Includes predatory, fungivorous and omnivorous species.

Statistically significant A mathematical indication that treatment differences are real and unlikely to have occurred by chance e.g. $P < 0.05$ denotes that there is a 95% probability that the difference detected is a real difference and a 5% probability that it occurred by chance.

Sub-family A sub-division of a family.

Substrate-induced respiration A method that uses the physiological response of soil organisms (e.g. CO_2 production) to substrate amendment to provide an estimate of soil microbial biomass.

Suction sampling A method for estimating abundance of arthropods on the ground surface and vegetation. The 'D-vac' suction sampler is a backpack model that uses a petrol-driven engine to power a vacuum fan; the airflow draws arthropods from the soil or vegetation through a hand-held sampling nozzle into a collecting net.

Surface tension The property of a liquid surface to behave like a stretched elastic membrane.

Synthetic pyrethroid A type of synthetic insecticide developed to mimic the toxicity to insects of natural pyrethrum, which occurs in the chrysanthemum, *Chrysanthemum cinerariaefolium*.

Syrphidae (hover flies) A group (family) of flies (Diptera) with varied feeding habits; species with predatory larvae may be important natural enemies of pest aphids.

Systemic pesticide A pesticide which is capable of being absorbed, or passing into, a plant and is then mobile or transported within the plant.

T test A statistical test for comparing the means (averages) of two samples.

TALISMAN Acronym for: Towards A Lower Input System Minimising Agrochemicals and Nitrogen.

Tank-mix When two or more pesticide formulations are applied simultaneously by a crop sprayer following mixture of the products in the spray tank.

Taxa A biological category or group.

Threshold The number of pests above which their control is cost-effective.

Thymidine A precursor of DNA; its incorporation into cells may be used as a measure of cell growth rate.

Thysanoptera (thrips, thunderflies) A group (order) of small, elongate Hexapoda with mouthparts specialised for piercing and sucking. They appear wingless, as two pairs of narrow wings, when present, are held against the body. They have diverse feeding habits, some species occasionally being implicated in crop damage.

Tillers The shoots or stems produced by a cereal plant (e.g. wheat).

Tipulidae (crane flies, daddy long legs) A group (family) of flies (Diptera) with mixed feeding habits. Some large species have herbivorous larvae ('leatherjackets') that can be injurious to field crops but which may also be important as food for birds.

Tramlines Parallel lines through a crop created by the wheels of farm machinery and used to apply, accurately, agrochemicals.

Transect A line or direction along which a series of samples or measurements may be taken.

Trophic group A group of organisms which share a similar position in the food chain.

Variable costs Costs attributable directly to a particular crop such as seed, fertiliser and agrochemicals.

Vector An organism which transmits a virus.

Viable Alive; able to reproduce.

Viable count Measurement of the concentration of live cells in a microbial population.

Volunteer A previous year's crop plant growing spontaneously in the new crop.

Weed A plant growing where it is not wanted.

Weed biomass The dry weight of weeds present on a given area of ground.

Weed seedbank Viable weed seeds present in the soil and capable of germinating in future years.

APPENDICES

TALISMAN Appendix Tables

In **Appendix Tables 2.8.1–2.8.26,** yield and gross margin data are listed as site and cross-site means for each type of crop grown in TALISMAN. **Appendix Tables 2.8.27–2.8.29** give TALISMAN site and cross-site gross margin means, listed for crops grouped as cereals, break crops and 'all crops', respectively. In **Appendix Tables 2.8.30–2.8.32,** mean gross margins of the TALISMAN Standard and Alternative Rotations (merged Phases I and II) are shown for Boxworth, Drayton and High Mowthorpe, respectively.

In all TALISMAN tables, those SEDs prefixed by 'h' (horizontal) are for comparisons of sub-treatment means within the same level of nitrogen, whereas SEDs prefixed 'v' (vertical) are for sub-treatment comparisons within and between different levels of nitrogen. Values of statistical significance (e.g. $P < 0.05$) obtained from Analysis of Variance (ANOVA) are identified on the tables where appropriate.

Note that, in certain tables, because percentage values representing changes have been calculated using source data, then they may differ slightly from the percentage values calculated using the data cited in the tables, owing to rounding to an appropriate number of decimal places.

SCARAB Appendix Tables

The remaining **Appendix Tables 3.1.1–3.1.7** give a detailed account of insecticide, herbicide and fungicide use in the CFP and RIA treatment regimes applied at each of the SCARAB sites, including the pre-treatment phase of the study (1987–1990). Finally, **Appendix Table 3.1.8** provides details of the seed treatments used in SCARAB.

Appendix Table 2.8.1. Mean yields of first year winter wheat in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (172 d.f.)						
			SED v 0.202, h 0.089			SED 0.185
CCP Nitrogen	6.99	6.67 (95)	6.97 (100)	6.86 (98)	6.91 (99)	6.88
LIA Nitrogen	7.02	6.70 (95)	6.84 (97)	6.97 (99)	6.89 (100)	6.88
			SED 0.063***			
Cross-nitrogen means	7.01	6.68 (95)	6.91 (99)	6.92 (99)	6.90 (98)	
Drayton (80 d.f.)						
			SED v 0.219, h 0.129			SED 0.186*
CCP Nitrogen	8.27	8.05 (97)	8.49 (103)	8.13 (98)	8.39 (102)	8.26
LIA Nitrogen	7.88	7.53 (96)	7.83 (99)	7.80 (99)	8.07 (102)	7.82
			SED 0.091***			
Cross-nitrogen means	8.07	7.79 (97)	8.16 (101)	7.96 (99)	8.23 (102)	
H. Mowthorpe (176 d.f.)						
			SED v 0.208, h 0.113			SED 0.182***
CCP Nitrogen	9.01	8.08 (90)	8.74 (97)	9.06 (101)	8.81 (98)	8.74
LIA Nitrogen	7.72	7.12 (92)	7.43 (96)	7.64 (99)	7.64 (99)	7.51
			SED 0.080***			
Cross-nitrogen means	8.37	7.60 (91)	8.08 (97)	8.35 (100)	8.22 (98)	
Cross-site (428 d.f.)						
			SED v 0.125, h 0.063			SED 0.111***
CCP Nitrogen	8.06	7.51 (93)	7.98 (99)	7.99 (99)	7.97 (99)	7.90
LIA Nitrogen	7.47	7.03 (94)	7.27 (97)	7.40 (99)	7.42 (99)	7.32
			SED 0.045***			
Cross-nitrogen means	7.76	7.27 (94)	7.63 (98)	7.70 (99)	7.70 (99)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
*** $P < 0.001$.

Appendix Table 2.8.2. Mean gross margins from first year winter wheat crops in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (172 d.f.)						
			SED v 20.55, h 10.13			SED 18.45
CCP Nitrogen	708.5	714.4 (101)	722.5 (102)	718.8 (101)	700.0 (99)	712.9
LIA Nitrogen	727.1	733.6 (101)	723.5 (100)	746.4 (103)	713.5 (98)	728.8
			SED 7.16***			
Cross-nitrogen means	717.8	724.0 (101)	723.0 (101)	732.6 (102)	706.8 (99)	
Drayton (80 d.f.)						
			SED v 25.43, h 14.25			SED 22.01
CCP Nitrogen	767.7	830.5 (108)	836.6 (109)	778.0 (101)	789.3 (103)	800.4
LIA Nitrogen	738.9	789.9 (107)	782.3 (106)	760.7 (103)	770.4 (104)	768.5
			SED 10.07***			
Cross-nitrogen means	753.3	810.2 (108)	809.5 (108)	769.3 (102)	779.9 (104)	
H. Mowthorpe (176 d.f.)						
			SED v 26.64*, h 14.50*			SED 23.27***
CCP Nitrogen	1113.5	1043.3 (94)	1096.4 (99)	1154.1 (104)	1086.9 (98)	1098.8
LIA Nitrogen	930.8	905.8 (97)	907.0 (97)	956.9 (103)	921.5 (99)	924.4
			SED 10.26***			
Cross-nitrogen means	1022.1	974.5 (95)	1001.7 (98)	1055.5 (103)	1004.2 (98)	
Cross-site (428 d.f.)						
			SED v 14.51, h 7.66			SED 12.80***
CCP Nitrogen	882.3	869.2 (99)	894.9 (101)	904.8 (103)	872.6 (99)	884.8
LIA Nitrogen	811.0	813.7 (100)	808.7 (100)	833.5 (103)	808.1 (100)	815.0
			SED 5.42***			
Cross-nitrogen means	846.6	841.4 (99)	851.8 (101)	869.1 (103)	840.4 (99)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
*** $P < 0.001$.

Appendix Table 2.8.3. Mean yields of second year winter wheat in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (111 d.f.)						
			SED v 0.136, h 0.090			SED 0.109***
CCP Nitrogen	8.06	7.76 (96)	8.10 (101)	8.00 (99)	8.14 (101)	8.01
LIA Nitrogen	6.80	6.67 (98)	6.84 (101)	6.76 (99)	6.84 (101)	6.78
			SED 0.064***			
Cross-nitrogen means	7.43	7.21 (97)	7.47 (101)	7.38 (99)	7.49 (101)	
Drayton (80 d.f.)						
			SED v 0.281, h 0.186			SED 0.226***
CCP Nitrogen	8.17	7.61 (93)	8.09 (99)	7.90 (97)	8.21 (101)	7.99
LIA Nitrogen	6.27	6.26 (100)	6.49 (104)	6.43 (103)	6.53 (104)	6.39
			SED 0.132*			
Cross-nitrogen means	7.22	6.93 (96)	7.29 (101)	7.16 (99)	7.37 (102)	
H. Mowthorpe (32 d.f.)						
			SED v 0.340, h 0.158			SED 0.309*
CCP Nitrogen	8.91	7.87 (88)	8.45 (95)	8.64 (97)	8.73 (98)	8.52
LIA Nitrogen	6.67	5.88 (88)	5.98 (90)	6.44 (97)	6.55 (98)	6.30
			SED 0.112***			
Cross-nitrogen means	7.79	6.88 (88)	7.22 (93)	7.54 (97)	7.64 (98)	
Cross-site (223 d.f.)						
			SED v 0.130, h 0.083			SED 0.107**
CCP Nitrogen	8.25	7.72 (94)	8.16 (99)	8.08 (98)	8.27 (100)	8.10
LIA Nitrogen	6.59	6.38 (97)	6.56 (100)	6.59 (100)	6.68 (101)	6.56
			SED 0.059***			
Cross-nitrogen means	7.42	7.05 (95)	7.36 (99)	7.33 (99)	7.48 (101)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Appendix Table 2.8.4. Mean gross margins from second year winter wheat in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (111 d.f.)						
			SED v 19.48, h 11.32			SED 16.64***
CCP Nitrogen	1014.0	1008.2 (99)	1028.7 (102)	1028.8 (102)	1025.9 (101)	1021.1
LIA Nitrogen	877.3	893.2 (102)	892.1 (102)	894.5 (102)	883.8 (101)	888.2
			SED 8.01			
Cross-nitrogen means	945.6	950.7 (101)	960.4 (101)	961.6 (102)	954.8 (101)	
Drayton (80 d.f.)						
			SED v 31.02, h 18.64			SED 26.16*
CCP Nitrogen	689.4	757.4 (110)	736.9 (107)	711.0 (103)	714.0 (104)	721.7
LIA Nitrogen	523.3	646.3 (124)	601.0 (115)	589.1 (113)	570.0 (109)	585.9
			SED 13.18***			
Cross-nitrogen means	606.4	701.8 (116)	668.9 (110)	650.0 (107)	642.0 (106)	
H. Mowthorpe (32 d.f.)						
			SED v 35.05, h 16.39			SED 31.83**
CCP Nitrogen	854.1	832.2 (97)	844.4 (99)	873.8 (102)	837.3 (98)	848.3
LIA Nitrogen	665.6	669.3 (101)	636.5 (96)	683.5 (103)	654.1 (98)	661.8
			SED 11.59***			
Cross-nitrogen means	759.9	750.8 (99)	740.4 (97)	778.6 (103)	745.7 (98)	
Cross-site (223 d.f.)						
			SED v 15.55, h 8.99			SED 13.31***
CCP Nitrogen	871.2	888.6 (102)	893.2 (103)	889.3 (102)	882.5 (101)	885.0
LIA Nitrogen	715.0	766.6 (107)	744.3 (104)	749.5 (105)	732.5 (103)	741.5
			SED 6.36***			
Cross-nitrogen means	793.1	827.6 (104)	818.7 (103)	819.4 (103)	807.5 (102)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Appendix Table 2.8.5. Mean yields of all winter wheat crops (first and second year) in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (283 d.f.)						
			SED v 0.135, h 0.065			SED 0.122***
CCP Nitrogen	7.42	7.11 (96)	7.42 (100)	7.32 (99)	7.41 (100)	7.33
LIA Nitrogen	6.93	6.69 (97)	6.84 (99)	6.89 (99)	6.87 (99)	6.84
			SED 0.046***			
Cross-nitrogen means	7.18	6.90 (96)	7.13 (99)	7.10 (99)	7.14 (100)	
Drayton (160 d.f.)						
			SED v 0.178, h 0.113			SED 0.147***
CCP Nitrogen	8.22	7.83 (95)	8.29 (101)	8.01 (98)	8.30 (101)	8.13
LIA Nitrogen	7.07	6.89 (98)	7.16 (101)	7.12 (101)	7.30 (103)	7.11
			SED 0.080***			
Cross-nitrogen means	7.64	7.36 (96)	7.72 (101)	7.56 (99)	7.80 (102)	
H. Mowthorpe (208 d.f.)						
			SED v 0.183*, h 0.097*			SED 0.161***
CCP Nitrogen	8.99	8.04 (89)	8.68 (97)	8.97 (100)	8.80 (98)	8.70
LIA Nitrogen	7.51	6.87 (92)	7.14 (95)	7.40 (99)	7.42 (99)	7.27
			SED 0.069***			
Cross-nitrogen means	8.25	7.45 (90)	7.91 (96)	8.19 (99)	8.11 (98)	
Cross-site (651 d.f.)						
			SED v 0.094*, h 0.050*			SED 0.082***
CCP Nitrogen	8.13	7.59 (93)	8.05 (99)	8.02 (99)	8.08 (99)	7.97
LIA Nitrogen	7.15	6.80 (95)	7.02 (98)	7.11 (99)	7.16 (100)	7.05
			SED 0.036***			
Cross-nitrogen means	7.64	7.19 (94)	7.53 (99)	7.57 (99)	7.62 (100)	

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[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
*** $P < 0.001$.

Appendix Table 2.8.6. Mean gross margins from all winter wheat crops (first and second year) in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (283 d.f.)						
			SED v 14.7, h 7.58			SED 13.04**
CCP Nitrogen	830.7	832.0 (100)	845.0 (102)	842.8 (102)	830.4 (100)	836.2
LIA Nitrogen	787.2	797.4 (101)	791.0 (101)	805.6 (102)	781.6 (99)	792.6
			SED 5.63**			
Cross-nitrogen means	808.9	814.7 (101)	818.0 (101)	824.2 (102)	806.0 (100)	
Drayton (160 d.f.)						
			SED v 20.06, h 11.73			SED 17.09***
CCP Nitrogen	728.5	793.9 (109)	786.7 (108)	744.5 (102)	751.6 (103)	761.1
LIA Nitrogen	631.1	718.1 (114)	691.7 (110)	674.9 (107)	670.2 (106)	677.2
			SED 8.30***			
Cross-nitrogen means	679.8	756.0 (111)	739.2 (109)	709.7 (104)	710.9 (105)	
H. Mowthorpe (208 d.f.)						
			SED v 23.08*, h 12.28*			SED 20.31***
CCP Nitrogen	1061.6	1001.0 (94)	1046.0 (99)	1098.1 (103)	1037.0 (98)	1048.7
LIA Nitrogen	877.8	858.5 (98)	852.9 (97)	902.2 (103)	868.0 (99)	871.9
			SED 8.68***			
Cross-nitrogen means	969.7	929.8 (96)	949.4 (98)	1000.1 (103)	952.5 (98)	
Cross-site (651 d.f.)						
			SED v 10.94*, h 5.89*			SED 9.59***
CCP Nitrogen	878.3	876.2 (100)	894.3 (102)	899.2 (102)	876.2 (100)	884.8
LIA Nitrogen	776.3	796.7 (103)	785.4 (101)	803.1 (104)	780.7 (101)	788.4
			SED 4.16***			
Cross-nitrogen means	827.3	836.4 (101)	839.8 (102)	851.1 (103)	828.5 (100)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Appendix Table 2.8.7. Mean yields of spring barley in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Drayton (40 d.f.)						
		SED v 0.650*, h 0.316*				SED 0.585
CCP Nitrogen	6.54	6.12 (94)	6.37 (97)	6.06 (93)	6.45 (99)	6.31
LIA Nitrogen	5.39	5.18 (96)	4.96 (92)	5.80 (108)	4.75 (88)	5.22
			SED 0.224			
Cross-nitrogen means	5.96	5.65 (95)	5.66 (95)	5.93 (99)	5.60 (94)	
H. Mowthorpe (78 d.f.)						
		SED v 0.334, h 0.261				SED 0.239*
CCP Nitrogen	5.78	5.87 (102)	5.60 (97)	5.49 (95)	5.87 (102)	5.72
LIA Nitrogen	4.89	4.83 (99)	5.01 (102)	5.31 (109)	4.94 (101)	5.00
			SED 0.184			
Cross-nitrogen means	5.34	5.35 (100)	5.30 (99)	5.40 (101)	5.40 (101)	
Cross-site (119 d.f.)						
		SED v 0.338*, h 0.252*				SED 0.251***
CCP Nitrogen	6.03	5.95 (99)	5.86 (97)	5.68 (94)	6.06 (101)	5.92
LIA Nitrogen	5.06	4.95 (98)	4.66 (92)	5.47 (108)	4.88 (96)	5.00
			SED 0.178			
Cross-nitrogen means	5.55	5.45 (98)	5.26 (95)	5.58 (101)	5.47 (99)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
*** $P < 0.001$.

Appendix Table 2.8.8. Mean gross margins from spring barley in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Drayton (40 d.f.)						
			SED v 71.67*, h 31.74*			SED 65.81
CCP Nitrogen	431.6	462.0 (107)	446.1 (103)	384.7 (89)	463.3 (107)	437.5
LIA Nitrogen	338.1	389.4 (115)	326.6 (97)	378.2 (112)	316.1 (94)	349.7
			SED 22.44			
Cross-nitrogen means	384.9	425.7 (111)	386.4 (100)	381.4 (99)	389.7 (101)	
H. Mowthorpe (78 d.f.)						
			SED v 32.41, h 25.30			SED 23.20*
CCP Nitrogen	642.6	674.7 (105)	643.4 (100)	619.8 (96)	650.8 (101)	646.3
LIA Nitrogen	574.6	592.0 (103)	603.0 (105)	620.4 (108)	578.9 (101)	593.8
			SED 17.89			
Cross-nitrogen means	608.6	633.3 (104)	623.2 (102)	620.1 (102)	614.9 (101)	
Cross-site (119 d.f.)						
			SED v 32.20*, h 19.90*			SED 26.84*
CCP Nitrogen	572.3	603.8 (106)	577.6 (101)	541.4 (95)	588.3 (103)	576.7
LIA Nitrogen	495.8	524.5 (106)	510.9 (103)	539.7 (109)	491.3 (99)	512.4
			SED 14.07			
Cross-nitrogen means	534.0	564.1 (106)	544.3 (102)	540.5 (101)	539.8 (101)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.

Appendix Table 2.8.9. Mean yields of winter triticale in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment		Pesticide sub-treatment[1]				Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
Drayton (120 d.f.)						
			SED v 0.162, h 0.117			SED 0.123***
CCP Nitrogen	5.69	5.54 (97)	5.72 (101)	5.71 (100)	5.79 (102)	5.69
LIA Nitrogen	4.82	4.83 (100)	4.93 (102)	4.85 (101)	4.91 (102)	4.87
			SED 0.083			
Cross-nitrogen means	5.25	5.19 (99)	5.33 (101)	5.28 (101)	5.35 (102)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
*** $P < 0.001$.

Appendix Table 2.8.10. Mean gross margins from winter triticale in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment		Pesticide sub-treatment[1]			Cross-	
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	pesticide means
Drayton (120 d.f.)						
			SED v 17.43, h 12.18			SED 13.60***
CCP Nitrogen	508.5	571.3 (112)	562.9 (111)	516.5 (102)	542.3 (107)	540.3
LIA Nitrogen	432.6	512.9 (119)	495.2 (115)	441.7 (102)	465.3 (108)	469.5
			SED 8.62 ***			
Cross-nitrogen means	470.6	542.1 (115)	529.1 (112)	479.1 (102)	503.8 (107)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
*** $P < 0.001$.

Appendix Table 2.8.11. Mean yields of winter barley in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment		Pesticide sub-treatment[1]				Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
H. Mowthorpe (32 d.f.)						
			SED v 0.365, h 0.283			SED 0.262**
CCP Nitrogen	8.83	8.46 (96)	8.97 (102)	8.31 (94)	8.78 (99)	8.67
LIA Nitrogen	7.07	6.89 (97)	6.50 (92)	6.84 (97)	6.97 (99)	6.86
			SED 0.200			
Cross-nitrogen means	7.95	7.67 (97)	7.74 (97)	7.58 (95)	7.88 (99)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
** $P < 0.01$.

Appendix Table 2.8.12. Mean gross margins from winter barley in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment		Pesticide sub-treatment[1]				Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
H. Mowthorpe (32 d.f.)						
			SED v 35.97, h 28.26			SED 25.59**
CCP Nitrogen	893.1	907.3 (102)	934.8 (105)	863.9 (97)	893.9 (100)	898.6
LIA Nitrogen	747.7	781.1 (105)	721.1 (96)	748.4 (100)	738.8 (99)	747.4
			SED 19.98			
Cross-nitrogen means	820.4	844.2 (103)	827.9 (101)	806.2 (98)	816.4 (100)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
** $P < 0.01$.

Appendix Table 2.8.13. Mean yields of spring wheat in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (47 d.f.)						
		SED v 0.247, h 0.191				SED 0.179
CCP Nitrogen	5.96	5.38 (90)	5.34 (90)	5.88 (99)	5.94 (100)	5.70
LIA Nitrogen	5.89	5.12 (87)	5.24 (89)	5.50 (94)	5.83 (99)	5.52
			SED 0.135***			
Cross-nitrogen means	5.92	5.25 (89)	5.29 (89)	5.69 (96)	5.88 (99)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
*** *P* < 0.001.

Appendix Table 2.8.14. Mean gross margins from spring wheat in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (47 d.f.)						
		SED v 31.28, h 24.18				SED 22.59
CCP Nitrogen	771.4	727.2 (94)	702.9 (91)	780.5 (101)	769.9 (100)	750.4
LIA Nitrogen	781.8	713.4 (91)	710.1 (91)	751.9 (96)	774.3 (99)	746.3
			SED 17.10***			
Cross-nitrogen means	776.6	720.3 (93)	706.5 (91)	766.2 (99)	772.1 (99)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
*** *P* < 0.001.

Appendix Table 2.8.15. Mean yields of spring oats in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Drayton (32 d.f.)						
		SED v 0.232*, h 0.165*				SED 0.179
CCP Nitrogen	4.93	4.39 (89)	4.84 (98)	4.72 (96)	4.95 (101)	4.76
LIA Nitrogen	4.94	4.85 (98)	4.75 (96)	4.61 (93)	4.59 (93)	4.75
			SED 0.116			
Cross-nitrogen means	4.93	4.62 (94)	4.80 (97)	4.66 (95)	4.77 (97)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
* *P* < 0.05.

Appendix Table 2.8.16. Mean gross margins from spring oats in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Drayton (32 d.f.)						
		SED v 24.54*, h 17.13*				SED 19.16
CCP Nitrogen	494.0	457.9 (93)	495.2 (100)	481.5 (98)	498.5 (101)	485.4
LIA Nitrogen	514.8	524.1 (102)	503.1 (98)	487.8 (95)	481.2 (94)	502.2
			SED 12.11			
Cross-nitrogen means	504.4	491.0 (97)	499.2 (99)	484.7 (96)	489.8 (97)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
* *P* < 0.05.

Appendix Table 2.8.17. Mean yields of winter oilseed rape in TALISMAN, 1991–1996 (t/ha @ 91% d.m.).

Site & Main Treatment		Pesticide sub-treatment[1]				Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
Boxworth (24 d.f.)						
			SED v 0.232, h 0.223			SED 0.120
CCP Nitrogen	1.12	0.44 (39)	0.65 (58)	1.20 (108)	0.79 (71)	0.84
LIA Nitrogen	0.55	0.58 (105)	0.34 (62)	1.29 (233)	0.96 (173)	0.74
			SED 0.157***			
Cross-nitrogen means	0.83	0.51 (61)	0.49 (59)	1.24 (149)	0.87 (105)	
Drayton (16 d.f.)						
			SED v 0.341, h 0.366			SED 0.095
CCP Nitrogen	2.85	2.37 (83)	2.47 (87)	2.31 (81)	2.72 (96)	2.55
LIA Nitrogen	2.33	2.24 (96)	2.19 (94)	2.44 (105)	2.87 (123)	2.41
			SED 0.259			
Cross-nitrogen means	2.59	2.31 (90)	2.33 (90)	2.38 (92)	2.80 (108)	
H. Mowthorpe (31 d.f.)						
			SED v 0.176, h 0.161			SED 0.101**
CCP Nitrogen	3.85	3.50 (91)	3.90 (101)	4.00 (104)	4.05 (105)	3.86
LIA Nitrogen	3.30	3.00 (90)	3.06 (93)	3.27 (99)	3.42 (104)	3.20
			SED 0.114**			
Cross-nitrogen means	3.58	3.24 (91)	3.48 (97)	3.64 (102)	3.73 (105)	
Cross-site (71 d.f.)						
			SED v 0.134, h 0.132			SED 0.064*
CCP Nitrogen	2.78	2.30 (83)	2.57 (93)	2.75 (99)	2.74 (99)	2.63
LIA Nitrogen	2.23	2.07 (93)	2.02 (91)	2.47 (111)	2.53 (114)	2.26
			SED 0.093***			
Cross-nitrogen means	2.50	2.18 (87)	2.30 (92)	2.61 (104)	2.64 (105)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Appendix Table 2.8.18. Mean gross margins from winter oilseed rape in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment		Pesticide sub-treatment[1]				Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
Boxworth (24 d.f.)						
			SED v 61.80, h 59.20			SED 31.90
CCP Nitrogen	105.0	-41.0 (na)	-6.0 (na)	149.0 (na)	18.0 (na)	45.0
LIA Nitrogen	-5.0	39.0 (na)	-49.0 (na)	213.0 (na)	103.0 (na)	60.0
			SED 41.90***			
Cross-nitrogen means	50.0	-1.0 (na)	-28.0 (na)	181.0 (na)	60.0 (na)	
Drayton (16 d.f.)						
			SED v 90.80, h 97.40			SED 25.40
CCP Nitrogen	420.0	356.0 (85)	351.0 (84)	297.0 (71)	397.0 (95)	364.0
LIA Nitrogen	326.0	366.0 (112)	321.0 (99)	379.0 (116)	480.0 (147)	374.0
			SED 68.90			
Cross-nitrogen means	373.0	361.0 (97)	336.0 (90)	338.0 (91)	438.0 (117)	
H. Mowthorpe (31 d.f.)						
			SED v 37.56, h 33.10			SED 23.11**
CCP Nitrogen	886.6	851.7 (96)	922.6 (104)	919.6 (103)	925.1 (104)	901.1
LIA Nitrogen	771.5	742.5 (96)	747.9 (97)	775.5 (101)	809.8 (105)	769.4
			SED 23.41			
Cross-nitrogen means	829.0	797.1 (96)	835.2 (101)	847.6 (102)	867.5 (105)	
Cross-site (71 d.f.)						
			SED v 33.32, h 32.86			SED 15.71*
CCP Nitrogen	538.5	462.7 (86)	504.8 (94)	539.0 (100)	524.2 (97)	513.8
LIA Nitrogen	429.7	439.1 (102)	404.1 (94)	510.8 (119)	516.0 (120)	459.9
			SED 23.23**			
Cross-nitrogen means	484.1	450.9 (93)	454.5 (94)	524.9 (108)	520.1 (107)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
na Calculation not appropriate due to negative values.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Appendix Table 2.8.19. Mean yields of spring oilseed rape in TALISMAN, 1991–1996 (t/ha @ 91% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (24 d.f.)						
			SED v 0.183, h 0.142			SED 0.132*
CCP Nitrogen	1.23	0.68 (55)	0.85 (69)	0.93 (76)	0.98 (80)	0.94
LIA Nitrogen	0.58	0.41 (71)	0.41 (71)	0.31 (55)	0.51 (88)	0.44
			SED 0.100*			
Cross-nitrogen means	0.91	0.55 (60)	0.63 (69)	0.62 (69)	0.74 (82)	
Drayton (16 d.f.)						
			SED v 0.213, h 0.124			SED 0.182
CCP Nitrogen	0.34	0.56 (167)	0.45 (133)	0.59 (176)	0.52 (154)	0.49
LIA Nitrogen	0.13	0.15 (120)	0.17 (131)	0.19 (152)	0.17 (130)	0.16
			SED 0.088			
Cross-nitrogen means	0.23	0.36 (154)	0.31 (132)	0.39 (169)	0.34 (147)	
Cross-site (40 d.f.)						
			SED v 0.139, h 0.098			SED 0.108*
CCP Nitrogen	0.85	0.63 (74)	0.68 (80)	0.78 (92)	0.78 (92)	0.74
LIA Nitrogen	0.38	0.30 (78)	0.30 (79)	0.26 (69)	0.36 (94)	0.32
			SED 0.069			
Cross-nitrogen means	0.62	0.46 (75)	0.49 (80)	0.52 (85)	0.57 (93)	

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[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.

* $P < 0.05$.

Appendix Table 2.8.20. Mean gross margins from spring oilseed rape in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (24 d.f.)						
			SED v 32.89, h 25.52			SED 23.69
CCP Nitrogen	398.6	362.5 (91)	363.1 (91)	373.1 (94)	353.3 (89)	370.1
LIA Nitrogen	294.5	327.9 (111)	298.3 (101)	276.6 (94)	282.1 (96)	295.9
			SED 18.04			
Cross-nitrogen means	346.5	345.2 (100)	330.7 (95)	324.8 (94)	317.7 (92)	
Drayton (16 d.f.)						
			SED v 37.98, h 22.34			SED 32.30
CCP Nitrogen	337.0	398.9 (118)	374.1 (111)	382.7 (114)	374.4 (111)	373.4
LIA Nitrogen	311.1	339.7 (109)	337.9 (109)	325.5 (105)	325.0 (105)	327.8
			SED 15.80			
Cross-nitrogen means	324.1	369.3 (114)	356.0 (110)	354.1 (109)	349.7 (108)	
Cross-site (40 d.f.)						
			SED v 24.87, h 17.57			SED 19.27*
CCP Nitrogen	372.2	378.1 (102)	367.8 (99)	377.2 (101)	362.4 (97)	371.5
LIA Nitrogen	301.6	332.9 (110)	315.2 (105)	297.6 (99)	300.5 (100)	309.6
			SED 12.43			
Cross-nitrogen means	336.9	355.5 (106)	341.5 (101)	337.4 (100)	331.4 (98)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.

* $P < 0.05$.

Appendix Table 2.8.21. Mean yields of winter beans in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment		Pesticide sub-treatment[1]				Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
Boxworth (48 d.f.)						
		SED v 0.156, h 0.118				SED 0.115
CCP Nitrogen	4.15	4.30 (104)	4.30 (104)	4.16 (100)	4.33 (104)	4.25
LIA Nitrogen	4.01	4.08 (102)	4.07 (101)	4.22 (105)	4.22 (105)	4.12
			SED 0.083			
Cross-nitrogen means	4.08	4.19 (103)	4.19 (103)	4.19 (103)	4.28 (105)	
Drayton (32 d.f.)						
		SED v 0.143, h 0.135				SED 0.076
CCP Nitrogen	3.95	4.16 (105)	4.32 (109)	3.89 (98)	4.26 (108)	4.12
LIA Nitrogen	4.06	3.90 (96)	4.05 (100)	4.03 (99)	4.07 (100)	4.02
			SED 0.095			
Cross-nitrogen means	4.01	4.03 (101)	4.19 (104)	3.96 (99)	4.17 (104)	
H. Mowthorpe (32 d.f.)						
		SED v 0.183, h 0.122				SED 0.147
CCP Nitrogen	4.95	4.57 (92)	4.89 (99)	4.88 (99)	4.71 (95)	4.80
LIA Nitrogen	4.77	4.77 (100)	4.87 (102)	5.00 (105)	4.60 (96)	4.80
			SED 0.086**			
Cross-nitrogen means	4.86	4.67 (96)	4.88 (100)	4.94 (102)	4.65 (96)	
Cross-site (112 d.f.)						
		SED v 0.094, h 0.072				SED 0.068
CCP Nitrogen	4.33	4.34 (100)	4.48 (104)	4.30 (99)	4.42 (102)	4.38
LIA Nitrogen	4.25	4.23 (100)	4.31 (101)	4.40 (103)	4.29 (101)	4.30
			SED 0.051			
Cross-nitrogen means	4.29	4.29 (100)	4.40 (102)	4.35 (101)	4.36 (102)	

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[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.

** $P < 0.01$.

Appendix Table 2.8.22. Mean gross margins from winter beans in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment		Pesticide sub-treatment[1]				Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
Boxworth (48 d.f.)						
		SED v 26.61, h 18.97				SED 20.50
CCP Nitrogen	632.4	695.2 (110)	673.8 (107)	656.4 (104)	659.2 (104)	663.4
LIA Nitrogen	609.1	652.8 (107)	638.9 (105)	663.3 (109)	647.0 (106)	642.2
			SED 13.41**			
Cross-nitrogen means	620.8	674.0 (109)	656.3 (106)	659.9 (106)	653.1 (105)	
Drayton (32 d.f.)						
		SED v 21.61, h 22.32				SED 8.26
CCP Nitrogen	555.1	637.7 (115)	651.4 (117)	551.6 (99)	597.8 (108)	598.7
LIA Nitrogen	577.5	595.3 (103)	607.9 (105)	579.5 (100)	569.0 (99)	585.5
			SED 15.78***			
Cross-nitrogen means	566.3	616.5 (109)	629.6 (111)	565.6 (100)	583.4 (103)	
H. Mowthorpe (32 d.f.)						
		SED v 28.88, h 16.58				SED 24.78
CCP Nitrogen	754.1	706.6 (94)	751.4 (100)	747.0 (99)	722.2 (96)	736.3
LIA Nitrogen	735.7	743.0 (101)	748.0 (102)	779.1 (106)	715.7 (97)	744.3
			SED 11.73**			
Cross-nitrogen means	744.9	724.8 (97)	749.7 (101)	763.1 (102)	718.9 (97)	
Cross-site (112 d.f.)						
		SED v 15.26*, h 11.31*				SED 11.43
CCP Nitrogen	645.8	681.4 (106)	690.4 (107)	652.2 (101)	659.7 (102)	665.9
LIA Nitrogen	637.6	662.6 (104)	662.3 (104)	672.9 (106)	644.2 (101)	655.9
			SED 8.00***			
Cross-nitrogen means	641.7	672.0 (105)	676.3 (105)	662.5 (103)	651.9 (102)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Appendix Table 2.8.23. Mean yields of spring beans in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (17 d.f.)						
			SED v 0.375, h 0.327			SED 0.235
CCP Nitrogen	1.56	1.44 (93)	1.67 (107)	1.95 (125)	2.01 (129)	1.72
LIA Nitrogen	1.91	1.48 (77)	0.82 (43)	1.62 (85)	1.48 (78)	1.46
			SED 0.231			
Cross-nitrogen means	1.74	1.46 (84)	1.24 (72)	1.79 (103)	1.75 (101)	
Drayton (32 d.f.)						
			SED v 0.279, h 0.123			SED 0.256
CCP Nitrogen	3.39	2.99 (88)	3.31 (98)	3.33 (98)	3.11 (92)	3.23
LIA Nitrogen	3.08	2.80 (91)	3.20 (104)	3.07 (100)	2.74 (89)	2.98
			SED 0.087***			
Cross-nitrogen means	3.23	2.89 (90)	3.26 (101)	3.20 (99)	2.92 (90)	
H. Mowthorpe (32 d.f.)						
			SED v 0.192 , h 0.152			SED 0.135
CCP Nitrogen	4.47	4.32 (97)	4.21 (94)	4.36 (98)	4.36 (98)	4.35
LIA Nitrogen	4.44	4.17 (94)	4.30 (97)	4.54 (102)	4.61 (104)	4.41
			SED 0.108			
Cross-nitrogen means	4.46	4.25 (95)	4.26 (96)	4.45 (100)	4.49 (101)	
Cross-site (81 d.f.)						
			SED v 0.156, h 0.106			SED 0.123
CCP Nitrogen	3.36	3.10 (93)	3.24 (97)	3.37 (101)	3.30 (99)	3.27
LIA Nitrogen	3.30	3.00 (91)	3.02 (91)	3.26 (99)	3.13 (95)	3.14
			SED 0.075**			
Cross-nitrogen means	3.32	3.04 (92)	3.13 (94)	3.32 (100)	3.22 (97)	

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[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
** $P < 0.01$.
*** $P < 0.001$.

Appendix Table 2.8.24. Mean gross margins from spring beans in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (17 d.f.)						
			SED v 36.38, h 31.71			SED 22.78
CCP Nitrogen	311.2	378.4 (122)	374.0 (120)	363.9 (117)	367.3 (118)	359.0
LIA Nitrogen	345.8	381.8 (110)	291.3 (84)	331.7 (96)	316.6 (92)	333.4
			SED 22.42			
Cross-nitrogen means	328.5	380.1 (116)	332.7 (101)	347.8 (106)	341.9 (104)	
Drayton (32 d.f.)						
			SED v 30.56, h 19.1			SED 25.34
CCP Nitrogen	501.7	480.5 (96)	511.4 (102)	510.8 (102)	460.5 (92)	493.0
LIA Nitrogen	470.1	469.2 (100)	508.4 (108)	486.0 (103)	408.8 (87)	468.5
			SED 13.51***			
Cross-nitrogen means	485.9	474.9 (98)	509.9 (105)	498.4 (103)	434.7 (90)	
H. Mowthorpe (32 d.f.)						
			SED v 30.40, h 22.51			SED 22.78
CCP Nitrogen	680.1	679.0 (100)	656.1 (97)	662.8 (98)	663.3 (98)	668.2
LIA Nitrogen	678.6	650.6 (96)	663.3 (98)	696.2 (103)	693.8 (102)	676.5
			SED 15.92			
Cross-nitrogen means	679.3	664.8 (98)	659.7 (97)	679.5 (100)	678.5 (100)	
Cross-site (81 d.f.)						
			SED v 18.41, h 13.49			SED 13.91
CCP Nitrogen	521.0	529.4 (102)	531.3 (102)	531.1 (102)	513.2 (99)	525.2
LIA Nitrogen	517.2	515.4 (100)	512.3 (99)	526.3 (102)	492.6 (95)	512.8
			SED 9.54			
Cross-nitrogen means	519.1	522.4 (101)	521.8 (101)	528.7 (102)	502.9 (97)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
*** $P < 0.001$.

Appendix Table 2.8.25. Mean yields of spring linseed in TALISMAN, 1991–1996 (t/ha @ 91% d.m.).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (24 d.f.)						
			SED v 0.084, h 0.086			SED 0.034
CCP Nitrogen	2.53	2.46 (97)	2.38 (94)	2.56 (101)	2.47 (98)	2.48
LIA Nitrogen	2.43	2.41 (99)	2.35 (97)	2.48 (102)	2.53 (104)	2.44
			SED 0.061			
Cross-nitrogen means	2.48	2.43 (98)	2.36 (95)	2.52 (102)	2.50 (101)	
H. Mowthorpe (31 d.f.)						
			SED v 0.099 , h 0.080			SED 0.069
CCP Nitrogen	1.71	1.77 (103)	1.72 (100)	1.85 (108)	1.81 (105)	1.77
LIA Nitrogen	1.72	1.71 (100)	1.64 (96)	1.77 (103)	1.70 (99)	1.71
			SED 0.056			
Cross-nitrogen means	1.72	1.74 (102)	1.68 (98)	1.81 (105)	1.75 (102)	
Cross-site (55 d.f.)						
			SED v 0.068, h 0.059			SED 0.043
CCP Nitrogen	2.04	2.04 (100)	1.98 (97)	2.13 (105)	2.07 (102)	2.05
LIA Nitrogen	2.00	1.99 (100)	1.92 (96)	2.05 (103)	2.03 (102)	2.00
			SED 0.041*			
Cross-nitrogen means	2.02	2.02 (100)	1.95 (97)	2.09 (104)	2.05 (102)	

[1] Figures in parentheses are yields expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.

Appendix Table 2.8.26. Mean gross margins from spring linseed in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (24 d.f.)						
			SED v 8.72, h 8.92			SED 3.53
CCP Nitrogen	696.6	682.2 (98)	672.3 (97)	699.7 (101)	692.4 (99)	688.6
LIA Nitrogen	699.4	691.3 (99)	683.3 (98)	704.9 (101)	711.9 (102)	698.2
			SED 6.31**			
Cross-nitrogen means	698.0	686.8 (98)	677.8 (97)	702.3 (101)	702.2 (101)	
H. Mowthorpe (31 d.f.)						
			SED v 12.81, h 10.32			SED 8.89
CCP Nitrogen	559.6	580.6 (104)	575.2 (103)	576.9 (103)	569.6 (102)	572.4
LIA Nitrogen	570.9	582.8 (102)	573.0 (100)	575.6 (101)	567.7 (99)	574.0
			SED 7.29			
Cross-nitrogen means	565.2	581.7 (103)	574.1 (102)	576.3 (102)	568.6 (101)	
Cross-site (55 d.f.)						
			SED v 8.32 , h 7.06			SED 5.41
CCP Nitrogen	614.4	621.3 (101)	614.1 (100)	626.0 (102)	618.7 (101)	618.9
LIA Nitrogen	622.3	626.2 (101)	617.1 (99)	627.4 (101)	625.4 (101)	623.7
			SED 4.99			
Cross-nitrogen means	618.3	623.8 (101)	615.6 (100)	626.7 (101)	622.0 (101)	

[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
** $P < 0.01$.

Appendix Table 2.8.27. Mean gross margins from cereal crops in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (346 d.f.)						
			SED v 27.79, h 8.11			SED 26.82
CCP Nitrogen	820.8	814.5 (99)	823.0 (100)	832.4 (101)	820.4 (100)	822.2
LIA Nitrogen	786.3	783.4 (100)	777.5 (99)	796.7 (101)	780.4 (99)	784.9
			SED 5.73*			
Cross-nitrogen means	803.6	799.0 (99)	800.2 (100)	814.6 (101)	800.4 (100)	
Drayton (352 d.f.)						
			SED v 32.85, h 8.54			SED 31.95*
CCP Nitrogen	608.9	669.0 (110)	660.2 (108)	614.0 (101)	637.1 (105)	637.8
LIA Nitrogen	520.1	600.1 (115)	572.4 (110)	550.3 (106)	549.1 (106)	558.4
			SED 6.04***			
Cross-nitrogen means	564.5	634.5 (112)	616.3 (109)	582.2 (103)	593.1 (105)	
H. Mowthorpe (350 d.f.)						
			SED v 24.59, h 11.18			SED 22.47***
CCP Nitrogen	935.8	907.7 (97)	931.4 (100)	949.2 (101)	922.6 (99)	929.3
LIA Nitrogen	785.7	782.2 (100)	773.0 (98)	812.9 (104)	779.6 (99)	786.7
			SED 7.91***			
Cross-nitrogen means	860.7	845.0 (98)	852.2 (99)	881.1 (102)	851.1 (99)	
Cross-site (1048 d.f.)						
			SED v 16.52*, h 5.41*			SED 15.80***
CCP Nitrogen	788.5	797.1 (101)	804.9 (102)	798.6 (101)	793.3 (101)	796.5
LIA Nitrogen	697.4	721.9 (104)	707.6 (101)	720.0 (103)	703.0 (101)	710.0
			SED 3.83***			
Cross-nitrogen means	742.9	759.5 (102)	756.3 (102)	759.3 (102)	748.2 (101)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.

* $P < 0.05$.

*** $P < 0.001$.

Appendix Table 2.8.28. Mean gross margins from break crops in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Boxworth (169 d.f.)						
			SED v 78.31, h 15.98			SED 76.99
CCP Nitrogen	462.7	461.4 (100)	457.9 (99)	483.2 (104)	458.3 (99)	464.7
LIA Nitrogen	425.5	456.4 (107)	422.5 (99)	475.4 (112)	451.2 (106)	446.2
			SED 11.30**			
Cross-nitrogen means	444.1	458.9 (103)	440.2 (99)	479.3 (108)	454.7 (102)	
Drayton (176 d.f.)						
			SED v 33.46, h 16.48			SED 30.30
CCP Nitrogen	482.4	488.4 (101)	505.1 (105)	471.0 (98)	485.6 (101)	486.5
LIA Nitrogen	470.2	485.3 (103)	487.2 (104)	476.3 (101)	465.3 (99)	476.9
			SED 11.65			
Cross-nitrogen means	476.3	486.9 (102)	496.1 (104)	473.7 (100)	475.5 (100)	
H. Mowthorpe (174 d.f.)						
			SED v 36.95, h 11.75			SED 35.43
CCP Nitrogen	720.1	704.5 (98)	726.3 (101)	726.4 (101)	720.0 (100)	719.5
LIA Nitrogen	689.1	679.7 (99)	683.0 (99)	706.6 (103)	695.5 (101)	690.8
			SED 8.31			
Cross-nitrogen means	704.6	692.1 (98)	704.7 (100)	716.5 (102)	707.8 (101)	
Cross-site (519 d.f.)						
			SED v 30.65, h 8.59			SED 29.67
CCP Nitrogen	555.1	551.4 (99)	563.1 (101)	560.2 (101)	554.6 (100)	556.9
LIA Nitrogen	528.3	540.5 (102)	530.9 (100)	552.8 (105)	537.3 (102)	538.0
			SED 6.08			
Cross-nitrogen means	541.7	546.0 (101)	547.0 (101)	556.5 (103)	546.0 (101)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.

** $P < 0.01$.

Appendix Table 2.8.29. Mean gross margins from all crops in TALISMAN, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1]				Cross-pesticide means
		All Low	Low Herbicide	Low Fungicide	Low Insecticide	
Boxworth (515 d.f.)						
			SED v 32.00, h 7.57			SED 31.28
CCP Nitrogen	701.5	696.8 (99)	701.3 (100)	716.0 (102)	699.7 (100)	703.0
LIA Nitrogen	666.0	674.4 (101)	659.2 (99)	689.6 (104)	670.6 (101)	672.0
			SED 5.36***			
Cross-nitrogen means	683.7	685.6 (100)	680.2 (100)	702.8 (103)	685.2 (100)	
Drayton (528 d.f.)						
			SED v 24.57, h 7.91			SED 23.53*
CCP Nitrogen	566.7	608.8 (107)	608.5 (107)	566.3 (100)	586.6 (104)	587.4
LIA Nitrogen	503.4	561.8 (112)	544.0 (108)	525.7 (104)	521.2 (104)	531.2
			SED 5.59***			
Cross-nitrogen means	535.1	585.3 (109)	576.2 (108)	546.0 (102)	553.9 (104)	
H. Mowthorpe (524 d.f.)						
			SED v 20.51, h 8.42			SED 19.07***
CCP Nitrogen	863.9	840.0 (97)	863.1 (100)	875.0 (101)	855.1 (94)	859.4
LIA Nitrogen	753.5	748.0 (99)	743.0 (99)	777.5 (103)	751.6 (100)	754.7
			SED 5.96***			
Cross-nitrogen means	808.7	794.0 (98)	803.1 (99)	826.2 (102)	803.3 (99)	
Cross-site (1567 d.f.)						
			SED v 15.02*, h 4.61*			SED 14.45***
CCP Nitrogen	710.7	715.2 (101)	724.3 (102)	719.1 (101)	713.8 (100)	716.6
LIA Nitrogen	641.0	661.4 (103)	648.7 (101)	664.3 (104)	647.8 (101)	652.6
			SED 3.26***			
Cross-nitrogen means	675.8	688.3 (102)	686.5 (102)	691.7 (102)	680.8 (101)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.

* $P < 0.05$; *** $P < 0.001$.

Appendix Table 2.8.30. Mean gross margins from combined phases of the Standard and Alternative Rotations in TALISMAN at Boxworth, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1]				Cross-pesticide means
		All Low	Low Herbicide	Low Fungicide	Low Insecticide	
Standard Rotation (467 d.f.)						
			SED v 28.91, h 8.79			SED 27.82
CCP Nitrogen	730.5	724.5 (99)	735.8 (101)	741.2 (102)	727.5 (100)	731.9
LIA Nitrogen	672.7	694.7 (103)	674.7 (100)	711.4 (106)	686.9 (102)	688.1
			SED v 20.44, h 6.21			
Cross-nitrogen means	701.6	709.6 (101)	705.2 (101)	726.3 (104)	707.2 (101)	
Alternative Rotation (467 d.f.)						
			SED v 40.89, h 12.43			SED 39.35
CCP Nitrogen	643.3	642.1 (100)	629.5 (98)	665.7 (104)	643.9 (100)	644.9
LIA Nitrogen	652.7	635.1 (97)	619.6 (95)	646.8 (99)	638.1 (98)	638.5
			SED v 29.91, h 8.79			
Cross-nitrogen means	648.0	638.6 (99)	624.6 (97)	656.2 (101)	641.0 (99)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.

Appendix Table 2.8.31. Mean gross margins from combined phases of the Standard and Alternative Rotations in TALISMAN at Drayton, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Standard Rotation (480 d.f.)						
		SED v 21.06, h 10.92				SED 18.66
CCP Nitrogen	641.3	698.5 (109)	693.5 (108)	644.9 (101)	665.0 (104)	668.6
LIA Nitrogen	570.1	636.7 (112)	617.3 (108)	605.2 (106)	608.7 (107)	607.6
		SED v 14.89, h 7.72				
Cross-nitrogen means	605.7	667.6 (110)	655.4 (108)	625.1 (103)	636.8 (105)	
Alternative Rotation (480 d.f.)						
		SED v 21.06, h 10.92				SED 18.66
CCP Nitrogen	492.1	519.1 (106)	523.6 (106)	487.7 (99)	508.2 (103)	506.1
LIA Nitrogen	436.8	486.9 (112)	470.6 (108)	446.2 (102)	433.7 (99)	454.8
		SED v 14.89, h 7.72				
Cross-nitrogen means	464.5	503.0 (108)	497.1 (107)	467.0 (101)	470.9 (101)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.

Appendix Table 2.8.32. Mean gross margins from combined phases of the Standard and Alternative Rotations in TALISMAN at High Mowthorpe, 1991–1996 (£/ha).

Site & Main Treatment	All High	Pesticide sub-treatment[1] All Low	Low Herbicide	Low Fungicide	Low Insecticide	Cross-pesticide means
Standard Rotation (476 d.f.)						
		SED v 22.45***, h 11.75***				SED 19.84*
CCP Nitrogen	932.9	881.4 (95)	942.1 (101)	951.6 (102)	917.8 (98)	925.1
LIA Nitrogen	792.5	788.3 (100)	773.8 (98)	813.1 (103)	790.6 (100)	791.6
		SED v 15.87, h 8.31				
Cross-nitrogen means	862.7	834.8 (97)	857.9 (99)	882.3 (102)	854.2 (99)	
Alternative Rotation (476 d.f.)						
		SED v 22.45***, h 11.75***				SED 19.84*
CCP Nitrogen	794.9	798.6 (101)	784.1 (99)	798.3 (100)	792.3 (100)	793.7
LIA Nitrogen	714.6	707.8 (99)	713.5 (100)	741.4 (104)	712.3 (100)	717.9
		SED v 15.87, h 8.31				
Cross-nitrogen means	754.7	753.2 (100)	748.8 (99)	769.9 (102)	752.3 (100)	

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[1] Figures in parentheses are gross margins expressed as a percentage of the All High pesticide sub-treatment.
* $P < 0.05$.
*** $P < 0.001$.

Appendix Table 3.1.1. SCARAB pesticide use, Drayton, 'Field 1', 1987–1996.

Year	Crop	Insecticide					Herbicide					Fungicide				
			CFP		RIA			CFP		RIA			CFP		RIA	
		Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units
Pre-treatment years*																
1987	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
1988	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
1989	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
1990	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
Treatment years																
1991	Winter wheat	deltamethrin	5	1	0	0	isoproturon	1500	1	0	0	chlorothalonil	1000	1	500	0.5
							metsulfuron-methyl	6	1	3	0.5	propiconazole	125	1	62	0.5
							fluroxypyr	200	1	100	0.5	carbendazim	250	1	0	0
												maneb	1600	1	0	0
1992	Winter wheat	deltamethrin	5	1	0	0	diflufenican	100	1	50	0.5	prochloraz	405	1	202	0.5
							isoproturon	1000	1	500	0.5	propiconazole	125	1	62	0.5
							metsulfuron-methyl	6	1	3	0.5	fenpropimorph	562	1	281	0.5
							fluroxypyr	200	1	100	0.5	chlorothalonil	500	1	250	0.5
1993	Grass	omethoate	644	1	0	0	paraquat	600	1	0	0	nil	0	0	0	0
1994	Grass	nil	0	0	0	0	nil	0	0	0	0	propiconazole	125	1	0	0
1995	Grass	nil	0	0	0	0	nil	0	0	0	0	propiconazole	125	1	0	0
1996	Grass	nil	0	0	0	0	mecoprop-P	1200	1	600	0.5	propiconazole	125	1	0	0
Total			654	3	0	0		4812	9	1356	3.5		4942	11	1357	3
Mean of all treatment years			109	0.5	0	0		802	1.5	226	0.6		824	1.8	226	0.5

*The last crop to receive pesticides was wheat/triticale in 1985. Paraquat, tri-allate, isoproturon, bromoxynil + ioxynil + mecoprop, benazolin + bromoxynil + ioxynil, mecoprop, carbendazim, benzoylprop-ethyl, propiconazole were used but not all of these pesticides were applied to the whole field.

Appendix Table 3.1.2. SCARAB pesticide use, Drayton, 'Field 5', 1987–1996.

Year	Crop		Insecticide					Herbicide					Fungicide			
			CFP		RIA			CFP		RIA			CFP		RIA	
		Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units
Pre-treatment years*																
1987	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
1988	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
1989	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
1990	Grass	nil	0	0	0	0	nil	0	0	0	0	nil	0	0	0	0
Treatment years																
1991	Grass	chlorpyrifos	720	1	0	0	nil	0	0	0	0	nil	0	0	0	0
1992	Winter wheat	dimethoate	340	1	0	0	diflufenican	100	1	50	0.5	propiconazole	250	2	125	1
							isoproturon	1000	1	500	0.5					
							metsulfuron-methyl	6	1	3	0.5					
							fluroxypyr	200	1	100	0.5					
1993	Winter wheat	dimethoate	340	1	0	0	paraquat	800	1	400	0.5	cyproconazole	60	1	30	0.5
							diflufenican	100	1	50	0.5	prochloraz	400	1	200	0.5
							isoproturon	1000	1	500	0.5	propiconazole	250	2	125	1
							fenoxaprop-P-ethyl	69	1	34	0.5	fenpropimorph	375	1	187	0.5
							metsulfuron-methyl	6	1	3	0.5					
							mecoprop-P	1380	1	690	0.5					
1994	Grass	chlorpyrifos	720	1	0	0	nil	0	0	0	0	nil	0	0	0	0
1995	Grass	chlorpyrifos	720	1	0	0	nil	0	0	0	0	propiconazole	125	1	0	0
1996	Grass	nil	0	0	0	0	nil	0	0	0	0	propiconazole	125	1	0	0
Total			2840	5	0	0		4661	10	2330	5		1585	9	667	3.5
Mean of all treatment years			473	0.8	0	0		777	1.7	388	0.8		264	1.5	111	0.6

* The last crop to receive pesticide was grass in 1984; paraquat was applied during seedbed preparation.

Appendix Table 3.1.3. SCARAB pesticide use, Gleadthorpe, 'Balk' field, 1987–1996.

Year	Crop	Insecticide					Herbicide					Fungicide				
		Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units	Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units	Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units
Pre-treatment years																
1987	Spring barley	omethoate	633	1	633	1	nil	0	0	0	0	nil	0	0	0	0
1988	Winter barley	cypermethrin pirimicarb	25 140	1 1	25 140	1 1	terbutryn	1500	1	1500	1	carbendazim prochloraz propiconazole tridemorph	150 399 125 250	1 1 1 1	150 399 125 250	1 1 1 1
1989	Winter barley/Rye	cypermethrin	25	1	25	1	terbutryn isoproturon	1500 2500	1 1	1500 2500	1 1	carbendazim prochloraz fenpropimorph	150 399 750	1 1 1	150 399 750	1 1 1
1990	Winter barley	cypermethrin	25	1	25	1	terbutryn metsulfuron-methyl	675 6	1 1	675 6	1 1	tridemorph prochloraz carbendazim	525 400 150	1 1 1	525 400 150	1 1 1
Treatment years																
1991	Sugar beet	aldicarb pirimicarb	760 140	1 1	0 0	0 0	chloridazon ethofumesate phenmedipham metamitron	962 895 628 1750	1 2 3 2	962 895 628 1750	1 2 3 2	nil	0	0	0	0
1992	Spring wheat	dimethoate	340	1	0	0	metsulfuron-methyl	6	1	3	0.5	fenpropidin triadimenol tridemorph	750 125 375	1 1 1	375 62 188	0.5 0.5 0.5
1993	Winter barley	cypermethrin	25	1	0	0	isoproturon pendimethalin	500 1000	1 1	250 500	0.5 0.5	carbendazim flusilazole propiconazole tridemorph	78 156 125 350	1 1 1 1	39 78 0 0	0.5 0.5 0 0
1994	Potato	pirimicarb	140	1	0	0	glufosinate-ammonium metribuzin diquat	450 490 600	1 0.67 1	225 490 600	0.5 0.67 1	cymoxanil mancozeb oxadixyl	240 7016 600	3 5 3	240 7016 600	3 5 3
1995	Spring wheat	chlorpyrifos	480	1	0	0	metsulfuron-methyl	6	1	3	0.5	tebuconazole	250	1	125	0.5
1996	Winter barley	cypermethrin	25	1	0	0	terbutryn paraquat	1470 300	1 1	735 150	0.5 0.5	epoxiconazole	125	1	0	0
Total			1910	7	0	0		9057	16.67	7191	13.17		10190	20	8723	14
Mean of all treatment years			318	1.1	0	0		1510	2.8	1199	2.2		1698	3.3	1454	2.3

Appendix Table 3.1.4. SCARAB pesticide use, Gleadthorpe, 'South' field, 1987–1996.

Year	Crop	Insecticide					Herbicide					Fungicide				
		Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units	Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units	Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units
Pre-treatment years																
1987*	Rye (CFP) Winter barley (RIA)	cypermethrin	25	1	25	1	terbutryn	1500	1	1500	1	prochloraz carbendazim fenpropimorph	450 0 750	1 0 1	822 140 1275	2 1 1
1988	Winter oilseed rape	cypermethrin	50	2	50	2	propyzamide clopyralid	701 70	1 1	701 70	1 1	nil	0	0	0	0
1989	Winter wheat	cypermethrin	25	1	25	1	terbutryn	1500	1	1500	1	fenpropimorph chlorothalonil triadimenol tridemorph	750 500 125 375	1 1 1 1	750 500 125 375	1 1 1 1
1990	Winter barley	cypermethrin	25	1	25	1	mecoprop metsulfuron-methyl	1710 6	1 1	1710 6	1 1	prochloraz carbendazim	400 150	1 1	400 150	1 1
Treatment years																
1991	Potato	pirimicarb	140	1	0	0	metribuzin diquat	735 800	1 1	735 800	1 1	cymoxanil mancozeb oxadixyl fentin hydroxide fentin acetate maneb	160 6880 400 269 270 80	2 5 2 1 1 1	80 5480 200 269 270 80	1 4 1 1 1 1
1992	Spring wheat	omethoate dimethoate	644 340	1 1	0 0	0 0	metsulfuron-methyl	6	1	3	0.5	fenpropidin triadimenol tridemorph	750 125 375	1 1 1	375 62 188	0.5 0.5 0.5
1993	Winter barley	cypermethrin	25	1	0	0	isoproturon pendimethalin	500 1000	1 1	250 500	0.5 0.5	carbendazim flusilazole propiconazole tridemorph	78 156 125 350	1 1 1 1	39 78 0 0	0.5 0.5 0 0
1994	Sugar beet	aldicarb	760	1	0	0	chlorpropham fenuron propham chloridazon metamitron ethofumesate phenmedipham lenacil clopyralid	90 60 360 731 875 170 535 184 400	1 1 1 1 1 1 2 1 2	45 30 180 366 438 85 268 92 200	0.5 0.5 0.5 0.5 0.5 0.5 1 0.5 1	nil	0	0	0	0

Continued...

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Appendix Table 3.1.4. SCARAB pesticide use, Gleadthorpe, 'South' field, 1987–1996.

Year	Crop		Insecticide					Herbicide					Fungicide			
			CFP		RIA			CFP		RIA			CFP		RIA	
		Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units
1995	Spring wheat	dimethoate	680	1	0	0	bromoxynil	196	1	98	0.5	tebuconazole	250	1	125	0.5
		dimethoate	340	1	0	0	ioxynil	196	1	98	0.5					
							mecoprop	784	1	392	0.5					
1996	Winter barley	cypermethrin	25	1	0	0	terbutryn	1470	1	735	0.5	epoxiconazole	125	1	0	0
							paraquat	300	1	150	0.5					
Total			2954	8	0	0		9392	21	5465	11.5		10393	21	7246	12
Mean of all treatment years			492	1.3	0	0		1565	3.5	911	1.9		1732	3.5	1208	2

*Rye grown in CFP and winter barley in RIA sections of field, with pesticides apportioned as listed.

Appendix Table 3.1.5. SCARAB pesticide use, Gleadthorpe, 'Near Kingston' field, 1987–1996.

Year	Crop	Insecticide					Herbicide					Fungicide				
		Active ingredient	CFP		RIA		Active ingredient	CFP		RIA		Active ingredient	CFP		RIA	
			a.i. g/ha	units	a.i. g/ha	units		a.i. g/ha	units	a.i. g/ha	units		a.i. g/ha	units	a.i. g/ha	units
Pre-treatment years																
1987	Spring barley	chlorpyrifos	720	1	720	1	bromoxynil	168	1	168	1	nil	0	0	0	0
							ioxynil	168	1	168	1					
							mecoprop	1344	1	1344	1					
							glyphosate	720	0.5	720	0.5					
1988	Potatoes	aldicarb	3350	1	3350	1	glyphosate	990	1	990	1	mancozeb	5400	4	5400	4
							linuron	900	1	900	1	metalaxyl	600	4	600	4
							paraquat	400	1	400	1					
1989	Winter wheat	cypermethrin	25	1	25	1	isoproturon	2100	1	2100	1	fenpropimorph	375	1	375	1
		fonofos	880	1	880	1						triadimenol	125	1	125	1
												tridemorph	375	1	375	1
												chlorothalonil	500	1	500	1
1990	Sugar beet	aldicarb	760	1	760	1	chloridazon	452	1	452	1	nil	0	0	0	0
							ethofumesate	640	2	640	2					
							phenmedipham	628	3	628	3					
							metamitron	1750	2	1750	2					
							clopyralid	200	1	200	1					
Treatment years																
1991	Spring barley	chlorpyrifos	720	1	0	0	metsulfuron-methyl	6	1	3	0.5	fenpropimorph	750	1	375	0.5
												propiconazole	125	1	62	0.5
												tridemorph	350	1	175	0.5
1992	Winter barley	cypermethrin	25	1	0	0	diflufenican	100	1	50	0.5	carbendazim	78	1	39	0.5
							isoproturon	1000	1	500	0.5	flusilazole	156	1	78	0.5
1993	Spring beans	pirimicarb	140	1	0	0	simazine	103	1	52	0.5	benomyl	550	1	275	0.5
							trietazine	724	1	362	0.5	chlorothalonil	500	1	250	0.5
1994	Winter wheat	pirimicarb	140	1	0	0	isoproturon	500	1	250	0.5	propiconazole	125	1	62	0.5
							pendimethalin	1000	1	500	0.5	fenpropidin	750	1	375	0.5
							mecoprop	1995	1	998	0.5					
1995	Winter barley	cypermethrin	25	1	0	0	terbutryn	1470	1	735	0.5	carbendazim	100	1	50	0.5
												flusilazole	200	1	100	0.5

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Appendix Table 3.1.5. SCARAB pesticide use, Gleadthorpe, 'Near Kingston' field, 1987–1996.

Year	Crop		Insecticide					Herbicide					Fungicide			
			CFP		RIA			CFP		RIA			CFP		RIA	
		Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units
1996	Sugar beet	aldicarb	760	1	0	0	glyphosate	618	2	354	1.5	nil	0	0	0	0
		cypermethrin	25	1	0	0	chlorpropham	90	1	45	0.5					
							fenuron	60	1	30	0.5					
							propham	360	1	180	0.5					
							chloridazon	731	1	366	0.5					
							metamitron	2065	2	1033	1					
							phenmedipham	479	2	239	1					
							ethofumesate	300	1	150	0.5					
Total			1835	7	0	0		11601	20	5847	10.5		3684	11	1841	5.5
Mean of all treatment years			306	1.2	0	0		1934	3.3	975	1.8		614	1.8	307	0.9

Appendix Table 3.1.6. SCARAB pesticide use, High Mowthorpe, 'Bugdale', 1987–1996.

Year	Crop	Insecticide					Herbicide					Fungicide				
		Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units	Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units	Active ingredient	CFP a.i. g/ha	CFP units	RIA a.i. g/ha	RIA units
Pre-treatment years																
1987	Winter barley	nil	0	0	0	0	pendimethalin	1600	1	1600	1	prochloraz	450	1	450	1
							isoproturon	1500	1	1500	1	fenpropimorph	375	1	375	1
							glyphosate	720	0.5	720	0.5					
1988	Winter oilseed rape	gamma-HCH	280	1	280	1	metazachlor	1250	1	1250	1	prochloraz	562	1	562	1
		triazophos	420	1	420	1	propyzamide	700	1	700	1					
1989	Winter wheat	nil	0	0	0	0	pendimethalin	1600	1	1600	1	propiconazole	125	1	125	1
							isoproturon	1250	1	1250	1	fenpropimorph	375	1	375	1
1990	Winter barley	cypermethrin	25	1	25	1	diflufenican	100	1	100	1	prochloraz	450	1	450	1
							isoproturon	1000	1	1000	1	propiconazole	125	1	125	1
												tridemorph	350	1	350	1
Treatment years																
1991	Winter oilseed rape	triazophos	420	1	0	0	propyzamide	875	1	435	0.5	prochloraz	450	1	0	0
1992	Winter wheat	dimethoate	340	1	0	0	diflufenican	100	1	50	0.5	prochloraz	405	1	202	0.5
							isoproturon	1000	1	500	0.5	propiconazole	125	1	0	0
												chlorothalonil	1000	1	0	0
1993	Spring barley	dimethoate	340	1	0	0	bromoxynil	196	1	98	0.5	propiconazole	125	1	62	0.5
							ioxynil	196	1	98	0.5	tridemorph	350	1	175	0.5
							mecoprop	1568	1	784	0.5					
1994	Spring beans	cypermethrin	25	1	0	0	terbuthylazine	420	1	210	0.5	nil	0	0	0	0
							terbutryn	980	1	490	0.5					
1995	Winter wheat	chlorpyrifos	480	1	0	0	diflufenican	100	1	50	0.5	chlorothalonil	1750	2	200	0.2
		dimethoate	340	1	0	0	isoproturon	1000	1	500	0.5	flutriafol	94	1	0	0
							glyphosate	540	1	540	1	tebuconazole	250	1	100	0.4
												triadimenol	125	1	50	0.4
												propiconazole	125	1	50	0.4
1996	Winter barley	cypermethrin	25	1	0	0	diflufenican	100	1	50	0.5	carbendazim	75	1	38	0.5
							isoproturon	1000	1	500	0.5	flusilazole	150	1	75	0.5
							metsulfuron-methyl	6	1	3	0.5	fenpropimorph	563	1	281	0.5
							fluroxypyr	200	1	100	0.5					
Total			1970	7	0	0		8281	15	4408	8		5587	15	1233	4.4
Mean of all treatment years			328	1.2	0	0		1380	2.5	735	1.3		931	2.5	206	0.7

Appendix Table 3.1.7. SCARAB pesticide use, High Mowthorpe, 'Old Type', 1987–1996.

Year	Crop	Insecticide					Herbicide					Fungicide				
			CFP		RIA			CFP		RIA			CFP		RIA	
		Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units	Active ingredient	a.i. g/ha	units	a.i. g/ha	units
Pre-treatment years																
1987	Winter wheat	nil	0	0	0	0	pendimethalin	1600	1	1600	1	fenpropimorph	750	1	750	1
							isoproturon	1500	1	1500	1					
1988*	Winter wheat (CFP) / Winter barley (RIA)	nil	0	0	0	0	pendimethalin	0	0	1600	1	prochloraz	450	1	450	1
							isoproturon	1625	1	1250	1	propiconazole	125	1	125	1
							ioxynil	325	1	0	0	fenpropimorph	375	1	0	0
							mecoprop	1170	1	0	0					
1989	Winter barley	nil	0	0	0	0	pendimethalin	1600	1	1600	1	prochloraz	450	1	450	1
							isoproturon	1250	1	1250	1					
1990	Winter barley	cypermethrin	25	1	25	1	diflufenican	100	1	100	1	tridemorph	875	2	875	2
							isoproturon	1000	1	1000	1	prochloraz	450	1	450	1
												propiconazole	125	1	125	1
Treatment years																
1991	Spring beans	pirimicarb	140	1	0	0	bentazone	1440	1	720	0.5	metalaxyl	150	1	75	0.5
							glyphosate	1080	1	540	0.5	chlorothalonil	2500	2	1250	1
1992	Winter wheat	dimethoate	340	1	0	0	diflufenican	100	1	50	0.5	prochloraz	405	1	202	0.5
							isoproturon	1000	1	500	0.5	propiconazole	125	1	62	0.5
												chlorothalonil	1000	1	0	0
1993	Winter barley	cypermethrin	25	1	0	0	diflufenican	100	1	38	0.38	carbendazim	100	1	50	0.5
							isoproturon	1000	1	380	0.38	flusilazole	200	1	100	0.5
												fenpropimorph	375	1	187	0.5
1994	Winter oilseed rape	triazophos	420	1	0	0	metazachlor	1250	1	1250	1	nil	0	0	0	0
							propyzamide	35	0	0	0					
1995	Winter wheat	dimethoate	340	1	0	0	diflufenican	100	1	50	0.5	chlorothalonil	1750	2	200	0.2
							isoproturon	1000	1	500	0.5	flutriafol	94	1	0	0
							glyphosate	540	1	540	1	tebuconazole	250	1	100	0.4
												triadimenol	125	1	50	0.4
												propiconazole	125	1	50	0.4
1996	Spring barley	dimethoate	340	1	0	0	bromoxynil	196	1	98	0.5	propiconazole	125	1	62	0.5
							ioxynil	196	1	98	0.5	fenpropimorph	562	1	281	0.5
							mecoprop-P	784	1	392	0.5					
							glyphosate	540	1	540	1					
Total			1605	6	0	0		9361	14	5696	8.26		7886	17	2669	6.4
Mean of all treatment years			268	1	0	0		1560	2.3	949	1.4		1314	2.8	445	1.1

*Winter wheat grown in CFP and winter barley in RIA sections of field, with pesticides apportioned as listed.

Appendix Table 3.1.8. SCARAB seed treatments used.

Site	Field name	Year	Crop	CFP	RIA
Drayton	Field 1	1991	W. wheat	carboxin (f) thiabendazole (f)	nil nil
		1992	W. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
	Field 5	1992	W. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1993	W. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
Gleadthorpe	Balk	1991	Su. beet	thiram (f) hymexazole (f)	thiram (f) hymexazole (f)
		1992	S. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1993	W. barley	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1994	Potatoes	tolclofos-methyl (f)	nil
		1995	S. wheat	carboxin (f) thiabendazole (f) fonofos (i)	carboxin (f) thiabendazole (f) nil
		1996	W. barley	tebuconazole (f) triazoxide (f)	tebuconazole (f) triazoxide (f)
	Near Kingston	1991	S. barley	phenylmercury acetate (f)	phenylmercury acetate (f)
		1992	W. barley	guazatine (f)	guazatine (f)
		1993	S. beans	nil	nil
		1994	W. wheat	guazatine (f)	guazatine (f)
		1995	W. barley	tebuconazole (f) triazoxide (f)	tebuconazole (f) triazoxide (f)
		1996	Su. beet	thiram (f) hymexazole (f)	thiram (f) hymexazole (f)
	South	1991	Potatoes	tolclofos-methyl (f)	nil
		1992	S. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1993	W. barley	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1994	Su. beet	thiram (f) hymexazole (f)	thiram (f) hymexazole (f)
		1995	S. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1996	W. barley	tebuconazole (f) triazoxide (f)	tebuconazole (f) triazoxide (f)
High Mowthorpe	Bugdale	1991	W. oilseed rape	fenpropimorph (f) thiram (f) gamma-HCH (i)	nil nil nil
		1992	W. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1993	S. barley	carboxin (f) imazalil (f) thiabendazole (f)	carboxin (f) imazalil (f) thiabendazole (f)
		1994	S. beans	nil	nil
		1995	W. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1996	W. barley	carboxin (f) imazalil (f) thiabendazole (f)	carboxin (f) imazalil (f) thiabendazole (f)

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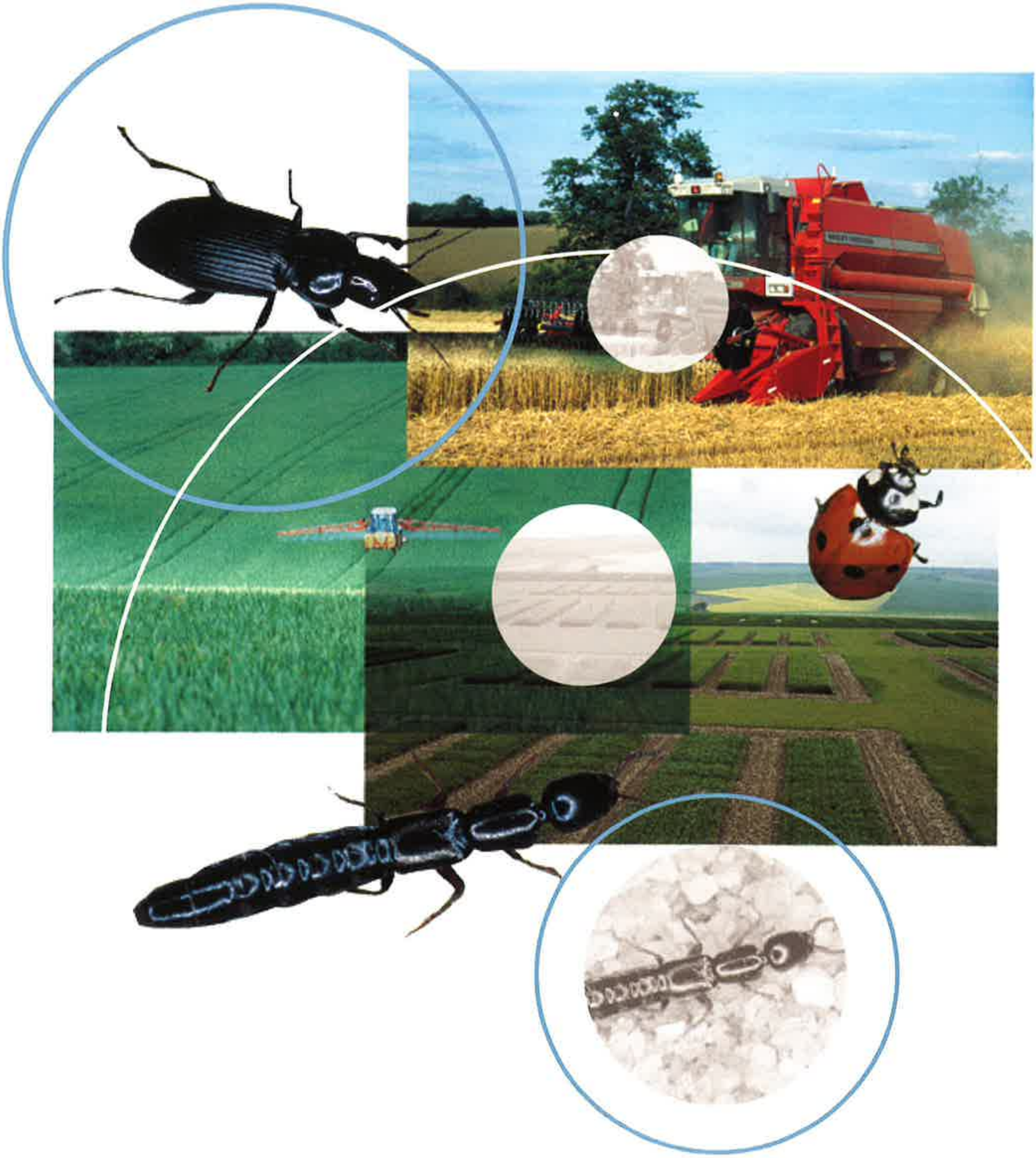
Appendix Table 3.1.8. SCARAB seed treatments used.

Site	Field name	Year	Crop	CFP	RIA
	Old Type N & S	1991	S. beans	nil	nil
		1992	W. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1993	W. barley	carboxin (f) imazalil (f) thiabendazole (f)	carboxin (f) imazalil (f) thiabendazole (f)
		1994	W. oilseed rape	fenpropimorph (f) thiram (f) gamma-HCH (i)	fenpropimorph (f) thiram (f) gamma-HCH (i)
		1995	W. wheat	carboxin (f) thiabendazole (f)	carboxin (f) thiabendazole (f)
		1996	S. barley	carboxin (f) imazalil (f) thiabendazole (f)	carboxin (f) imazalil (f) thiabendazole (f)

W, Winter; S, Spring.
Su, Sugar
f = fungicide seed treatment.
i = insecticide seed treatment.



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