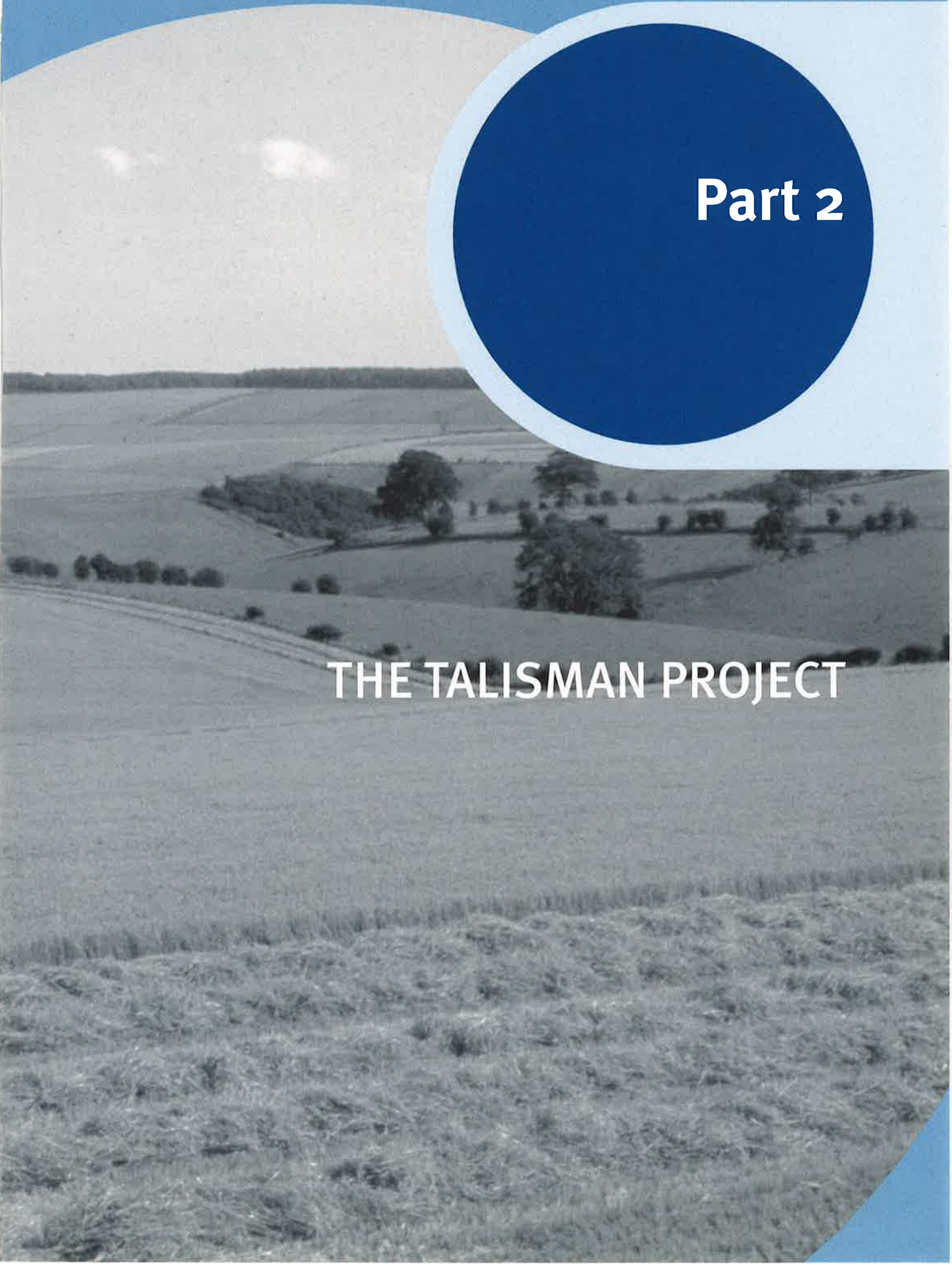

Part 2

THE TALISMAN PROJECT

EXPERIMENT DESIGN, TREATMENTS AND PESTICIDE USE

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Design of TALISMAN

The overall aim of TALISMAN was to investigate the economic and agronomic consequences of reducing pesticide use. A traditional small-plot randomised block design was chosen for this project in order to achieve the degree of replication and statistical reliability demanded in the analysis and interpretation of economic and agronomic data, although small plots are known to have their limitations in agricultural system studies (Fisher, 1998). The large split-field design of the SCARAB project complemented that of TALISMAN by focusing primarily on ecological objectives.

A unique feature of TALISMAN was the inclusion of contrasting arable crop rotations of six-year duration. The economic and agronomic effects of reducing nitrogen and pesticide use could, therefore, be studied over a long and continuous period that spanned the full term of each crop rotation. The experimental plots remained in the same position at each site for the entire lifespan of the study. This design offered a major advantage in that the long-term and cumulative effects of reduced pesticide use on weed, pest and disease problems could be followed and assessed in detail across each crop rotation. In addition, the replicated small-plot design also offered the precision required for statistically reliable measurement of crop yield.

Figure 2.1.1. Location of TALISMAN sites.

TALISMAN was located at three ADAS research centres: Boxworth in Cambridgeshire; Drayton in Warwickshire; and High Mowthorpe in North Yorkshire (**Fig. 2.1.1**). These sites provided a useful geographical spread, with contrasting local conditions (**Table 2.1.1**) representative of a large proportion of English arable farms. The TALISMAN experiments were of a randomised block, split-plot design with four (five at Boxworth) replicates of each experimental treatment (**Fig. 2.1.2**). The overall design incorporated the concept of 'main treatments' and 'sub-treatments', details of which are provided in the sections below. The main treatments comprised crop rotation and nitrogen, whereas the sub-treatments focused on the specific effects of individual pesticide groups (e.g. herbicides, fungicides, insecticides).

The main treatments were applied to main plots with a minimum size of 18 m × 20 m. The five sub-treatments were superimposed on each main plot, in sub-plots with a minimum size of 2.7 m × 18 m. The main plots of the replicate (block) nearest the headland at each site were not split into sub-plots, in order to permit invertebrate monitoring (Chapter 2.7) to be done within that block of main treatments. A boundary of mown perennial ryegrass (12 m wide) was established around all main plots to provide a turning area for machinery and a consistent buffer zone with the surrounding field.

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.

Main treatments

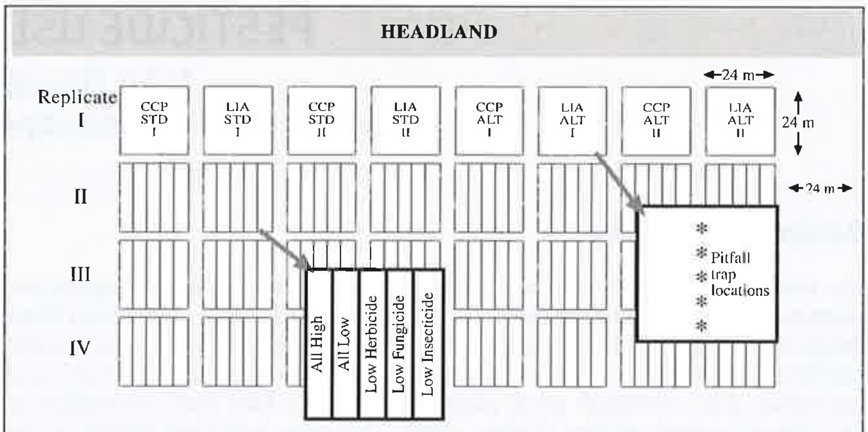

Figure 2.1.2. Layout of a typical TALISMAN site showing the randomised block design and location of sub-plots. To allow invertebrate monitoring, the main plots of Replicate I did not contain sub-plots. CCP: Current Commercial Practice LIA: Low Input Approach. STD: Standard Rotation Phase I or II. ALT: Alternative Rotation Phase I or II.

The main treatments comprised two contrasting crop rotations, namely the 'Standard Rotation' and the 'Alternative Rotation' (**Tables 2.1.2 & 2.1.3**). The Standard Rotation reflected the recent trend towards the generally higher yielding and more reliable autumn-sown crops, and was based entirely on autumn-sown cereals and break crops such as winter beans and winter oilseed rape. The Alternative Rotation contained a large proportion of spring-sown cereals and break crops such as spring linseed; these crops tend to be lower yielding, but have an inherently lower demand for nitrogen and pesticides. Each rotation was present in two 'phases'. The first phase (Phase I) commenced in the first year of the study with the first crop in each six-crop rotational sequence. In contrast, the second phase (Phase II) commenced with the fourth crop in each rotation. Therefore, data were gathered on each crop in each rotation in two distinct seasons. This had the advantage of overcoming seasonality, when extreme weather conditions in a given year could have unduly influenced crop performance. Furthermore, the phasing meant that data sets were available for all crops in each rotation by the third year of the six-year study. Both phases of the Standard and Alternative Rotations were present at each site, except at Boxworth where Phase II of the Alternative Rotation was not present (**Tables 2.1.2 & 2.1.3**). During the six-year course of TALISMAN, 66 crops were harvested (**Table 2.1.4**).

Two contrasting regimes of nitrogen and pesticide use were applied across each rotation (**Table 2.1.5**). These regimes were defined as Current Commercial Practice (CCP) and the Low Input Approach (LIA). Nitrogen use in CCP was defined according to ADAS 'Fertiplan' which is a fertiliser planning system based on previous cropping, soil type and yield prediction (Chapter 2.2). Pesticide use in CCP was according to the manufacturers' recommended rate as given on the product labels (= label rate). It was recognised at the outset that, in appropriate circumstances, many farmers apply pesticides at less than the label recommended rates. However, the full rate is robust and gives optimum control in most situations and provides the only officially recognised standard against which comparisons can be made. This issue is given further consideration later in this chapter and also in Chapters 2.3, 2.5 & 2.6 which deal with specific experiences relating to herbicides, fungicides and insecticides respectively. Pesticides were selected for use according to the most commonly applied active ingredient for a given use, as indicated by the most recently available MAFF Pesticide Usage Survey Report (PUSR) (e.g. Thomas *et al.*, 1997). In any given application of a pesticide, the same product was used in both the CCP and LIA regimes.

A major objective of TALISMAN was to reduce pesticide use in LIA by at least 50% below that used in CCP. To that end, LIA pesticide applications could be omitted altogether or applied at a rate at least 50% (but no more than 75%) less than the label rate used in the CCP. In practice, the majority of herbicide and fungicide LIA applications were made at reduced rates, whereas with insecticides, a high proportion of LIA applications were omitted (see Pesticide Use section below). In extreme situations, pesticide applications at full label rate were permitted in LIA. These situations involved difficult targets such as slugs, black-grass or wild oats, where it was considered that half-rate application would fail to remedy the problem and would threaten the viability of the experiment.

Sub-treatments

Five sub-treatments were superimposed on the main treatments, to investigate the combined and individual effects of applying herbicides, fungicides and insecticides in the CCP or LIA regimes (**Table 2.1.6**).

The sub-treatments are referred to as follows:

'All High'	all pesticide groups applied according to CCP rules;
'All Low'	all pesticide groups applied according to LIA rules;
'Low Herbicide'	herbicides applied according to LIA rules, with fungicides and insecticides applied according to CCP rules;
'Low Fungicide'	fungicides applied according to LIA rules, with herbicides and insecticides applied according to CCP rules;
'Low Insecticide'	insecticides and molluscicides applied according to LIA rules, with herbicides and fungicides applied according to CCP rules.

Therefore, the latter three sub-treatments allowed the isolation and assessment of the component effects of each pesticide group: herbicide, fungicide or insecticide (including molluscicide).

Methodology and treatment decisions

The main plots were established using full-size commercial farm equipment. The sub-plots were drilled individually at High Mowthorpe whereas at the other sites they were created by 'cutting out' with either a contact herbicide or a rotavator after crop emergence. Nitrogen fertiliser was applied with conventional farm equipment, normally pneumatic (air-blower) boom spreaders. Spinning disc applicators were not used because of the risk of inter-plot contamination with fertiliser granules. With the exception of slug pellets (molluscicides), all pesticides were applied as sprays. Conventional, full-size, hydraulic sprayers were used to apply pesticides to the undivided main plots used for invertebrate monitoring. However, within the sub-plots of the remaining blocks, small-plot, gas-pressurised, precision sprayers were used. Slug pellets were applied by manual 'pepper-pot' broadcasting to the sub-plots or with a conventional mechanical spreader to the undivided main plots.

The crops were monitored frequently throughout each growing season to assess and measure crop morphology (e.g. plant population and growth stage) and the incidence of weeds, diseases and invertebrate pests. Residual soil mineral nitrogen levels were also measured in the autumn and spring of each year. Crop yields were measured using combine-harvesters specifically modified for small-plot work. Non-pest arthropods (invertebrates) were monitored using pitfall traps and suction sampling in the undivided main plots of the replicate nearest the headland at each site (Chapter 2.7). The incidence of plant seeds in the soil (seedbanks) and soil nematode populations were monitored by researchers at the Scottish Crop Research Institute (SCRI), details of which are presented in Chapters 2.4 & 2.7 respectively.

To ensure nitrogen and pesticide effects were not confounded with other non-treatment husbandry factors, crop cultivar (variety), cultivations and sowing dates were standardised within each phase of each crop rotation. Crop cultivars were chosen from the top-performing varieties in the recommended or provisionally recommended categories of current UK Recommended Lists (e.g. Anon., 2000).

Treatment decision-making was done by the Site Managers in consultation with a Technical Management Team (TMT) comprising various ADAS Consultants with specialist expertise. A telephone conference call was held at regular intervals to assist in the decision-making process. Decisions to apply pesticides to the CCP were normally driven by quantitative assessments of the target weed, disease or invertebrate pest.

Action thresholds have been developed to rationalise pesticide use by ensuring treatments are applied only when the incidence, or damage, relating to the target pest (weed, disease or invertebrate) population exceeds a certain level or threshold. Reliable thresholds depend on extensive research and practical development to ensure the expenditure of pesticide application is cost-effective in terms of preventing economic losses in crop yield or quality. In TALISMAN, this meant that action thresholds were used mostly in connection with invertebrate pests (**Table 2.6.1,** Chapter 2.6), as thresholds were not so widely available for weeds or diseases.

When thresholds were not available, CCP treatment decisions were governed by the experience and knowledge of the Site Managers together with the specialist advisers on the Technical Management Team. Once a decision was made to apply a CCP pesticide, a parallel decision had to be taken to omit or apply an equivalent low-rate application to the LIA plots. The preferred option was to avoid using pesticides altogether in LIA. However, when best estimates indicated that, as a result of not applying a LIA pesticide, losses in crop value were likely to exceed 10%, then a reduced-rate application was made to LIA. In practice, this meant that full label-rate applications of pesticide were made in CCP and a parallel application at 50% of the label rate was made in LIA. The 'rules of engagement' governing LIA pesticide use permitted LIA applications to be deferred and, if required, applied at a later date than the equivalent CCP pesticide. However, this did not occur in practice and the CCP and LIA pesticide applications were, in the vast majority of instances, applied on the same date. Further details of pesticide use in TALISMAN are reviewed in the Pesticide Use section of this chapter.

Plant growth regulators were permitted only when there was a high risk of cereal lodging. In this case, application would be restricted to the CCP main plots only, subject to discussion by the TMT. Additionally, the use of routine, overall, seed treatments was restricted to the use of non-mercurial products such as Cerevax or Rappor on cereals.

Data were analysed by analysis of variance using GENSTAT (1993). Most analyses were done at the individual site/crop level. Cross year and cross site/cross year analyses were also done on a range of parameters, including crop yields and gross margins.

Was TALISMAN Current Commercial Practice realistic?

It is important to assess how closely pesticide use, as dictated by the TALISMAN regime, simulated on-farm pesticide use as advocated commercially throughout the agricultural industry. There are immediate problems in designing a 'blueprint' of commercial pesticide use. Clearly, weed, pest and disease pressures can vary greatly between sites. TALISMAN addressed this problem by having a range of three geographically contrasting experimental locations. At each of these locations, local pressures and priorities in the control of weeds, pests and diseases were expressed in the management of each site. This situation realistically reflected the contrasting crop protection needs that are experienced between farms and between regions.

Decisions on pesticide use are ultimately in the hands of the farmer, with or without any recommendations supplied by his local crop consultant. Often, these decisions are made very strictly and objectively according to local needs at the farm, or even individual field, level.

- At one extreme, pesticide use may be dictated very precisely. In this case, pressure from weeds, pests or diseases may be monitored frequently through crop inspection, combined with information available from a variety of sources. For example, forecasts of pest or disease incidence may be available from consultancy organisations such as ADAS, or from agrochemical companies. Up-to-date information or 'crop intelligence' is also available from consultancy organisations and agrochemical companies in general support of their crop protection activities. Increasingly, there is a trend towards the precise and cost-effective use of pesticides. Computerised decision-making systems (e.g. DESSAC: Decision Support System for Arable Crops) are likely to become more readily available in the future as an aid to increasing the overall precision of pesticide use (Brooks, 1998).

- At the other end of the spectrum, pesticide use may be driven according to a routine strategy. In this instance, pesticides are applied on an 'insurance' or prophylactic (preventive) basis, thus providing a certain amount of 'peace of mind' to the practitioner. Against a background of falling farm incomes, together with wider concerns over environmental safety, the routine insurance approach to pesticide use has fallen from favour in the drive for greater precision, reduced costs and improved profitability.

The scientific demands of the TALISMAN experiment dictated that the treatment regimes were standardised at the outset and remained uniform throughout the course of the study. The CCP regime was judged to be an acceptable compromise which accurately represented on-farm pesticide use. TALISMAN pesticide use was always dictated by the needs of the CCP regime. Pesticide decisions in CCP were almost always driven by crop monitoring and quantitative assessments of weed, pest or disease incidence. Action thresholds were applied if they were available for the problem in hand. A full-rate pesticide application to CCP immediately demanded a response in the LIA treatment. The equivalent LIA decision then normally came down to applying the pesticide at half-rate (or less), or to completely omit the application. In terms of the number and timing of pesticide interventions required, the TALISMAN CCP can be taken to be at the forefront of commercial pesticide use on the most technically aware farms. However, it is recognised that dose-rate reduction has increased in commercial practice over the six years of the project.

Comparisons between TALISMAN and on-farm pesticide use can be drawn from the MAFF PUSRs (Davis *et al.*, 1993; Thomas *et al.*, 1997). The number of active ingredients (including repeat applications of the same a.i.) applied to the CCP break crops was consistently below that indicated for the equivalent set of break crops detailed in the 1996 PUSR (**Fig. 2.1.3**). However, a slightly different story emerged in the TALISMAN cereal crops (**Fig. 2.1.3**). Although the total number of all types of pesticide active ingredients and fungicide active ingredients applied to cereals in TALISMAN remained below that indicated by the 1996 PUSR, the reverse was true for herbicides and insecticides. This reflects the higher use of herbicides and insecticides demanded by grass weeds and slugs at Boxworth and Drayton, respectively. However, the overall use of pesticides in the CCP can generally be seen to be slightly more conservative than general commercial farm usage as indicated by the PUSR. This is believed to be a fair assumption on the grounds that an element of commercial pesticide use still relies on a routine 'insurance' strategy, which the TALISMAN CCP regime attempted to avoid in most cases.

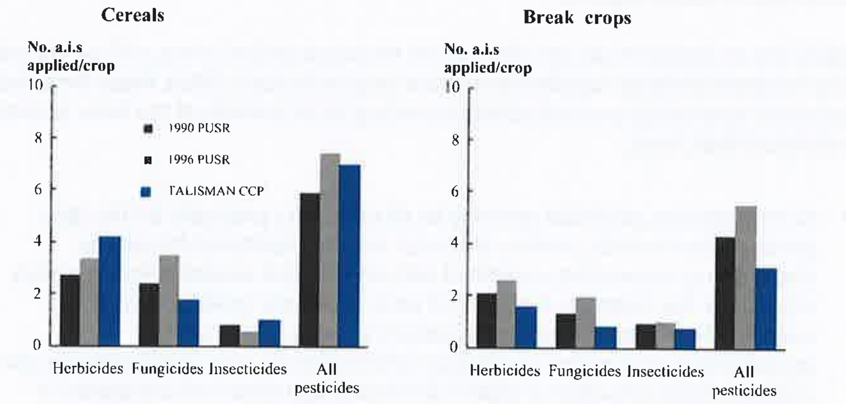

Figure 2.1.3. The average number of active ingredients (including repeat applications of the same a.i.) applied to cereal and break crops in TALISMAN Current Commercial Practice (CCP), compared with MAFF Pesticide Usage Survey Report (PUSR) data for the equivalent cereal and break crops.

The choice of which pesticide ingredient to apply in TALISMAN was not generally a problem. This decision was driven by whatever was the most frequently used pesticide, for any given crop/target combination, as indicated by the most recent PUSR. However, the chosen line on CCP pesticide dose-rate was more controversial. At the outset of TALISMAN, it was agreed that the full dose-rates of pesticide use, as given on the manufacturers' product labels ('label rate'), should be uniformly adopted in CCP pesticide applications. Label rates represent the legally permitted maximum dose but lower rates may be applied at the user's risk.

In practice, complete (100%) control of a target organism is not often achievable or cost-effective, hence label recommendations usually describe the rate that will consistently achieve a lower level of control, often, but not always, around 80–90% (Finney, 1993). Since the inception of TALISMAN in 1990, it has become an increasingly common on-farm practice for pesticides to be applied at less than label rate, particularly in the case of herbicides and fungicides (Thomas *et al.*, 1997).

The impact of this issue is assessed and discussed in more detail in the relevant TALISMAN chapters on herbicide, fungicide and insecticide use (Chapters 2.3, 2.5 & 2.6). The amount by which label rates may be reduced in any given situation is a complex decision and one which often comes down to a subjective decision by the practitioner. Accurate data relating to the scope and extent of rate-reducing practices on commercial farms were not available during the project. Owing to these uncertainties, it was vital to apply manufacturers' label rates in the CCP, as these rates were deemed to be the only official and reliable 'benchmark' against which the relative economic and agronomic effects of reducing pesticide use by at least 50% could be assessed and quantified.

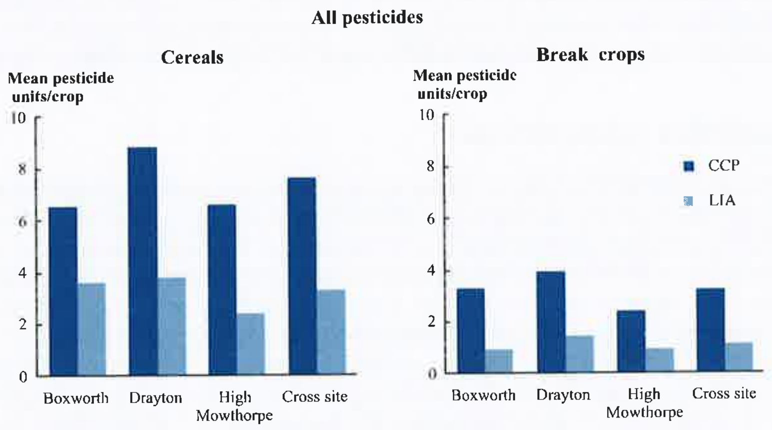

Figure 2.1.4. The effect of site and treatment regime on pesticide use (all groups) in TALISMAN cereal and break crops. CCP: Current Commercial Practice. LIA: Low Input Approach.

Pesticide use

In this section, reference to general pesticide use includes applications of herbicides, fungicides and insecticides. Furthermore, here the insecticide data include all applications of molluscicides. Pesticide use is quantified throughout by the use of 'pesticide units', whereby one unit equals one full-rate application of an active ingredient, as given on the product label for the specific use in question. For example, if a pesticide product containing two active ingredients was applied at the label recommended rate, this would be defined as two units (2 × 1 units). If the rate of the same product were to be cut by 50% below the label rate, this would count as one unit (2 × 0.5 units).

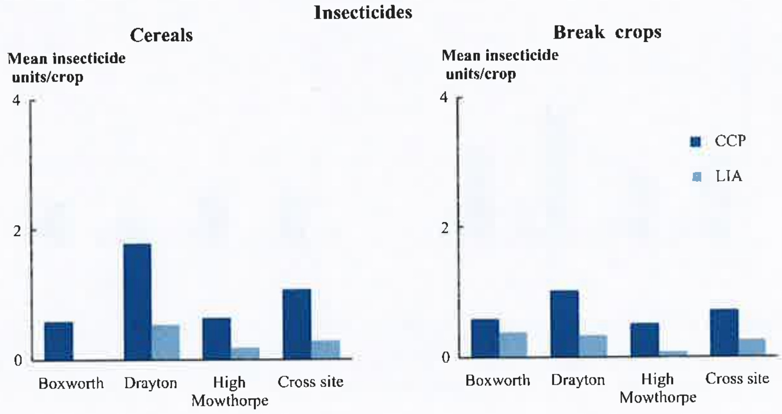

Figure 2.1.5. The effect of site and treatment regime on insecticide (including molluscicide) use in TALISMAN cereal and break crops. CCP: Current Commercial Practice. LIA: Low Input Approach.

The TALISMAN aim of reducing pesticide use by at least 50% was achieved. Pesticide use across all crops grown in TALISMAN was reduced by 58% in LIA, compared with CCP. An average of 6.1 CCP pesticide units was applied to each crop, compared with 2.5 in the LIA. Herbicides comprised the largest element of pesticide use (54%), followed by fungicides (31%) and insecticides (15%). Cereal crops had a heavier demand for pesticides than break crops (**Table 2.1.7 & Fig. 2.1.4**). An average of 7.5 CCP pesticide units was applied to cereal crops, compared with 3.2 in the break crops. Larger reductions in pesticide use in the LIA were possible in the break crops, where an overall reduction of 65% was achieved, compared with 56% in cereals. Within the various groups of pesticide, the greatest reductions in LIA use compared with the CCP were obtained with insecticides (72% reduction), followed by fungicides (68%) and herbicides (48%) (**Figs 2.1.5–7**).

Insecticide & molluscicide use

In a large number of instances (52%), insecticides were omitted altogether in the LIA regime (Chapter 2.6). The large reduction in insecticide use reflects the more sporadic nature of pest problems and the greater availability and wider, more rigorous, use of action thresholds for pest problems. Treatment thresholds for pests have been in use longer than those for diseases or weeds because the environmental consequences of insecticide use and the need for rational decision making in their application was first realised in the 1960s. In general, the decision to use an insecticide or a molluscicide is governed more strongly by a 'wait and see' approach than that of herbicides and fungicides. In contrast, the effective control of weeds and diseases demands a more prophylactic (preventive) strategy in the use of herbicides and fungicides.

Fungicide use

Fungicide use was reduced by 68% overall in LIA compared with CCP, which was well in excess of the 50% target. This was achieved primarily by reductions in dose rates rather than by omitting applications. The generally low disease pressure experienced during the six years of TALISMAN meant that consistent reductions in fungicide use could be achieved safely under LIA (Chapter 2.5). Consequently, the reductions in fungicide dose rate in LIA often exceeded the 50% target demanded by the LIA regime.

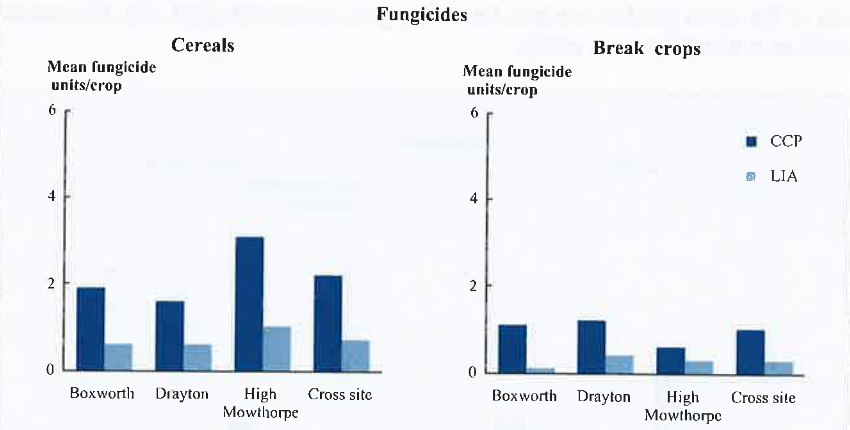

Figure 2.1.6. The effect of site and treatment regime on fungicide use in TALISMAN cereal and break crops. CCP: Current Commercial Practice. LIA: Low Input Approach.

Herbicide use

An overall 48% reduction in LIA herbicide use fell slightly short of the 50% target. In order to maintain control of weed populations, herbicide rate reductions under LIA rarely fell below the minimum 50% reduction required in the LIA regime. However, at Boxworth, it was deemed essential to maintain control of an aggressive black-grass population and, consequently, full label-rate use of isoproturon (IPU) was allowed at this site (Chapter 2.3). This subsequently resulted in the slight shortfall in attaining the planned required minimum 50% reduction in LIA herbicide use.

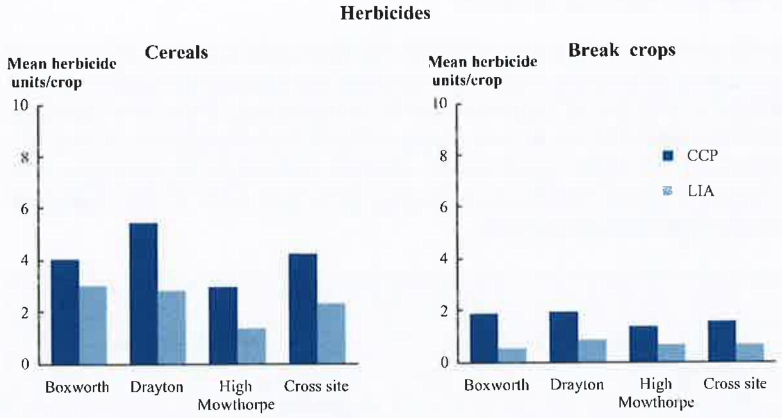

Figure 2.1.7. The effect of site and treatment regime on herbicide use in TALISMAN cereal and break crops. CCP: Current Commercial Practice. LIA: Low Input Approach.

Crop related differences in pesticide use

Within the various cereal crops grown in TALISMAN, the reductions in pesticide use obtained in LIA ranged from a 44% reduction in spring wheat, to a 64% reduction in winter barley (**Table 2.1.8**). A 50% reduction in pesticide use was not quite achieved in the spring wheat owing to a full-rate application of herbicide (fenoxyprop-ethyl) to both CCP and LIA. This treatment was sanctioned to control an uneven distribution of wild oats which was not related to treatment. Likewise, reductions in LIA herbicide use in the winter wheat also fell slightly short of the 50% target and averaged 41% (owing to the full-rate application of IPU detailed above). No such problems were encountered in the break crops, where reductions in LIA pesticide use did not fall below 50% and ranged from 50% to 76%. The largest reductions in pesticide use among the break crops were obtained in the winter and spring beans where LIA reductions compared with CCP, averaged 67% and 76% respectively (**Table 2.1.9**).

Site related differences in pesticide use

Strong differences emerged in the demand for pesticide use between sites. These differences reflected the differing pressures from weed, disease and invertebrate pest problems at each site. Drayton was consistently the highest total user of pesticides in cereals and break crops. In comparison, total pesticide use at Boxworth and High Mowthorpe was fairly similar overall (**Fig. 2.1.4**). The reason for these differences was mainly in the higher demand for herbicides and insecticides at Drayton (**Figs 2.1.5 & 7**). In contrast, High Mowthorpe was the highest overall user of fungicides in cereals (**Fig. 2.1.6**). Drayton demanded a higher use of herbicides, owing to problems with wild oats and other grass weeds. Furthermore, insecticide use (including molluscicides) was elevated at Drayton, owing to slug problems in oilseed rape and triticale. However, fungicide use in cereals at Drayton was comparatively small compared with the other sites, mainly because of the low requirement for disease control in the triticale. The greater demand for fungicides in cereals at High Mowthorpe was a result of the higher use of fungicides on winter barley at this site. Further details of weed, pest and disease problems encountered at the respective sites are provided in Chapters 2.3–2.6.

Pesticide use and crop rotations

Pesticide use in the contrasting Standard and Alternative Rotations followed a similar pattern across all sites and again indicated that Drayton was the highest overall user of pesticides (**Fig. 2.1.8**). However, within the Rotations, there was relatively little difference in pesticide use between Boxworth and High Mowthorpe. Across all sites, the proportion by which pesticide use was reduced in the LIA, compared with CCP, was similar in both rotations, averaging 57% and 60% in the Standard and Alternative Rotations respectively.

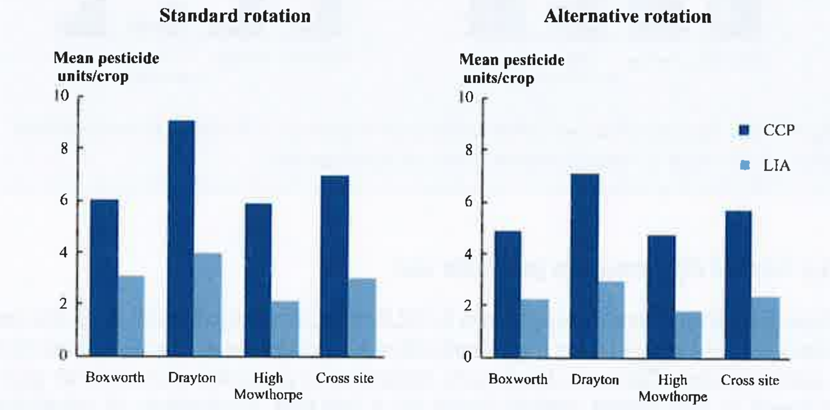

Figure 2.1.8. The effect of crop rotation on pesticide use (all groups) at the TALISMAN sites.

The Alternative and Standard Rotations were designed with the specific needs of each site in mind and the Standard Rotation was meant to represent local commercial cropping patterns. However, the Alternative Rotation was designed to have an inherently lower demand for pesticides than the Standard Rotation. This was to be achieved in the Alternative Rotation through the introduction of spring cropping, together with the use of low-input winter crops, such as triticale which was grown at Drayton.

Overall, a lower pesticide demand was achieved in the Alternative Rotation compared with the Standard Rotation. Total pesticide use was, on average, 18% lower in the Alternative than the Standard Rotation (**Fig. 2.1.8**). Within each pesticide category, herbicides comprised the largest part of the pesticide use in both rotations, followed by fungicides and insecticides. However, the reductions in pesticide use achieved in the Alternative Rotation compared with the Standard Rotation were not shared evenly between pesticide groups (**Fig. 2.1.9**). In the case of herbicides and insecticides, the

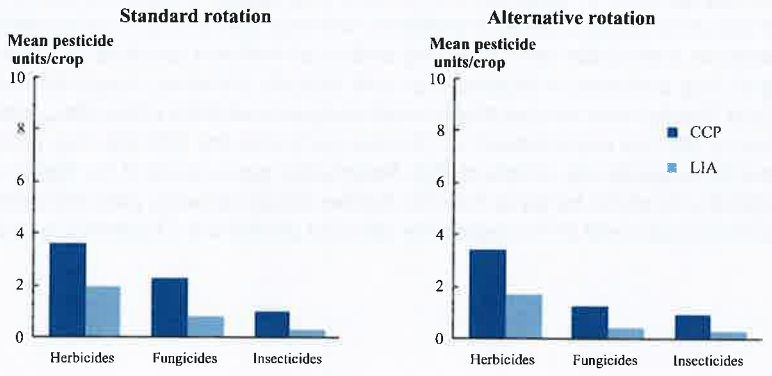

Figure 2.1.9. The effect of crop rotation on herbicide, fungicide and insecticide (including molluscicide) use in TALISMAN.

reductions were marginal. Their use in the CCP of the Alternative Rotation was, on average, 4% and 6% respectively less than that of the Standard Rotation. Reductions in fungicide use were, however, far greater in the Alternative Rotation, where fungicide usage was 46% less than that of the Standard Rotation (**Fig. 2.1.9**).

The underlying reasons for the differences in pesticide use between the Standard and Alternative Rotations are discussed in more detail in the respective chapters dealing with herbicide, fungicide and insecticide use in TALISMAN (Chapters 2.3–2.6). Essentially, weed control in the Alternative Rotation was not eased by the inclusion of spring cropping and weed populations built up to difficult levels at some sites (Chapter 2.3). Despite the spring crops, overall herbicide use in the Alternative Rotations could not be substantially relaxed. Furthermore, insecticide (including molluscicide) use was not greatly relieved by the Alternative Rotation. Slugs were a constant threat to the winter triticale at Drayton and aphid attacks occurred in some of the spring crops such as beans and oats. However, the Alternative Rotation did benefit from lower fungicide use, the main contributory factors being the low disease pressure in the winter triticale and spring linseed.

Discussion

During the formative stages of TALISMAN, there were European-wide initiatives to limit nitrogen and pesticide use (Reus *et al.*, 1994). Pesticide reduction plans, with national targets for reducing pesticide use, were implemented by European Union (EU) member states such as Denmark and the Netherlands (Hurst, 1992). There was concern that insufficient information was available on the implications of similar EU-driven policies being imposed in the UK. Consequently, one of the main objectives of TALISMAN was to provide the Ministry of Agriculture, Fisheries and Food (MAFF) with robust data on the economic and agronomic consequences of reducing nitrogen and pesticide inputs by 50%. Although TALISMAN and SCARAB evolved as follow-on studies to the Boxworth Project (Greig-Smith *et al.*, 1992), it must be borne in mind that TALISMAN was also conceived as a policy-driven project to address the 'what if' questions posed by the policy issues surrounding pesticide use at a European level.

TALISMAN was not intended or designed to provide direct 'blueprint' guidance to the farming industry on how best to cut pesticide and nitrogen inputs. Likewise, TALISMAN was not an Integrated Crop Management (ICM) study, although it shared many common features with ICM in relation to pesticide use. Nevetheless, the rigorous design and methodology employed in TALISMAN successfully enabled the economic and agronomic consequences of adopting a low-input system to be compared with conventional practice.

The following key points emerged in relation to pesticide use in TALISMAN:

- In terms of the number and timing of pesticide applications, the TALISMAN conventional regime was a fair representation of commercial practice.
- It was necessary to use label rates in TALISMAN as they were deemed to be the only 'benchmark' against which to assess the impact of reducing pesticide use by 50%.
- However, it is recognised that over the term of the project it has become increasingly common in commercial practice for herbicides and fungicides to be applied at less than their label rates (less so with insecticides).
- Across all crops grown in TALISMAN, pesticide use was reduced by 58% (as defined by pesticide units) in the low-input compared with the conventional regime.

- An average of 6.1 pesticide units/crop was applied in the conventional regime, compared with 2.5 in the low-input regime.
- Larger reductions in low input pesticide use were possible in the break crops (65% reduction) compared with the cereal crops (57% reduction).
- Within pesticide groups, herbicides comprised the largest use followed by fungicides and insecticides/molluscicides.
- Drayton was the highest user of pesticides in cereals and break crops, mainly due to the higher demand for herbicides and molluscicides on this heavy-land site.
- The Alternative Rotation (mainly spring-sown crops), as expected, had a lower overall demand on pesticide use than the Standard Rotation (mainly winter-sown crops). Total pesticide units applied were 18% lower in the Alternative Rotation than in the Standard Rotation.
- Insecticide and herbicide use were not greatly eased by the spring-crop dominated Alternative Rotation. However, fungicide units applied were substantially lower (46%) in the Alternative Rotation compared with the Standard Rotation, owing to lower disease pressure.

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Table 2.1.1. TALISMAN site details, pre-treatment soil analysis and cropping.

	Boxworth	Drayton	High Mowthorpe
Field name	Big Field	Field 19	Crow Wood
Soil series	Hanslope	Drayton	Panholes
Soil texture	Well structured clay	Heavy clay	Silty clay loam
Drainage	Good	Good	Good
Soil analysis (1990)			
pH	7.8	7.1	7.8
P index	4	3	3
K index	3	3	3
Mg index	3	5	1
Organic matter (%)	4.1	3.8	4.2
Previous cropping			
1990	W. wheat	W. wheat	W. wheat
1989	W. oilseed rape	W. wheat	Potatoes
1988	W. wheat	W. wheat	S. barley

W, Winter; S, Spring.

Table 2.1.2. TALISMAN main treatments.

		Site	
Main treatment	Boxworth	Drayton	H. Mowthorpe
1. Standard Rotation Phase I Current Commercial Practice Full-rate Nitrogen	+	+	+
2. Standard Rotation Phase I Low Input Approach Half-rate Nitrogen	+	+	+
3. Standard Rotation Phase II Current Commercial Practice Full-rate Nitrogen	+	+	+
4. Standard Rotation Phase II Low Input Approach Half-rate Nitrogen	+	+	+
5. Alternative Rotation Phase I Current Commercial Practice Full-rate Nitrogen	+	+	+
6. Alternative Rotation Phase I Low Input Approach Half-rate Nitrogen	+	+	+
7. Alternative Rotation Phase II Current Commercial Practice Full-rate Nitrogen	-	+	+
8. Alternative Rotation Phase II Low Input Approach Half-rate Nitrogen	-	+	+

+ treatment present; - treatment absent.

Table 2.1.3. The TALISMAN crop rotations, 1990–1996.

Site	Rotation	Harvest year					
		1991	1992	1993	1994	1995	1996
Boxworth	Standard Phase I	W. beans	W. wheat	W. wheat	W. OSR[2]	W. wheat	W. wheat
	Standard Phase II	W. OSR	W. wheat	W. wheat	W. beans	W. wheat	W. wheat
	Alternative Phase I	S. linseed	W. wheat	S. wheat	S. beans	W. wheat	S. wheat
Drayton	Standard Phase I	W. OSR	W. wheat	W. wheat	W. beans	W. wheat	W. wheat
	Standard Phase II	W. beans	W. wheat	W. wheat	W. OSR[2]	W. wheat	W. wheat
	Alternative Phase I	S. beans	W. triticale	W. triticale[1]	S. oats	W. triticale	W. triticale
	Alternative Phase II	S. oats	W. triticale	W. triticale[1]	S. beans	W. triticale	W. triticale
H. Mowthorpe	Standard Phase I	W. OSR	W. wheat	W. wheat	W. beans	W. wheat	W. barley
	Standard Phase II	W. beans	W. wheat	W. barley	W. OSR	W. wheat	W. wheat
	Alternative Phase I	S. linseed	W. wheat	S. barley	S. beans	W. wheat	S. barley
	Alternative Phase II	S. beans	W. wheat	S. barley	S. linseed	W. wheat	S. barley

[1] Replaced with spring barley.
[2] Replaced with spring oilseed rape.
W, Winter; S, Spring.

Table 2.1.4. A summary of the type and number of crops harvested in TALISMAN, 1991–1996.

Crop	Site			
	Boxworth	Drayton	H. Mowthorpe	Total
Cereals				
Winter wheat	10	8	10	28
Winter triticale	-	6	-	6
Spring barley*	-	2	4	6
Winter barley	-	-	2	2
Spring wheat	2	-	-	2
Total cereals	12	16	16	44
Break crops				
Winter beans	2	2	2	6
Spring beans	1	2	2	5
Winter oilseed rape	1	1	2	4
Spring linseed	1	-	2	3
Spring oilseed rape**	1	1	-	2
Spring oats***	-	2	-	2
Total break crops	6	8	8	22
Total all crops	18	24	24	66

* Replaced two winter triticale crops at Drayton.
** Both crops replaced winter oilseed rape.
*** Grown as a break crop at Drayton.

Table 2.1.5. Summary of the features of the nitrogen and pesticide Current Commercial Practice (CCP) and Low Input Approach (LIA) treatment regimes of TALISMAN.

Pesticide and nitrogen regime	
Current Commercial Practice CCP	**Low Input Approach LIA**
Based on commercial use of nitrogen and pesticides.	Overall pesticide and nitrogen use restricted to 50% of a.i. applied to CCP.
Treatment decisions according to action thresholds or Technical Management Team.	Treatment decisions triggered by CCP and pesticide applied only if estimated loss in crop value exceeded 10%.
Pesticides applied at manufacturers' label recommended rates.	Pesticides omitted or applied at least 50% lower than label rate in CCP.
Optimum fertiliser use determined using ADAS 'Fertiplan'.	Nitrogen fertiliser use 50% less than CCP.
Pesticides selected are those most commonly used according to MAFF survey data.	Same pesticide active ingredients as in CCP.
Crop cultivars (varieties) chosen from top performers on NIAB Recommended Lists.	Same crop cultivars, sowing dates and cultivations as in CCP.

Table 2.1.6. The TALISMAN pesticide sub-treatments. CCP = Current Commercial Practice; LIA = Low Input Approach.

Sub-treatment identity	Pesticide group and treatment regime applied		
	Herbicide	**Fungicide**	**Insecticide**
1. **All High**	CCP	CCP	CCP
2. **All Low**	LIA	LIA	LIA
3. **Low Herbicide**	LIA	CCP	CCP
4. **Low Fungicide**	CCP	LIA	CCP
5. **Low Insecticide**	CCP	CCP	LIA

Table 2.1.7. Summary of pesticide use in cereals, breaks and total crops in TALISMAN. Data given are the average number of pesticide units applied per crop. One pesticide unit equals one full label-rate application of a single active ingredient.

Crop (no. grown)	Pesticide group	CCP	LIA	% reduction in LIA cf. CCP
Cereal crops (46*)	Herbicide	4.20	2.29	45
	Fungicide	2.20	0.70	68
	Insecticide	1.07	0.26	76
	All pesticides	7.47	3.29	56
Break crops (24**)	Herbicide	1.50	0.58	61
	Fungicide	1.00	0.30	70
	Insecticide	0.71	0.25	65
	All pesticides	3.21	1.13	65
All crops(70)	Herbicide	3.27	1.70	48
	Fungicide	1.87	0.59	68
	Insecticide	0.94	0.26	72
	All pesticides	6.08	2.55	58

* Includes two crops of spring barley sown as replacements for winter triticale.
** Includes two crops sown as replacements for winter oilseed rape.

Table 2.1.8. Pesticide use in TALISMAN cereal crops. Data given are the average number of pesticide units applied per crop. One pesticide unit equals one full label-rate application of a single active ingredient.

Crop (no. grown)	Pesticide group	CCP	LIA	% reduction in LIA cf. CCP
Winter wheat (28)	Herbicide	4.11	2.41	41
	Fungicide	3.10	1.00	68
	Insecticide	1.04	0.23	78
	All pesticides	8.25	3.64	56
Winter triticale (8*)	Herbicide	4.25	2.00	53
	Fungicide	0.30	0.00	100
	Insecticide	2.13	0.44	79
	All pesticides	6.68	2.44	63
Spring barley (6**)	Herbicide	5.00	2.50	50
	Fungicide	0.67	0.33	50
	Insecticide	0.33	0.33	0
	All pesticides	6.00	3.16	47
Winter barley (2)	Herbicide	3.50	1.40	60
	Fungicide	3.00	1.15	62
	Insecticide	0.50	0.00	100
	All pesticides	7.00	2.55	64
Spring wheat (2)	Herbicide	3.50	2.00	43
	Fungicide	1.00	0.50	50
	Insecticide	0.00	0.00	0
	All pesticides	4.50	2.50	44

* Includes two failed crops.
** Includes two crops sown as replacements for failed winter triticale.

Table 2.1.9. Pesticide use in TALISMAN break crops. Data given are the average number of pesticide units applied per crop. One pesticide unit equals one full label-rate application of a single active ingredient.

Crop (no. grown)	Pesticide group	CCP	LIA	% reduction in LIA cf. CCP
Winter oilseed rape (6*)	Herbicide	1.17	0.58	50
	Fungicide	0.50	0.00	100
	Insecticide	1.67	0.75	55
	All pesticides	3.34	1.33	60
Spring oilseed rape (2**)	Herbicide	2.00	1.00	50
	Fungicide	1.00	0.00	100
	Insecticide	0.50	0.25	50
	All pesticides	3.50	1.25	64
Winter beans (6)	Herbicide	1.50	0.42	72
	Fungicide	1.70	0.70	59
	Insecticide	0.17	0.00	100
	All pesticides	3.33	1.09	67
Spring beans (5)	Herbicide	1.60	0.40	75
	Fungicide	1.40	0.40	71
	Insecticide	0.40	0.00	100
	All pesticides	3.40	0.80	76
Linseed (3)	Herbicide	1.33	0.67	50
	Fungicide	0.00	0.00	0
	Insecticide	0.33	0.17	48
	All pesticides	1.66	0.84	49
Spring oats (2)	Herbicide	2.00	1.00	50
	Fungicide	1.00	0.50	50
	Insecticide	1.00	0.25	75
	All pesticides	4.00	1.75	56

* Includes two failed crops.

** Two crops sown as replacements for failed winter oilseed rape.

THE AGRONOMIC AND ECONOMIC EFFECTS OF REDUCING NITROGEN FERTILISER USE

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Introduction

Increasing levels of nitrate in water supplies and the aquatic environment are a great cause of concern. A common reaction is to demand that nitrogen fertiliser rates are reduced. Certainly, if excessive fertilisation of crops is avoided (e.g. by better prediction techniques) this can lead to a reduction in nitrate pollution (Sylvester-Bradley & Chambers, 1992; Johnson *et al.*, 1996a). However, it must be realised that nitrate pollution can also derive from mineralisation of organic matter and crop residues at times when it cannot be taken up by actively growing crops. If the nitrogen re-cycling process can be efficiently balanced, the unwanted nitrate contamination of aquifers and water courses can be reduced.

Owing to the shape of the nitrogen (N) response curve, small reductions in N use from the optimum will have very small effects on crop yield and profitability (**Fig. 2.2.1**). However, the same scale of reductions may cause harmful effects on crop quality, particularly grain protein, and this is an important consideration when growing wheat for the bread-making market. Within TALISMAN, a decision was made to reduce nitrogen fertiliser rates by 50% so that measurable effects would be seen clearly and to enable policy-makers to assess the economic and agronomic impact of an 'across-the-board' 50% reduction in nitrogen use. TALISMAN was neither designed nor intended to investigate optimum, cost-effective, nitrogen use.

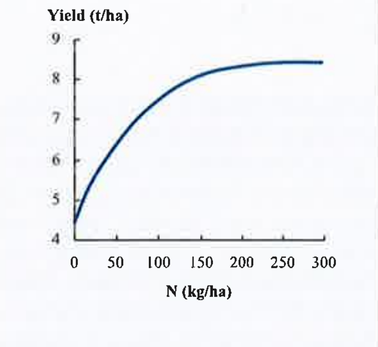

Figure 2.2.1. A typical nitrogen response curve for a responsive crop (e.g. winter wheat).

Current Commercial Practice (CCP) rates of nitrogen were determined by the standard methods used in ADAS Fertiplan. The Fertiplan system is based on information derived from previous cropping history, soil type and yield prediction. Most of the nitrogen recommendations given in Fertiplan are similar to those outlined in MAFF Reference Book 209 '*Fertiliser Recommendations for Arable and Horticultural Crops*' (Anon., 1994). Nitrogen use in the TALISMAN Low Input Approach (LIA) regime was generally adjusted to be 50% of CCP rates.

Crop yield

One of the reasons for including two contrasting rates of nitrogen (CCP and LIA) was to check for the supplementary effects of nitrogen use on crop protection decisions. However, there were few interactions between nitrogen application rate and pesticide regime, and there was no consistency in those that did occur. Therefore, in this chapter, yield data relate only to the two main treatment nitrogen regimes (CCP and LIA) applied throughout TALISMAN.

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

Boxworth

In all three rotations tested (**Table 2.2.1**), yields were normally larger where the CCP nitrogen application was made, with the obvious exception of N-fixing crops such as beans and harvest year 1992 (**Fig. 2.2.2**). In 1992, higher yields were obtained on the LIA-rate nitrogen treatments in all three rotations, thus there was a significant ($P < 0.05$) interaction between year and nitrogen rate for first wheats. This suggests that the nitrogen application rates used in 1992 were too high. Examination of the Soil Mineral Nitrogen (SMN) levels determined in spring 1992 confirmed this suggestion (**Fig. 2.2.3**). The mean SMN figure for the site was 310 kg/ha in the top 90 cm, ranging from 192 kg/ha on the Standard Rotation Phase II LIA-nitrogen plots to 447 kg/ha on the Alternative Rotation Phase I CCP-nitrogen plots. Based on SMN figures, the maximum nitrogen application rate should have been less than 100 kg/ha and on most of the area no nitrogen was required.

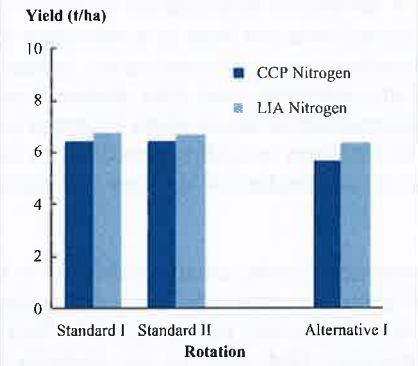

Figure 2.2.2. The effect of nitrogen regime on the yield of first winter wheats at Boxworth in 1992.

The variation in actual N requirement from that predicted can be large (Sylvester-Bradley & Chambers, 1992). Therefore, in hindsight, the discrepancy noted here may not be unusual. The lesson is that if extra evidence is available it should be taken into account in the decision-making process. However, in the broader context, it would be unusual to find an agronomist or soil scientist who would suggest that SMN sampling is carried out routinely in this typical farming situation.

Reductions in yield on the LIA treatments were greatest, and highly significant, with second wheats. The largest loss was, however, experienced in the spring oilseed rape of Standard Rotation Phase I, the overall yield of which was very poor (Chapter 2.8).

Drayton

As at Boxworth, CCP-nitrogen applications at Drayton resulted in higher yields, except in beans and in 1992 (**Table 2.2.2**). SMN levels in both autumn 1990 and autumn 1991 were high, and particularly so in 1990 in Standard Rotation Phase I. This was not reflected in the response of the oilseed rape crop to the CCP-rate of nitrogen. However, this crop has a fairly flat response curve (Chalmers, 1989) and the increase in yield of 0.14 t/ha was not economic. A lower yield of spring oats was recorded on the CCP-nitrogen treatment of Alternative Rotation Phase II, which again indicates excessive applications of nitrogen. All the cereal crops grown in harvest year 1992, except for the triticale of Alternative Rotation Phase I, showed higher yields in the LIA nitrogen treatments. As at Boxworth, there was a significant year/nitrogen rate interaction for first wheats ($P < 0.001$). This again reflected the high SMN levels (ranging from 139 to 206 kg/ha, with a mean of 218 kg/ha) in autumn 1991. The positive response to the application of CCP-rate nitrogen by one of the triticale crops was, in hindsight, unexpected. The loss of yield associated with the LIA-rates of N application was significant for all second wheat crops, averaging 20%. Similarly, in the Standard Rotation first wheats of 1995, there was an average yield loss of 15%. As at Boxworth, the yield of spring oilseed rape was not up to expectation, owing to pigeon damage (Chapter 2.8).

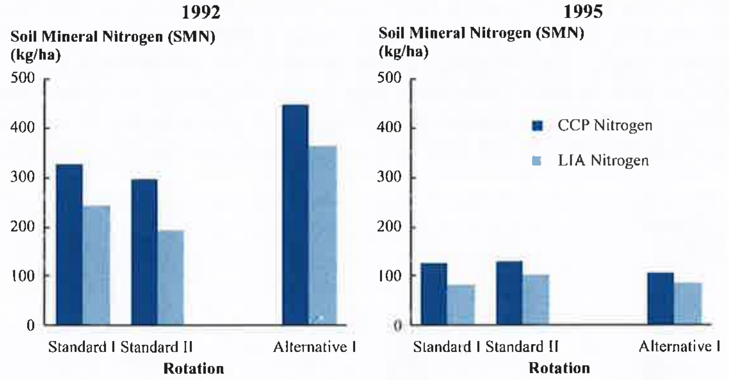

Figure 2.2.3. Soil Mineral Nitrogen levels associated with first winter wheat crops grown at Boxworth in 1992 and 1995.

In the Alternative Rotation, there were significant yield losses in the LIA-nitrogen treatment of cereal crops in both 1995 and 1996 (**Table 2.2.2**). Earlier years were influenced by the very high SMN levels, as discussed above. Where these yield reductions were statistically significant, they averaged 20%.

High Mowthorpe

Unlike the other sites, yields at High Mowthorpe (**Table 2.2.3**) were, with the expected exception of beans and linseed in the Alternative Rotation Phase II in 1994, increased by the application of the CCP-rate of nitrogen, compared with LIA. Linseed is not particularly responsive to the application of nitrogen (Freer & Sansome, 1991), so the lack of response observed in 1994 was not unexpected.

Yield losses associated with the LIA-nitrogen treatment were often significant in the Standard Rotation (except for beans). Cereal yield losses averaged 21% in the LIA compared with the CCP-nitrogen treatment of the Standard Rotation.

However, in the Alternative Rotation, yield losses were smaller and mostly not statistically significant (**Table 2.2.3**). This in part reflects the lower yields and nitrogen responses expected of the spring-sown crops grown.

Nitrogen balance

The Apparent Nitrogen Balance (ANB) was taken to be the difference between the total amount of nitrogen fertiliser applied and the amount of nitrogen removed by each individual crop harvested. Within TALISMAN, a full nitrogen balance could not be calculated, as no measurements were made of N losses by leaching, N deposition from the atmosphere, volatilisation of N from the soil surface following N applications, denitrification losses or the actual fixation of N by leguminous crops. However, a figure for N fixation by winter bean crops of 285 kg/ha (Sylvester-Bradley, 1993) was included in the ANB calculations. For the spring-sown bean crops, owing to the shorter growing season, a lower N fixation figure of 190 kg/ha was used.

At Boxworth, a small negative ANB was recorded in the LIA-nitrogen treatment of Standard Rotation II and Alternative Rotation I (**Fig. 2.2.4**). At Drayton, negative ANBs were recorded in the LIA-nitrogen treatments of both Phases of the Alternative Rotation (**Fig. 2.2.5**). Lower, but positive, ANBs were recorded in the LIA-nitrogen of the other rotations at Drayton. All rotations at High Mowthorpe had positive ANBs (**Fig. 2.2.6**). These apparent differences in nitrogen balance were not reflected in total soil nitrogen values at the end of the experiments at either Drayton or High Mowthorpe. Although it might be claimed that low or negative ANBs will result in excess N being removed from the environment, there are negative aspects to this situation. Long-term reductions in nitrogen use have been shown to result in lower soil organic-matter content (Mihaila & Hera, 1994; Johnson & Chambers, 1996). If soil organic-matter content falls, soil fertility is reduced. A decrease in soil fertility ultimately results in reductions in crop yield and profitability. Furthermore, lowering the organic-matter content of soil can also result in a deterioration in soil structure and an increased risk of soil erosion.

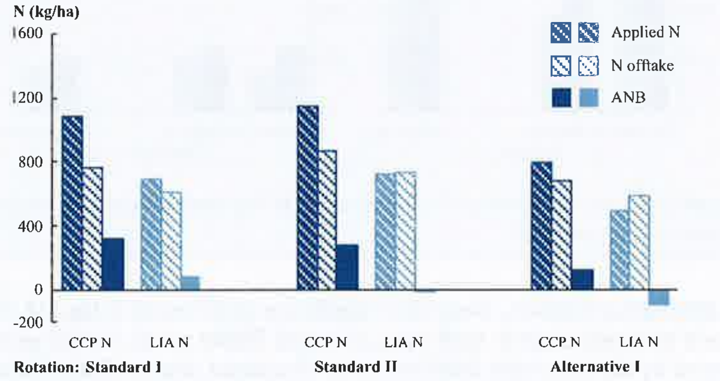

Figure 2.2.4. Apparent Nitrogen Balance (ANB) of the TALISMAN rotations at Boxworth, 1991–1996.

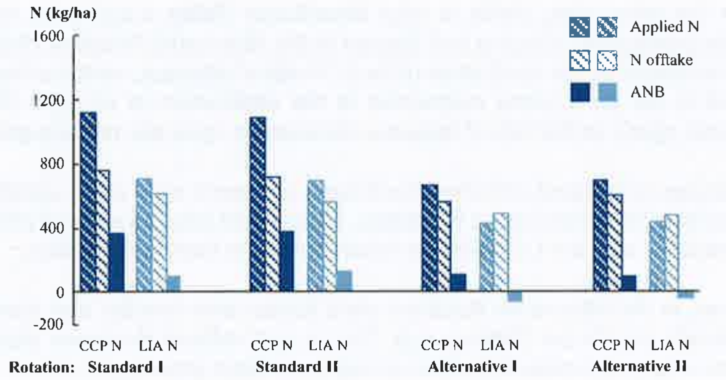

Figure 2.2.5. Apparent Nitrogen Balance (ANB) of the TALISMAN rotations at Drayton, 1991–1996.

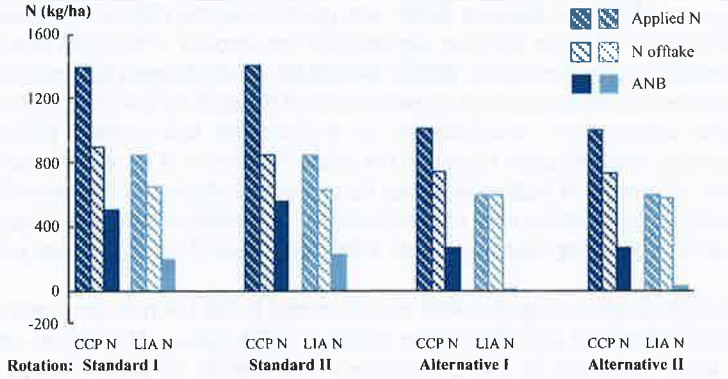

Figure 2.2.6. Apparent Nitrogen Balance (ANB) of the TALISMAN rotations at High Mowthorpe, 1991–1996.

Gross margins

At both Boxworth and Drayton, the mean gross margins were seriously distorted by the problems arising from the excessive use of nitrogen in 1992 (**Table 2.2.4** and **Fig. 2.2.7**). The figures for the other five years (given in parentheses) are probably more representative, though it should be borne in mind that a bean crop was grown at each site (a crop that receives no nitrogen applications).

The gross margins at High Mowthorpe were not distorted by problems with N application rates and are representative of farming in that area. Because of higher yields, particularly of winter wheat, gross margins at High Mowthorpe were greater than at the other two sites on all nitrogen rates and rotations.

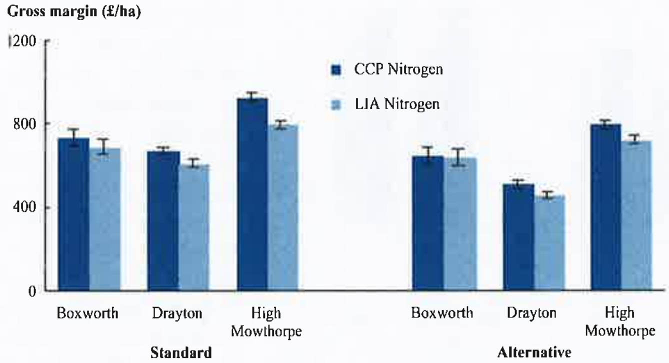

Figure 2.2.7. The effect of nitrogen regime and rotation on mean gross margins for the TALISMAN sites, 1991–1996. Error bars denote SEDs.

However, at all three sites, reducing the rate of N by half in the LIA regime reduced gross margins across all rotations, although only marginally so in the Boxworth Alternative Rotation. Apart from the spring beans, where no nitrogen was required, the Alternative Rotation also featured linseed, which is commonly unresponsive to applications of nitrogen (nitrogen recommendations for this crop have recently been reduced), as is shown by the lack of response of this crop to nitrogen at High Mowthorpe.

With a greater emphasis on lower-yielding spring-sown crops in the Alternative Rotations, it was not surprising that the average gross margins of the Alternative Rotation were lower than those of the Standard Rotation at all three sites. Taken across all three sites, the mean gross margin was reduced by 10% in the Standard Rotations and by 7% in the Alternative Rotations, when the nitrogen rate was cut by half in the LIA regime. The lower mean percentage loss in the Alternative Rotations arises because there was basically no loss at Boxworth as the spring-sown crops grown there showed little response to the CCP-nitrogen regime. The reduction in gross margins of the Standard Rotations was of the same scale as that reported by Johnson *et al.* (1996b) when nitrogen rates were cut by half in a five-course rotation of combinable crops in Lincolnshire.

Crop quality

Protein contents of grain from all first wheat crops were, in most cases, significantly lower where half-rate nitrogen was applied in the LIA treatments, a not unexpected result. However, this did not always affect the sale price of the wheat. At Boxworth, there were no differential treatment effects on the protein content of wheat. Both CCP and LIA always attained similar levels and sale prices remained the same in both treatments at this site.

There were few examples of the LIA-nitrogen treatment affecting gross margins through reductions in crop quality, as opposed to yield. One such example, however, did occur in the winter wheat of the Alternative Rotation at High Mowthorpe in 1992. The grain protein content of the LIA-nitrogen was too low for the crop to be sold as bread-making quality wheat, whereas the CCP-nitrogen treatment exceeded the required protein content of 11% (**Fig. 2.2.8**). Consequently, the Alternative Rotation CCP-nitrogen treatments at High Mowthorpe benefited from a premium (£25/tonne) for sale as milling wheats in 1992. On all other occasions, there was either no premium because protein levels were too low, or both CCP-nitrogen and LIA-nitrogen treatments attracted a milling premium.

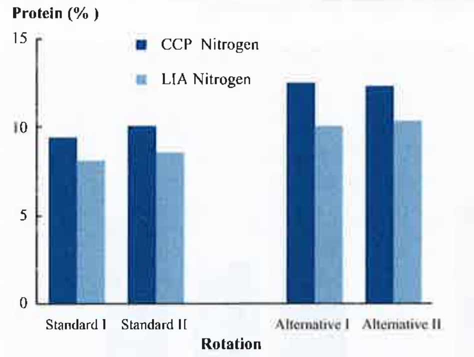

Figure 2.2.8. The effect of nitrogen regime on the protein content of winter wheat at High Mowthorpe, 1992.

Specific weights (bulk density) of wheat grain were significantly higher in the LIA-nitrogen treatments on 50% of the first wheats; again, this was not unexpected because of the excessive levels of N applied or available from soil reserves at Boxworth and Drayton in 1992 (Eagle, 1968). For individual crops, there were few significant nitrogen effects on Hagberg Falling Number (HFN) and Sodium Dodecyl Sulphate (SDS) sedimentation values. Overall, the HFN of first wheats was significantly ($P < 0.001$) lower where LIA-nitrogen was applied (LIA-nitrogen, 326 seconds; CCP-nitrogen, 347 seconds). Value for SDS sedimentation tests was also significantly ($P < 0.001$) lower (LIA-nitrogen, 76.4 ml; CCP-nitrogen, 82.4 ml) in the LIA-nitrogen treatment of first wheat taken overall. The use of standard CCP-nitrogen applications, therefore, produced grain of a higher quality than where LIA-nitrogen was used on first wheats.

Overall, specific weights of the second wheats were significantly higher with CCP-nitrogen than with LIA-nitrogen (77.4 & 76.5 kg/hl; $P < 0.001$). However, in the case of the two spring wheat crops of the Alternative Rotation at Boxworth, the reverse was the case (79.3 & 80.8 kg/hl; $P < 0.001$).

Grain nitrogen content of barley was generally higher with CCP-nitrogen at Drayton and High Mowthorpe, which reflected all previous work on this crop (Garstang *et al.*, 1993). As is normally expected, the oil content of the winter oilseed rape seed was lower where the higher CCP-rate nitrogen (Chalmers, 1989) had been applied (CCP, 42.5%; LIA, 44.5%; $P < 0.001$) and glucosinolate levels were higher. There were no effects of nitrogen on the oil or glucosinolate content of the spring oilseed rape.

Conclusions

The arbitrary 50% reductions in nitrogen use applied in TALISMAN exerted a severe negative effect on yields and gross margins. Furthermore, recent studies have shown that such reductions in nitrogen use do not have a large effect on N losses by leaching (Johnson *et al.*, 1996a) and are not the way forward. Excessive reductions in nitrogen can also have serious long-term consequences for soil sustainability if organic matter levels in the soil become depleted (Johnson & Chambers, 1996).

Improvements in the prediction of the nitrogen fertiliser needs of the crop are required. This point is illustrated by the cases of Boxworth and Drayton in 1992, where high SMN reserves were not detected prior to applying nitrogen. This is probably not uncommon. On the vast majority of farms, soil mineral nitrogen samples are not taken in spring following beans or oilseed rape and, therefore, high SMN levels can remain undetected and high losses of nitrogen into the environment can occur. 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 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 the appropriate use of 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.

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Table 2.2.1. TALISMAN crop yields and nitrogen application rates at Boxworth.

Year	Crop	Yield (t/ha)		Difference	SED	N applied (kg/ha)	
		CCP	LIA	of LIA cf. CCP	(3 d.f.)	CCP	LIA
Standard Rotation Phase I							
1991	W.beans	3.86	3.66	-5%	0.22	0	0
1992	W.wheat	6.42	6.70	+4%	0.06*	190	95
1993	W.wheat	6.55	5.51	-16%	0.07***	170	85
1994	S.OSR	0.94	0.44	-53%	0.13	100	50
1995	W.wheat	8.24	7.62	-7%	0.19*	150	75
1996	W.wheat	9.29	7.53	-19%	0.15***	172	86
Standard Rotation Phase II							
1991	W.OSR	0.84	0.74	-12%	0.12	230	115
1992	W.wheat	6.41	6.70	+5%	0.06*	130	65
1993	W.wheat	6.95	5.97	-14%	0.05***	170	85
1994	W.beans	4.64	4.58	-1%	0.06	0	0
1995	W.wheat	7.81	7.86	+1%	0.05	150	75
1996	W.wheat	9.25	8.12	-12%	0.10**	172	86
Alternative Rotation Phase I							
1991	S.linseed	2.48	2.44	-2%	0.03	80	40
1992	W.wheat	5.62	6.29	+12%	0.17*	170	85
1993	S.wheat	6.41	6.36	-1%	0.25	150	75
1994	S.beans	1.73	1.46	-16%	0.24	0	0
1995	W.wheat	6.77	6.10	-10%	0.27	106	53
1996	S.wheat	5.00	4.67	-7%	0.25	100	50

S, Spring; W, Winter; OSR, Oilseed rape.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 2.2.2. TALISMAN crop yields and nitrogen application rates at Drayton.

Year	Crop	Yield (t/ha)		Difference	SED	N applied (kg/ha)	
		CCP	LIA	of LIA cf. CCP	(2 d.f.)	CCP	LIA
Standard Rotation Phase I							
1991	W.OSR	2.55	2.41	-5%	0.10	230	115
1992	W.wheat	7.40	7.86	+6%	0.29	90	45
1993	W.wheat	7.11	5.31	-25%	0.37*	170	85
1994	W.beans	4.03	3.97	-1%	0.13	0	0
1995	W.wheat	9.48	8.39	-11%	0.06**	170	85
1996	W.wheat	8.62	7.35	-15%	0.14*	165	82
Standard Rotation Phase II							
1991	W.beans	4.20	4.07	-3%	0.07	0	0
1992	W.wheat	7.04	7.76	+10%	0.25	145	72
1993	W.wheat	7.50	5.56	-26%	1.06	180	75
1994	S.OSR	0.49	0.16	-67%	0.18	130	65
1995	W.wheat	9.15	7.28	-20%	0.44	170	85
1996	W.wheat	8.74	7.35	-16%	0.21*	165	82
Alternative Rotation Phase I							
1991	S.beans	3.78	3.77	0%	0.07	0	0
1992	W.triticale	5.16	5.05	-2%	0.13	65	32
1993	S.barley	5.61	5.24	-7%	0.09	140	70
1994	S.oats	3.82	3.55	-7%	0.27	90	45
1995	W.triticale	5.59	4.45	-20%	0.09**	90	45
1996	W.triticale	6.22	4.88	-21%	0.10**	90	45
Alternative Rotation Phase II							
1991	S.oats	5.71	5.94	+4%	0.24	90	45
1992	W.triticale	4.80	5.37	+12%	0.48	90	45
1993	S.barley	7.00	5.20	-26%	0.28*	140	70
1994	S.beans	2.67	2.18	-18%	0.51	0	0
1995	W.triticale	6.09	4.78	-21%	0.13**	90	45
1996	W.triticale	6.28	4.68	-25%	0.06**	90	45

S, Spring; W, Winter; OSR, Oilseed rape.

* $P < 0.05$.

** $P < 0.01$.

Table 2.2.3. TALISMAN crop yields and nitrogen application rates at High Mowthorpe.

Year	Crop	Yield (t/ha)		Difference	SED	N applied (kg/ha)	
		CCP	LIA	of LIA cf. CCP	(2 d.f.)	CCP	LIA
Standard Rotation Phase I							
1991	W.OSR	3.91	3.07	-21%	0.15*	220	110
1992	W.wheat	9.32	7.31	-22%	0.37*	192	95
1993	W.wheat	9.48	7.38	-22%	0.43*	250	125
1994	W.beans	4.98	4.81	-3%	0.13	0	0
1995	W.wheat	9.15	6.72	-27%	0.35*	250	125
1996	W.barley	9.45	7.60	-20%	0.24*	183	91
Standard Rotation Phase II							
1991	W.beans	4.61	4.79	+4%	0.26	0	0
1992	W.wheat	9.22	8.40	-9%	0.74	214	107
1993	W.barley	7.89	6.11	-23%	0.47	200	80
1994	W.OSR	3.81	3.33	-13%	0.14	228	114
1995	W.wheat	8.31	6.97	-16%	0.50	240	120
1996	W.wheat	7.56	5.22	-31%	0.44*	223	111
Alternative Rotation Phase I							
1991	S.linseed	2.16	2.02	-6%	0.09	75	40
1992	W.wheat	8.42	7.85	-7%	0.32	229	108
1993	S.barley	5.56	5.65	+2%	0.45	150	75
1994	S.beans	4.48	4.57	+2%	0.12	0	0
1995	W.wheat	8.40	7.58	-10%	0.21	250	125
1996	S.barley	5.51	4.62	-16%	0.09**	110	55
Alternative Rotation Phase II							
1991	S.beans	4.21	4.25	+1%	0.24	0	0
1992	W.wheat	8.77	7.95	-9%	0.21	214	107
1993	S.barley	5.95	5.17	-13%	0.41	150	75
1994	S.linseed	1.38	1.39	+1%	0.10	75	37
1995	W.wheat	8.32	7.28	-12%	0.04**	260	130
1996	S.barley	5.85	4.54	-22%	0.20*	110	55

S, Spring; W, Winter; OSR, Oilseed rape.

* $P < 0.05$.

** $P < 0.01$.

Table 2.2.4. The effect of nitrogen regime on the average gross margins of the TALISMAN crop rotations, 1991–1996 (£/ha). Figures in parentheses exclude data from 1992 first wheats, see text.

Site	Rotation	CCP-nitrogen	LIA-nitrogen	SED	Loss (%) from LIA-rate N
Boxworth					
	Standard	732 (795)	688 (726)	27.8	6 (9)
	Alternative	645 (708)	639 (675)	39.4	1 (5)
Drayton					
	Standard	669 (699)	608 (603)	18.7	9 (14)
	Alternative	506 (550)	455 (478)	18.7	10 (13)
High Mowthorpe					
	Standard	925	792	19.8*	14
	Alternative	794	718	19.8*	10
Mean					
	Standard	775	696	na	10
	Alternative	648	604	na	7

na, not applicable.
* $P < 0.05$.

WEED CONTROL: THE AGRONOMIC AND ECONOMIC EFFECTS OF REDUCING HERBICIDE USE

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Introduction

Maintaining a high standard of weed control in arable crops is of great importance as weed infestations can ultimately lead to severe or total loss of crop. Weeds need to be removed from crops to avoid competition between crop and weed for space, nutrients, water and light. The control of weed populations also reduces a potential source of certain pests and diseases, facilitates harvesting and helps maintain crop quality. Furthermore, the long-term implications of lapses in weed control are of major importance. The traditional saying of 'one year's seeds, seven year's weed' has never been more true. The prevention of weed 'seedbanks' building up in the soil is a vital part of the overall strategy of weed control in arable crops.

The use of herbicides must be regarded as a long-term strategy throughout the crop rotation, rather than as specific treatments for problems in individual crops and years. The choice of herbicide is influenced by many factors – including price, soil type, weed size and spectrum, cultivations, weather conditions, method of straw disposal, crop rotation, crop growth stage and vigour.

The effect of weeds on crops has been quantified but only to a limited degree. In winter wheat, the level of yield loss resulting from weed infestations can be assessed by using the concept of 'crop equivalents' (Wilson & Wright, 1990). A 'crop equivalent' is the number of weeds present in a crop that will cause a 2% loss of yield. Low populations of very competitive weeds (e.g. cleavers, *Galium aparine*) can lead to sizeable yield losses, but greater numbers of less competitive weeds (e.g. field pansy, *Viola arvensis*) can be tolerated (**Table 2.3.1**). A similar ranking of the competitiveness of weeds in winter oilseed rape has also been developed (Lutman *et al.*, 1995)

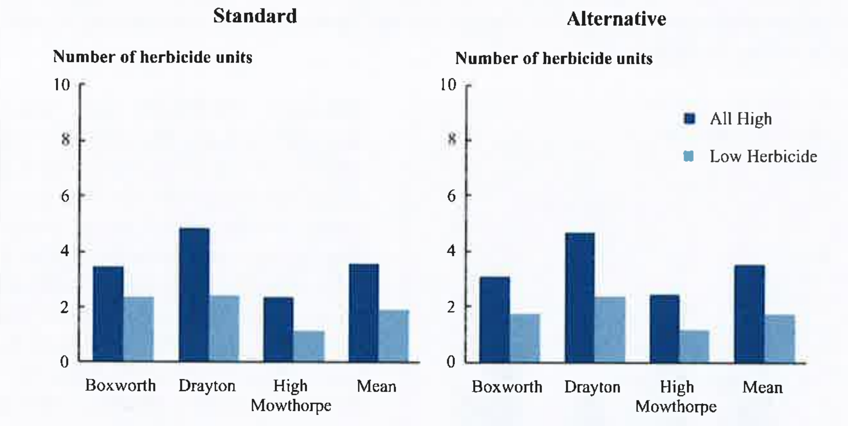

Figure 2.3.1. Herbicide units used per year in each rotation at each site (one herbicide unit = 1 full-rate application of a single active ingredient).

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.

Opportunities for reducing pesticide use in cereal-based rotations have been demonstrated previously by Proven *et al.* (1991), and in the Boxworth Project (Greig-Smith *et al.*, 1992). This chapter examines the effects of reducing herbicide doses on weed populations, yield and gross margins in rotations involving six years of cropping at three sites in the TALISMAN experiment.

Herbicide inputs

Herbicide use was tailored to individual sites as these were located in contrasting geographical areas, each with a specific soil type and a unique weed flora. The weed flora are detailed later in this chapter and weed seedbanks are discussed in Chapter 2.4. Thresholds were infrequently used as an aid for decision making for weed control, as few were available. Decisions were made by the Site Managers in consultation with the Technical Management Team (Chapter 2.1), taking into account the factors previously described in the introduction. The product choice was, where possible, typical of those most frequently used as indicated by the most recent MAFF Pesticide Usage Survey Report (e.g. Thomas *et al.*, 1997).

In both the Standard and the Alternative Rotations, mean herbicide usage, in terms of number of active ingredient units applied, was decreased by 48% in the LIA compared with CCP (**Fig. 2.3.1**). Total herbicide use was similar for both rotations. Although the Alternative Rotation was designed to have a lower requirement for pesticides through the inclusion of spring cropping, there was no marked reduction in herbicide use in the Alternative Rotation compared with the Standard Rotation (**Table 2.3.2**). Each crop, whether winter or spring sown, received a similar number of herbicides to control both grass and broad-leaved weeds.

The target 50% reduction in herbicide use in TALISMAN was attained almost exclusively by cutting the dose-rate of herbicides in the LIA regime, rather than by entirely omitting applications. Therefore, in the majority of instances, the full-rate application of a herbicide in the CCP regime was mirrored by an equivalent application of the same a.i. in the LIA but at least 50% below the label rate used in the CCP.

The greatest amount of herbicide, in both rotations, was used at Drayton and the least at High Mowthorpe (**Fig. 2.3.1**). At both of these sites, reductions of approximately 50% were made in the LIA of both rotations. However, at Boxworth, black-grass was known to be a major problem. The use of full label rate isoproturon (IPU) was, therefore, permitted at this site to prevent the black-grass population from becoming unmanageable. Consequently, herbicide use was reduced by only 36% in the LIA regime at Boxworth.

Although TALISMAN was partly designed to study the effects of crop rotation, it is of interest to look at herbicide usage in the individual crops. In the major crop groups (**Fig. 2.3.2**), the greatest number of units of herbicide was applied to the cereals and less than 50% of this amount to the break crops. A full 50% reduction in herbicide use in the LIA was not achieved in winter wheat (actual reduction: 41% – mean of all sites) owing to the full-rate use of IPU at Boxworth. However, in the break crops, a decrease of 61% (mean of all sites) was obtained.

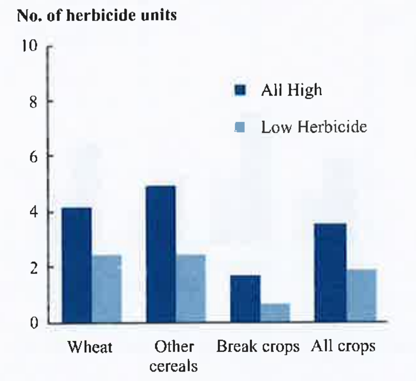

Figure 2.3.2. Number of herbicide units applied per crop group – mean of all sites and rotations 1991–1996 (herbicide units/year).

In the Standard Rotation, herbicide use was greatest at Drayton, in both the wheat and break crops (**Table 2.3.2**). In the Alternative Rotation, herbicide use in wheat was lower than in the Standard Rotation, due to lower usage of IPU and spring broad-leaved weed herbicides. However, herbicide use in the Alternative Rotation break crops was similar to the Standard Rotation, despite all crops being spring-sown. Each break crop generally received individual herbicides for both broad-leaved and grass weed control. At Drayton, herbicide use was high on both winter triticale and spring barley, owing to problems with wild-oats (*Avena* spp.) and other grass weeds.

Thirty different herbicide active ingredients were used on 11 crops during the course of TALISMAN. The most commonly used herbicides were IPU and diflufenican (DFF), which were used principally as a tank mix for broad-spectrum weed control in winter wheat (**Table 2.3.3**). Simazine was the main herbicide used on beans, whereas cycloxydim was used most often for grass weed control on break crops.

In the Standard Rotation, the range of crops grown at each site was similar, and this was reflected in the similarities between the herbicides used. Boxworth and Drayton used IPU and DFF to a greater extent than High Mowthorpe. The use of the spring-applied contact herbicides ioxynil, bromoxynil and mecoprop (for broad-leaved weed control) was greater at Drayton and High Mowthorpe owing to the weed flora present at these sites.

Assessing changes in commercial herbicide use

Since TALISMAN began, there have been changes in herbicide use on farms which, to some extent, can be assessed using information available in the MAFF Pesticide Usage Survey Reports (PUSRs) (Davies *et al.*, 1991; Thomas *et al.*, 1997). The 1996 PUSR survey data show that the number of herbicide spray rounds applied increased slightly in comparison with 1990 by 0.3 (a spray round being defined as a single pass of a sprayer containing one or more active ingredients) (**Table 2.3.4**). The number of TALISMAN herbicide spray rounds was similar to the PUSR figures. However, a greater number of spray rounds was made to the winter triticale and spring barley in TALISMAN, owing to the problems encountered with grass weeds at Drayton. A similar pattern emerged in the number of active ingredients (a.i.s) applied, including repeat applications of the same a.i. (**Table 2.3.5**). In this case, there was an increase of 0.6 a.i.s applied per crop from 1990 to 1996. Overall, there has been a greater increase in the number of a.i.s applied to crops than in the number of applications made. This increase can, in part, be attributed to large increases in herbicide use in triticale and linseed.

Before proceeding to discuss dose-rates, a note of caution. The findings of the PUSR must be viewed in context since the data are complicated by the way in which the average rates of use are calculated. Additionally, the majority of herbicides have a dose-rate linked to specific weed targets; this dose-rate can also be altered by factors such as weed size, date of application, soil type and options for tank-mixing with other herbicides. Taking isoproturon in winter wheat as an example, application rates can range from 1500 g a.i./ha to 2500 g a.i./ha depending on whether the target is annual meadow grass or black-grass. Information from the survey will therefore be an average working dose for a range of local circumstances. Other factors to be considered are a general switch in the industry towards using more complicated tank mixtures which involve lower rates of a wider range of herbicides. Also, in some cases, existing a.i.s have been reformulated using a more biological active isomer of the same a.i. (e.g. mecoprop and fenoxaprop).

Since the inception of TALISMAN in 1990, there has been an increasing tendency by farmers to apply herbicides at rates less than those recommended on the manufacturers' product labels (label rates); in addition, tank mixes of herbicides are more common (i.e. more a.i.s used). These trends are confirmed by the PUSR data (**Tables 2.3.5 & 6**).

There has also been a general decrease in mean dose-rates applied, as indicated by the PUSR data (**Table 2.3.6**). Examination of the major cereal herbicides indicated that their rate reductions varied from 0% to 40% when compared with the average label rate in 1990 and 19% to 67% in 1996 (**Table 2.3.6**). Isoproturon remains one of the most commonly used herbicides in cereals and the PUSR data show that the dose-rate of this a.i. decreased by 10% in wheat between 1990 and 1996. In contrast, the greatest reductions were apparent in the diflufenican/isoproturon mixtures, where rate reductions amounted to 32% over the same period. This herbicide, along with fenoxaprop-ethyl, mecoprop-P and bromoxynil/ioxynil, are preferred components of tank-mixes. We can conclude from this evidence that whilst the full label rates of CCP did not fully reflect the true commercial situation, the 50% decrease in herbicide label rates applied in LIA nevertheless represented a greater reduction than commercial practice.

Weed populations

Through the six years of TALISMAN, weed numbers could have been influenced by a range of factors such as herbicide choice, weed seedbank populations, reduced rates of herbicide, lower nitrogen rates and crop competition. Herbicide product choice was similar to that commonly used in the UK and did not differ between CCP and LIA, as discussed in the previous section. Seedbank populations were monitored throughout the period of the experiment and the results are discussed in the following chapter (2.4) .

The effect of reducing herbicide rates

In the Standard Rotation, weed numbers reached greater populations at High Mowthorpe and Boxworth (up to 100 weeds/m^2) than at Drayton (up to 60 weeds/m^2). At all sites, weed numbers increased during the course of the Standard Rotation (**Fig. 2.3.3**). At Boxworth and High Mowthorpe, there were some significant differences in populations (20–50 weeds/m^2) between the All High and Low Herbicide sub-treatments, with higher numbers on the Low Herbicide treatment. At Drayton, weed numbers were generally significantly higher in the Low Herbicide sub-treatment ($P < 0.05$).

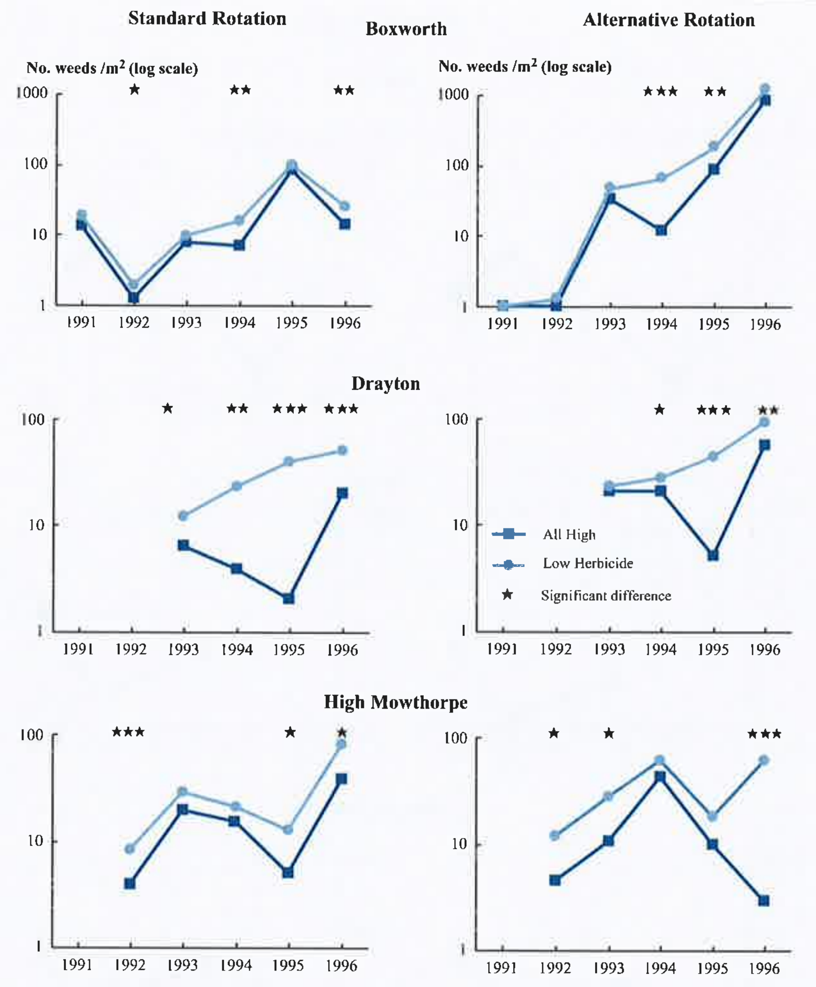

Figure 2.3.3. Total weed numbers for All High and All Low herbicide treatments in the Standard and Alternative Rotations – mean of all crops and nitrogen rates. Significant differences: ★ $P < 0.05$; ★★ $P < 0.01$; ★★★ $P < 0.001$.

Weed numbers tended to be slightly higher in the Alternative Rotation than in the Standard Rotation. Numbers were greater at Boxworth than at the other two sites (**Fig. 2.3.3**). As in the Standard Rotation, weed numbers tended to increase through the life of the Alternative Rotation. At Boxworth, there were only differences in weed populations between the All High and Low Herbicide in 1994 and 1995 ($P < 0.05$). At Drayton, again, weed numbers increased through the rotation but numbers were significantly greater only at the Low Herbicide rate in 1994, 1995 and 1996 ($P < 0.05$). Weed populations at High Mowthorpe tended to be higher in the Low Herbicide treatment throughout the whole rotation, significantly so in 1992, 1993 and 1996 ($P < 0.05$).

The effect of nitrogen and herbicide rate on weed populations

In the Standard Rotations at Boxworth and High Mowthorpe, the Low Herbicide sub-treatment usually had higher weed populations than the All High Herbicide, at both levels of nitrogen, but this was only significant in some years (**Fig. 2.3.4**). However, at Drayton the difference in weed numbers between the two herbicide treatments was greater at the CCP rate of nitrogen.

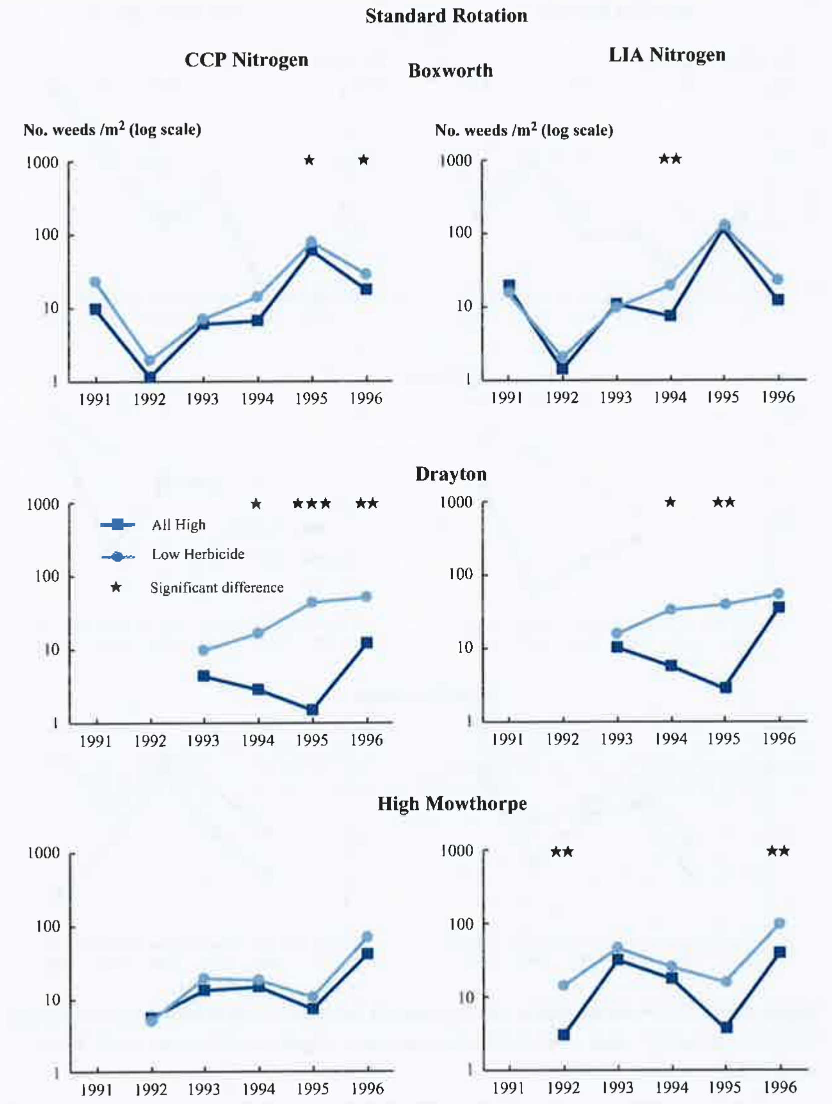

Figure 2.3.4. Total weed numbers for All High and All Low herbicide treatments in the Standard Rotation, at CCP and LIA nitrogen rates. Significant differences: ★ $P < 0.05$; ★★ $P < 0.01$; ★★★ $P < 0.001$.

In the Alternative Rotation, weed numbers followed a similar pattern to that of the Standard Rotation (**Fig. 2.3.5**). There was little difference between the weed numbers at the different nitrogen levels at any of the sites, although there were significant differences between some of the All High and All Low herbicide comparisons.

Herbicide effects on yields and gross margins

During the six-year term of TALISMAN, 66 crops were taken to harvest. Significant yield losses occurred in eight individual situations and these are discussed in the site scenarios below. When meaned across all crops, the use of low herbicide rates reduced the yield of break crops by 4%, but the yield differences resulting from low herbicide use varied from -41% to +32% according to the type of break crop grown (**Table 2.3.7**). The break crop least affected was winter beans, in which yields were increased by up to 4% in the Low Herbicide sub-treatment. From the cross-site means, yields were significantly lower in winter oilseed rape and spring beans ($P < 0.05$) at the low herbicide rate, but this was not the case at each site. Similar results have been reported previously (Cook *et al.*, 1991; Heath *et al.*, 1991).

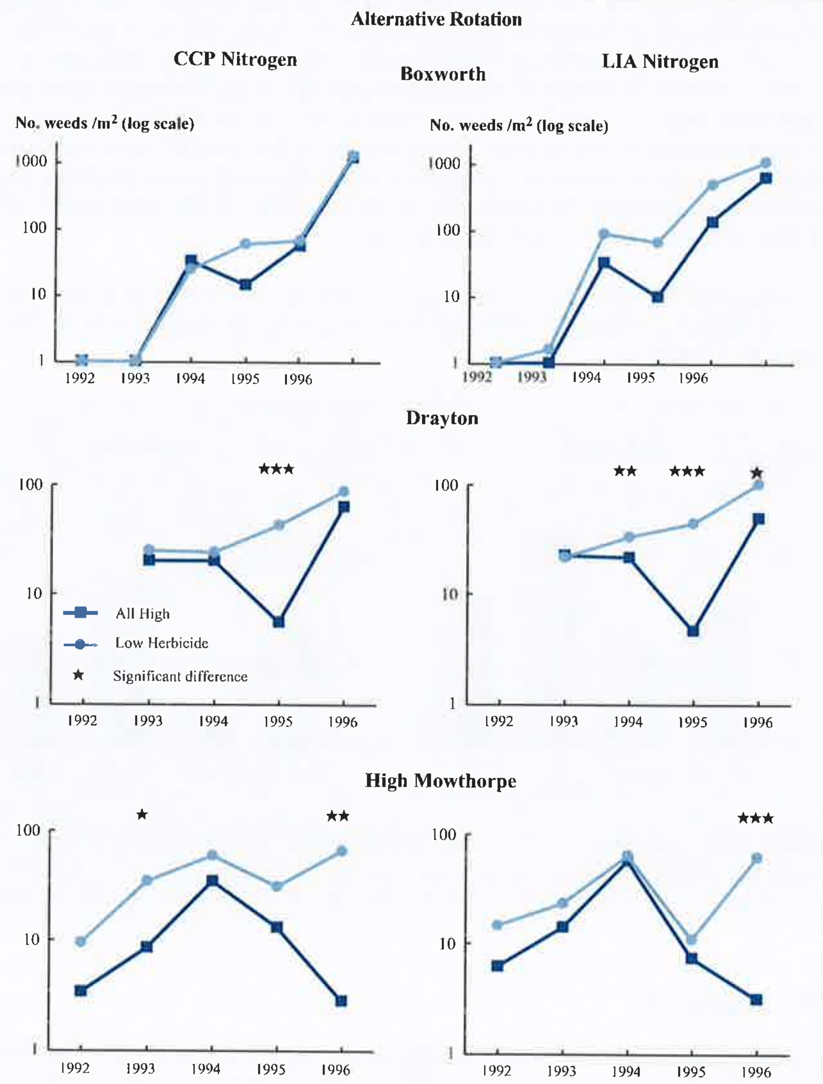

Figure 2.3.5. Total weed numbers for All High and All Low herbicide treatments in the Alternative Rotation, at CCP and LIA nitrogen rates. Significant differences: ★ $P < 0.05$; ★★ $P < 0.01$; ★★★ $P < 0.001$.

In general, cereals were relatively unaffected by decreasing the herbicide rate used (**Table 2.3.8**). Although at High Mowthorpe, yields of both first and second wheats were significantly lower in the All Low herbicide sub-treatment. The yield of spring wheat at Boxworth was also significantly affected, possibly because the weeds tended to emerge at the same time as the crop, and competition between crop and weed was severe in some cases.

Reductions in yield were usually compensated for by a reduction in pesticide costs; this was reflected in generally improved gross margins (**Tables 2.3.9 & 10**). At a site level, the gross margin of wheat was significantly increased at Drayton ($P < 0.05$), marginally increased at Boxworth but significantly reduced at High Mowthorpe by the Low Herbicide treatment. In the break crops, significant increases in gross margin (up to 11%) were seen in the winter beans ($P < 0.05$) at

Boxworth and Drayton. From the 66 crops taken to harvest, 12 significant increases in gross margin were noted and five significant decreases ($P < 0.05$); these results are discussed in the context of the individual sites below.

Across both rotations, cereal gross margins in the Low Herbicide sub-treatment were significantly increased at Drayton by 9% ($P < 0.05$), but were unaffected at Boxworth and High Mowthorpe (**Table 2.3.11**). Across all sites, there was a 2% (£13/ha) increase in the cereal crop gross margin ($P < 0.05$). Although some break crops were more susceptible to yield and gross margin effects from the Low Herbicide treatment, there were no significant differences in the overall gross margin, probably as a result of the variation within the results. Over all crops, gross margins were again significantly higher at Drayton (8%, £41/ha) and as a mean of all sites (2%, £11/ha) ($P < 0.05$; **Table 2.3.11**).

At a rotational and site level, gross margins were also increased at Drayton (8%) but unaffected at Boxworth and High Mowthorpe by the reduction in herbicide inputs (**Fig. 2.3.6**).

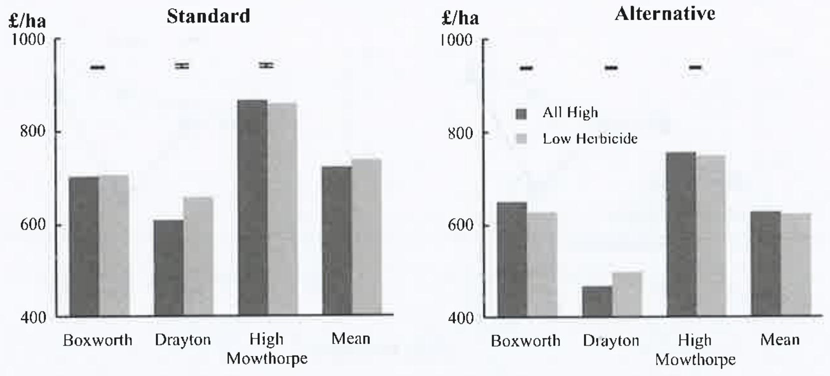

Figure 2.3.6. Gross margins for the Standard and Alternative Rotations – mean of nitrogen rates (£/ha). Error bars denote SEDs.

Site scenarios

Each site was unique in terms of weeds and herbicide use, but the effect of the TALISMAN treatments was broadly similar. In this section, site specific effects are detailed and discussed.

Boxworth

At Boxworth, the main weedswere black-grass (*Alopecurus myosuroides*), speedwells (*Veronica* spp.) and cleavers in the Standard Rotation and black-grass, cereal volunteers, fools' parsley (*Aethusa cynapium*), knotgrass (*Polygonum aviculare*), black bindweed (*Bilderdykia convolvulus*) and fat-hen (*Chenopodium album*) in the Alternative Rotation. At this site, because of the presence of black-grass, full label rates of black-grass herbicides were used in both LIA and CCP treatments.

Populations of cleavers at Boxworth increased annually in Phase I of both the Standard and Alternative Rotations but not in Standard Rotation Phase II (**Fig. 2.3.7**). Numbers were always greater at the LIA nitrogen level. The use of half-rate herbicides coupled with low nitrogen levels resulted in a steady increase in numbers of cleavers in less-competitive crops such as winter beans. In the Alternative Rotation, the addition of spring cropping prevented the steady build up of cleavers but numbers were still higher in the LIA nitrogen treatment.

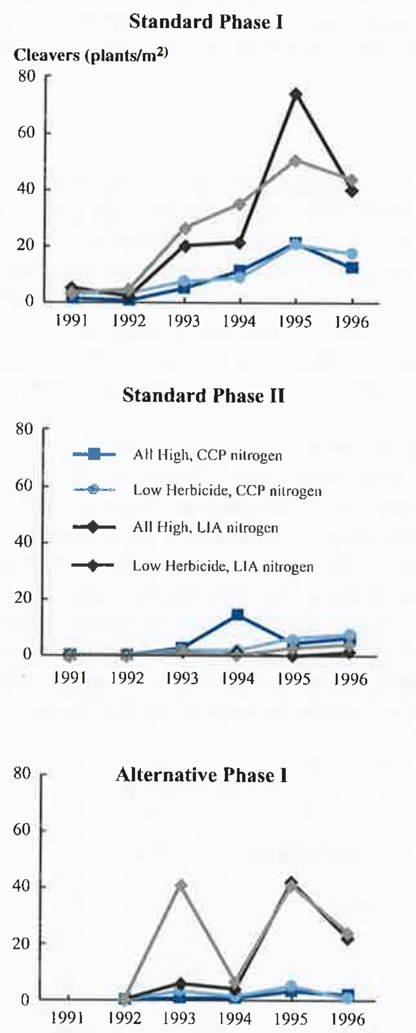

Figure 2.3.7. Populations of cleavers in the CCP and LIA nitrogen regimes of Standard Rotation Phases I and II and Alternative Rotation Phase I at Boxworth, 1991—1996.

At this site, there were only four instances where there was a significant ($P < 0.05$) yield decrease due to a reduction in herbicide use. The severest yield and gross margin reduction occurred in 1991 in the oilseed rape (£78/ha penalty). This was the result of a poorly established crop of winter oilseed rape, coupled with insufficient control from a reduced rate of fluazifop-P-butyl (**Table 2.3.12**). The cereal volunteers competed with the crop and yield was decreased by 61%. This confirms the results of previous work (Ogilvy, 1989). The following crop of winter wheat yielded significantly ($P < 0.05$) less in the Low Herbicide sub-treatment, probably due to the heavy burden of volunteer cereals in the previous crop of rape either removing a high level of nitrogen or allowing take-all to survive on the wheat volunteers through the break-crop.

In 1994, the winter rape crop failed due to slug attack and this was replaced by spring oilseed rape. The spring crop established poorly and pigeon damage was a problem; therefore, crop competitiveness was reduced. Weed populations were significantly higher in the Low Herbicide sub-treatment ($P < 0.05$). Weed control from the herbicides (half-rate benazolin, clopyralid and fluazifop-P-butyl) and crop competition were poor. Yields were decreased by 33% but the gross margin was less affected owing to the low-yielding crop (**Table 2.3.13**).

In the Alternative Rotation, in 1996, spring wheat had a high population (up to 1200/m²) of orache (*Atriplex patula*), scarlet pimpernel (*Anagallis arvensis*), charlock (*Sinapis arvensis*) and black-bindweed (**Table 2.3.14**). These weeds were not adequately controlled by half-rate bromoxynil, ioxynil and mecoprop. Yield and gross margin were subsequently decreased by 1.1 t/ha (21%) and £126/ha (16%), respectively ($P < 0.05$).

Drayton

At Drayton, herbicide applications were the highest of all the three sites. In some crops, herbicide usage was twice that of the other sites (**Table 2.3.2**). In addition to this, in the Standard Rotation, overall applications of either paraquat or glyphosate were made pre-drilling in 1993 and 1995 respectively, resulting in complete control of emerged weeds. The use of these full-rate broad-spectrum herbicides coupled with intensive use of herbicides had an effect on limiting or slowing the build up of weed seeds in the seedbank (Chapter 2.4). There were no significant yield effects from reducing herbicide use at Drayton. Relatively small yield increases led to significant ($P < 0.05$) increases in gross margins of 4% in break crops and 9% in cereals, as a result of large savings in herbicide costs from the LIA herbicide rate.

High Mowthorpe

The predominant weed at High Mowthorpe was poppy (*Papaver rhoeas*). Numbers were generally low in all rotations until 1993 when winter barley was grown in Standard Rotation Phase II, and spring barley in the Alternative Rotation. In both instances, poppy was not controlled and seed return to the seedbank was high. When poppies were present they were not controlled by successive low herbicide doses (**Fig. 2.3.8**). The increase in poppy populations was also clearly recorded in the seedbank study (Chapter 2.4). Grass weeds were not a problem at this site but there was a wide spectrum of spring-germinating annual broad-leaved weeds.

At this site, there were four cases where yields were significantly decreased by LIA herbicide use. Winter barley, cv. Fighter, was grown twice during the Standard Rotation. In the first crop, a yield decrease of 0.62 t/ha (8%) was seen in 1993 ($P < 0.05$). Bromoxynil, ioxynil and mecoprop were applied at full (196; 196; 1568 g a.i./ha, respectively) and at half rate to the All High and Low Herbicide sub-treatments, respectively. Weed populations, mainly poppy, cleavers and forget-me-not (*Myosotis arvensis*), were higher with the Low Herbicide (**Table 2.3.15**) and the gross margin was subsequently reduced by £50/ha (7%) ($P < 0.05$). In the second crop in 1996, poppies were well controlled by an autumn application of IPU and DFF and a spring application of metsulfuron-methyl and fluroxypyr.

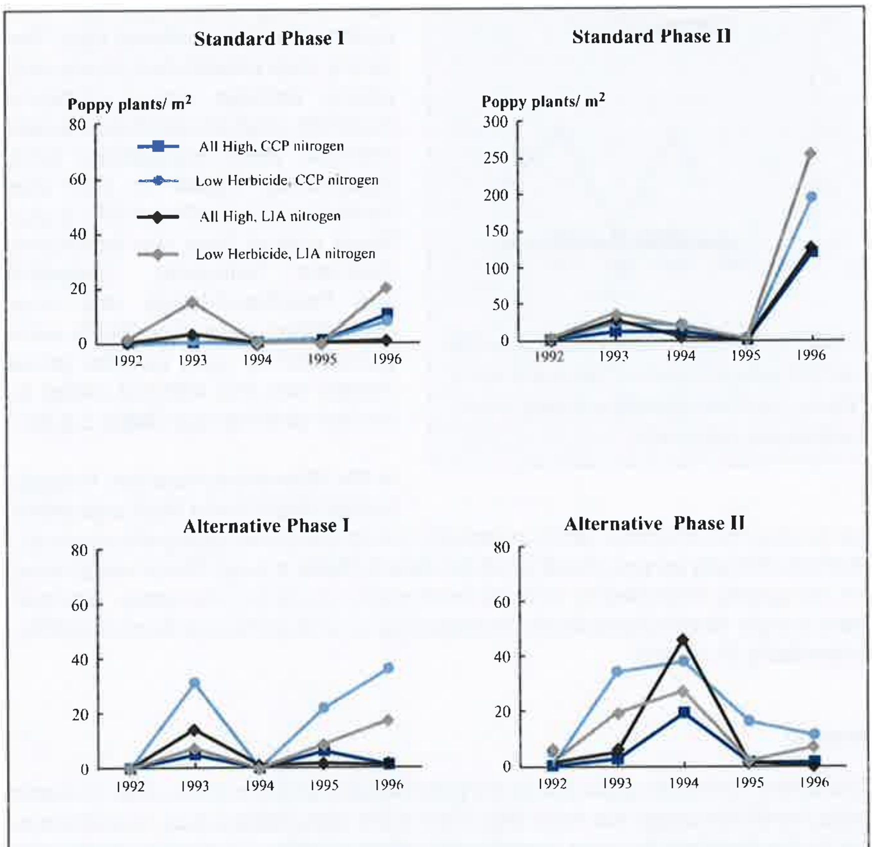

Figure 2.3.8. Poppy populations in the CCP and LIA nitrogen regimes of the Standard and Alternative Rotations (Phases I and II) at High Mowthorpe from 1991–1996.

In 1995, in winter wheat cv. Hereward, IPU and DFF were applied in the autumn at 1000 and 100 g a.i./ha respectively to the All High and 40% of this rate to the Low Herbicide sub-treatments. Control of weeds was poor in the Low Herbicide treatment and spring weed counts of mainly cleavers and poppy were up to 32 plants/m^2 (**Table 2.3.16**). There was a significant yield decrease of 5% or 0.5 t/ha ($P < 0.05$) and the gross margin was decreased by £35/ha. A similar situation occurred in 1996, in winter wheat cv. Buster. Identical rates of IPU and DFF were applied during November to the crop; poppy numbers were much higher (up to 150 plants/m^2) and the number of cleavers averaged 15/m^2 in the Low Herbicide treatment (**Table 2.3.17**). Yield was decreased by 1.06 t/ha (15%) and gross margin by £63/ha ($P < 0.05$).

Yield was decreased in spring barley in one year out of the four it was grown at this site. Spring barley (cv. Cooper) was drilled in April 1996 and received bromoxynil, ioxynil and mecoprop on 6 June. Full rate (196; 196; 1568 g a.i./ha, respectively) was used on the All High but only 25% of this rate on the Low Herbicide treatment. A combination of cleavers, chickweed (*Stellaria media*), black bindweed and poppy was present at a population of 75/m^2 (**Table 2.3.18**). Yield was decreased by 0.3 t/ha (7%) ($P < 0.05$) but gross margin was not significantly affected.

Discussion

Since the start of the TALISMAN Project, there has been a clear commercial trend to apply herbicides at less than the manufacturers' full label-recommended rates. Nevertheless, the LIA rates of herbicide use adopted in TALISMAN, which were mostly at least 50% less than the full label rate, continued to represent a real reduction in herbicide use compared with on-farm practices.

The move to lower than label-recommended rates has become known as the 'appropriate dose' strategy. Cost savings can be made by reducing herbicide rates in line with local weed pressure but full rates can be used when necessary. In this way, herbicide dose is customised to local needs. Financial returns are then maximised through savings in herbicide costs, whilst maintaining weed populations at manageable levels.

TALISMAN has shown that it is possible to successfully reduce the rates of herbicides to at least 50% of their full recommended rate for most weed targets in many situations. There was no consistent indication that overall weed numbers increased to a greater extent under the Low Herbicide regime or at the LIA rate of nitrogen over the full course of the TALISMAN rotations. Nevertheless, 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 not an entirely unexpected observation and has been noted by other workers (Proven *et al.*, 1991; Easson *et al.*, 1996).

When weed plants are able to survive, the return of weed seeds to the soil is inevitably increased. The weed seedbank study (Chapter 2.4) indicated that weed seed numbers were initially low but both rotation and herbicide inputs had strong effects. In the Standard Rotation, the CCP herbicide treatments kept the seedbank at these initial levels. The relaxation of herbicide management in the LIA regime caused the seedbanks (the characteristics of which were unique to each site) to increase. At Drayton, where herbicide inputs were always higher than at the other sites, weed seedbank populations remained low in both Rotations in both CCP and LIA herbicide regimes. At Boxworth, weed populations were maintained at a low level in both Rotations until 1993, following which, numbers increased dramatically in the Alternative Rotation, mainly as a result of the spring-sown crops. In contrast, at High Mowthorpe, although weed populations were consistently greater in the LIA regime than in the CCP regime, their numbers showed only a slight increase through the full course of the rotation, whilst, in comparison, the weed seedbank population increased dramatically (Chapter 2.4).

Yield losses owing to weeds did occur, and these were exacerbated where crop competition was lowered by other factors such as poor crop establishment and pigeon damage. Low nitrogen rates tended to reduce both weed and crop vigour, although these effects tended to cancel each other out. There were some instances where weed populations were greater at low nitrogen rates but these were not consistently seen throughout TALISMAN.

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%). However, winter beans proved to be a notable exception, as reductions in herbicide use resulted in overall yield increases (up to 4%). The various yield decreases observed were not penalised by decreases in gross margin, but gross margins were increased owing to savings made in herbicide costs. Other workers have noted similar effects in low-input situations (Leake, 1996). The differences between the sites were due to their different approaches to reducing herbicide use. At Boxworth and High Mowthorpe, herbicide use was arguably well optimised at the outset, whereas at Drayton, reductions were made from a higher starting point. As a consequence, at Drayton, reductions had a lesser effect on yield but the benefits on gross margin were clearly seen (8% increase overall). In contrast, at Boxworth and High Mowthorpe, gross margins over the rotations were unaffected.

If a low-input herbicide regime is adopted, the content and sequence of the crop rotation must be given serious consideration. For example, at Boxworth, at the start of TALISMAN, oilseed rape was less conducive to the build-up of cleavers than winter beans. At High Mowthorpe, poppy numbers escalated when poorly controlled in crops of barley. Aggressive weeds such as poppy and cleavers, when 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.

In general, weed build-up has not been an insurmountable problem in TALISMAN. Current knowledge has been 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.

TALISMAN has demonstrated that reducing herbicide use in a low-input regime can be cost effective. Depending on local circumstances, there is potential to improve the gross margins of certain crops through savings in herbicide costs. However, it is clear that greater management skill and knowledge is called for in retaining long-term control of problem weeds at critical periods in the crop rotation.

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Table 2.3.1. Weed populations (crop equivalents) expected to produce a yield penalty of 2% in winter wheat, after Wilson & Wright (1990).

Weed species	Common name	Weed population expected to give a crop loss of 2% (plants/m²)
Very competitive		
Galium aparine	Cleavers	1.6
Avena fatua	Spring wild-oat	0.5
Avena sativa	Winter wild-oat	0.5
Moderately competitive		
Matricaria spp.	Mayweeds	1.7
Myosotis spp.	Forget-me-not	6.0
Alopecurus myosuroides	Black-grass	8.3
Stellaria media	Chickweed	13.0
Papaver rhoeas	Poppy	21.0
Less competitive		
Lamium purpureum	Red dead-nettle	30.0
Veronica persica	Field speedwell	32.0
Viola arvensis	Field pansy	109.0

Table 2.3.2. Herbicide units* applied to crop and crop group, by site and rotation (mean units/crop).

a) Standard Rotation

Crop/crop group	Boxworth		Drayton		High Mowthorpe	
	All High	Low Herbicide	All High	Low Herbicide	All High	Low Herbicide
1st Winter wheat	4.5	3.2 (29)	6.8	3.1 (54)	2.3	1.0 (57)
2nd Winter wheat	4.0	3.4 (15)	5.8	3.1 (47)	3.5	1.7 (51)
Mean: all wheats	4.3	3.3 (23)	6.3	3.1 (51)	2.7	1.2 (56)
Spring oilseed rape	3.0	1.5 (50)	1.0	0.5 (50)	-	-
Winter oilseed rape	1.0	0.5 (50)	2.0	1.0 (50)	2.0	1.0 (50)
Winter beans	1.5	0.0 (100)	2.5	1.0 (60)	0.5	0.3 (40)
Mean: break crops	1.8	0.5 (72)	2.0	0.9 (55)	1.3	0.6 (54)
Winter barley	-	-	-	-	3.5	1.4 (60)
Mean: other cereals	-	-	-	-	3.5	1.4 (60)
Mean	3.6	2.3 (36)	4.8	2.4 (50)	2.3	1.1 (52)

b) Alternative Rotation

Crop/crop group	Boxworth		Drayton		High Mowthorpe	
	All High	Low Herbicide	All High	Low Herbicide	All High	Low Herbicide
Winter wheat	3.5	2.7 (23)	-	-	2.0	0.9 (55)
Spring wheat	3.5	2.0 (43)	-	-	-	-
Mean: all wheats	3.5	2.3 (34)	-	-	2.0	0.9 (55)
Spring beans	3.0	0.5 (83)	1.5	0.3 (80)	1.0	0.5 (50)
Spring oats	-	-	2.0	1.0 (50)	-	-
Spring linseed	1.0	0.5 (50)	-	-	1.5	0.8 (47)
Mean: break crops	2.0	0.5 (75)	1.8	0.6 (67)	1.3	0.6 (54)
Spring barley	-	-	7.0	4.3 (39)	4.0	1.6 (60)
Winter triticale	-	-	5.7	2.7 (53)	-	-
Mean: other cereals	-	-	6.0	3.1 (48)	4.0	1.6 (60)
Mean	3.0	1.7 (43)	4.6	2.3 (50)	2.4	1.1 (54)

*1 unit = 1 full-rate application of one active ingredient.
Figures in parentheses are percentage reductions in herbicide use in the Low Herbicide compared with the All High.

Table 2.3.3. The most frequently used herbicide active ingredients in TALISMAN, 1990–1996 (total number of applications).

Active ingredient	Target weed group controlled	Wheat CCP	Wheat LIA	Break crops CCP	Break crops LIA	Other cereals CCP	Other cereals LIA	All crops CCP	All crops LIA
Isoproturon	Grass	36	34	0	0	10	8	46	42
Diflufenican	Broad-leaved	27	25	0	0	6	5	33	30
Mecoprop/mecoprop-P	Broad-leaved	12	12	1	1	9	9	22	22
Fenoxaprop-ethyl	Grass	13	13	0	0	3	3	16	16
Ioxynil	Broad-leaved	8	8	1	1	9	9	18	18
Bromoxynil	Broad-leaved	8	8	1	1	9	9	18	18
Fluroxypyr	Broad-leaved	9	9	0	0	5	5	14	14
Metsulfuron-methyl	Broad-leaved	3	3	2	2	5	5	10	10
Simazine	Broad-leaved	0	0	7	2	0	0	7	2
Cycloxydim	Grass	0	0	5	4	0	0	5	4

Table 2.3.4. Number of spray rounds of herbicides applied to crops, 1990 and 1996 (including repeat applications) compared with that used in TALISMAN.

Crop	1990 England & Wales	1996 Great Britain	TALISMAN CCP	TALISMAN LIA
Wheat	2.0	2.2	2.2	2.2
Winter barley	1.7	1.8	1.5	1.5
Spring barley	1.3	1.4	2.7	2.7
Oats	1.3	1.5	1.0	1.0
Triticale	1.0	1.2	3.3	3.0
Oilseed rape	1.8	1.9	1.7	1.5
Linseed	1.2	2.5	1.3	1.3
Field beans	1.3	1.8	1.2	0.6

Source: MAFF Pesticide Usage Survey Reports.

Table 2.3.5. Number of herbicide active ingredients applied per crop, 1990 and 1996, compared with that used in TALISMAN.

Crop	1990 England & Wales	1996 Great Britain	TALISMAN CCP	TALISMAN LIA
Wheat	3.4	4.1	4.1	3.9
Winter barley	2.9	3.6	3.5	3.5
Spring barley	2.8	3.3	5.0	5.0
Oats	2.0	2.5	2.0	2.0
Triticale	1.5	2.4	4.3	3.8
Oilseed rape	2.2	2.5	1.8	1.7
Linseed	2.4	3.3	1.3	1.3
Field beans	1.7	2.1	1.5	0.7

Source: MAFF Pesticide Usage Survey Reports.

Table 2.3.6. Herbicide usage and estimated dose-rates on wheat in Great Britain, 1990 and 1996.

Active ingredient	Area treated (ha)		Tonnes a.i. applied		Grammes a.i./ha		% of label rate*	
	1990	1996	1990	1996	1990	1996	1990	1996
Diflufenican/isoproturon	512,206	754,163	623.85	459.37	1218.0	609.1	65	33
Fluroxypyr	356,599	700,547	56.26	85.51	157.8	122.1	105	81
Fenoxaprop-ethyl	184,322	95,633	25.26	7.29	137.0	76.2	91	51
Isoproturon	798,915	1,176,469	1427.39	1875.68	1786.7	1594.3	90	80
Mecoprop-P	81,072	319,870	85.46	212.67	1054.1	664.9	88	55
Metsulfuron-methyl	258,508	396,671	1.36	1.72	5.3	4.3	88	72
Bromoxynil/ioxynil	190,314	129,722	66.44	46.21	349.1	356.2	60	61

Source: MAFF Pesticide Usage Survey Reports.
*If a range of label rates was available, the average rate was used in this calculation.

Table 2.3.7. The effect of low-input herbicide use on the mean yields of break crops in TALISMAN, 1991–1996 (t/ha @ 85% d.m. or 91% d.m. for oilseeds).

Crop & Site	Pesticide sub-treatment[1]			SED
	All High	All Low	Low Herbicide	
Winter oilseed rape				
Boxworth (24 d.f.)	0.83	0.51 (61)	0.49 (59)	0.157***
Drayton (16 d.f.)	2.59	2.31 (90)	2.33 (90)	0.259
High Mowthorpe (31 d.f.)	3.58	3.24 (91)	3.48 (97)	0.114**
Cross site (71 d.f.)	2.50	2.18 (87)	2.30 (92)	0.093***
Spring oilseed rape				
Boxworth (24 d.f.)	0.91	0.55 (60)	0.63 (69)	0.100*
Drayton (16 d.f.)	0.23	0.36 (154)	0.31 (132)	0.088
Cross site (40 d.f.)	0.62	0.46 (75)	0.49 (80)	0.069
Winter beans				
Boxworth (48 d.f.)	4.08	4.19 (103)	4.19 (103)	0.083
Drayton (32 d.f.)	4.01	4.03 (101)	4.19 (104)	0.095
High Mowthorpe (32 d.f.)	4.86	4.67 (96)	4.88 (100)	0.086**
Cross site (112 d.f.)	4.29	4.29 (100)	4.40 (102)	0.051
Spring beans				
Boxworth (17 d.f.)	1.74	1.46 (84)	1.24 (72)	0.231
Drayton (32 d.f.)	3.23	2.89 (90)	3.26 (101)	0.087***
High Mowthorpe (32 d.f.)	4.46	4.25 (95)	4.26 (96)	0.108
Cross site (81 d.f.)	3.32	3.04 (92)	3.13 (94)	0.075**
Spring linseed				
Boxworth (24 d.f.)	2.48	2.43 (98)	2.36 (95)	0.061
High Mowthorpe (31 d.f.)	1.72	1.74 (102)	1.68 (98)	0.056
Cross site (55 d.f.)	2.02	2.02 (100)	1.95 (97)	0.041*
Spring oats				
Drayton (32 d.f.)	4.93	4.62 (94)	4.80 (97)	0.116

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

Table 2.3.8. The effect of low-input herbicide use on the mean yields of cereal crops in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Herbicide	
First winter wheat				
Boxworth (172 d.f.)	7.01	6.68 (95)	6.91 (99)	0.063***
Drayton (80 d.f.)	8.07	7.79 (97)	8.16 (101)	0.091***
High Mowthorpe (176 d.f.)	8.37	7.60 (91)	8.08 (97)	0.080***
Cross site (428 d.f.)	7.76	7.27 (94)	7.63 (98)	0.045***
Second winter wheat				
Boxworth (111 d.f.)	7.43	7.21 (97)	7.47 (101)	0.064***
Drayton (80 d.f.)	7.22	6.93 (96)	7.29 (101)	0.132*
High Mowthorpe (32 d.f.)	7.79	6.88 (88)	7.22 (93)	0.112***
Cross site (223 d.f.)	7.42	7.05 (95)	7.36 (99)	0.059***
All winter wheat				
Boxworth (283 d.f.)	7.18	6.90 (96)	7.13 (99)	0.046***
Drayton (160 d.f.)	7.64	7.36 (96)	7.72 (101)	0.080***
High Mowthorpe (208 d.f.)	8.25	7.45 (90)	7.91 (96)	0.069***
Cross site (651 d.f.)	7.64	7.19 (94)	7.53 (99)	0.036***
Spring barley				
Drayton (40 d.f.)	5.96	5.65 (95)	5.66 (95)	0.224
High Mowthorpe (78 d.f.)	5.34	5.35 (100)	5.30 (99)	0.184
Cross site (119 d.f.)	5.55	5.45 (98)	5.26 (95)	0.178
Winter triticale				
Drayton (120 d.f.)	5.25	5.19 (99)	5.33 (101)	0.083
Winter barley				
High Mowthorpe (32 d.f.)	7.95	7.67 (97)	7.74 (97)	0.200
Spring wheat				
Boxworth (47 d.f.)	5.92	5.25 (89)	5.29 (89)	0.135***

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

* $P < 0.05$.

*** $P < 0.001$.

Table 2.3.9. The effect of low-input herbicide use on the mean gross margins of cereal crops in TALISMAN, 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment[1]			SED
	All High	All Low	Low Herbicide	
First winter wheat				
Boxworth (172 d.f.)	717.8	724.0 (101)	723.0 (101)	7.16***
Drayton (80 d.f.)	753.3	810.2 (108)	809.5 (108)	10.07***
High Mowthorpe (176 d.f.)	1022.1	974.5 (95)	1001.7 (98)	10.26***
Cross site (428 d.f.)	846.6	841.4 (99)	851.8 (101)	5.42***
Second winter wheat				
Boxworth (111 d.f.)	945.6	950.7 (101)	960.4 (101)	8.01
Drayton (80 d.f.)	606.4	701.8 (116)	668.9 (110)	13.18***
High Mowthorpe (32 d.f.)	759.9	750.8 (99)	740.4 (97)	11.59***
Cross site (223 d.f.)	793.1	827.6 (104)	818.7 (103)	6.36***
All winter wheat				
Boxworth (283 d.f.)	808.9	814.7 (101)	818.0 (101)	5.63**
Drayton (160 d.f.)	679.8	756.0 (111)	739.2 (109)	8.30***
High Mowthorpe (208 d.f.)	969.7	929.8 (96)	949.4 (98)	8.68***
Cross site (651 d.f.)	827.3	836.4 (101)	839.8 (102)	4.16***
Spring barley				
Drayton (40 d.f.)	384.9	425.7 (111)	386.4 (100)	22.44
High Mowthorpe (78 d.f.)	608.6	633.3 (104)	623.2 (102)	17.89
Cross site (119 d.f.)	534.0	564.1 (106)	544.3 (102)	14.07
Winter triticale				
Drayton (120 d.f.)	470.6	542.1 (115)	529.1 (112)	8.62***
Winter barley				
High Mowthorpe (32 d.f.)	820.4	844.2 (103)	827.9 (101)	19.98
Spring wheat				
Boxworth (47 d.f.)	776.6	720.3 (93)	706.5 (91)	17.10***

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

*** $P < 0.001$.

Table 2.3.10. The effect of low-input herbicide use on the mean gross margins of break crops in TALISMAN, 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Herbicide	
Winter oilseed rape				
Boxworth (24 d.f.)	50.0	-1.0 (na)	-28.0 (na)	41.90***
Drayton (16 d.f.)	373.0	361.0 (97)	336.0 (90)	68.90
High Mowthorpe (31 d.f.)	829.1	797.1 (96)	835.2 (101)	23.41
Cross site (71 d.f.)	484.1	450.9 (93)	454.5 (94)	23.23**
Spring oilseed rape				
Boxworth (24 d.f.)	346.5	345.2 (100)	330.7 (95)	18.04
Drayton (16 d.f.)	324.1	369.3 (114)	356.0 (110)	15.80
Cross site (40 d.f.)	336.9	355.5 (106)	341.5 (101)	12.43
Winter beans				
Boxworth (48 d.f.)	620.8	674.0 (109)	656.3 (106)	13.41**
Drayton (32 d.f.)	566.3	616.5 (109)	629.6 (111)	15.78***
High Mowthorpe (32 d.f.)	744.9	724.8 (97)	749.7 (101)	11.73**
Cross site (112 d.f.)	641.7	672.0 (105)	676.3 (105)	8.00***
Spring beans				
Boxworth (17 d.f.)	328.5	380.1 (116)	332.7 (101)	22.42
Drayton (32 d.f.)	485.9	474.9 (98)	509.9 (105)	13.51***
High Mowthorpe (32 d.f.)	679.3	664.8 (98)	659.7 (97)	15.92
Cross site (81 d.f.)	519.1	522.4 (101)	521.8 (101)	9.54
Spring linseed				
Boxworth (24 d.f.)	698.0	686.8 (98)	677.8 (97)	6.31**
High Mowthorpe (31 d.f.)	565.2	581.7 (103)	574.1 (102)	7.29
Cross site (55 d.f.)	618.3	623.8 (101)	615.6 (100)	4.99
Spring oats				
Drayton (32 d.f.)	504.4	491.0 (97)	499.2 (99)	12.11

[1] Cross-nitrogen means. 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.

** $P < 0.01$.

*** $P < 0.001$.

Table 2.3.11. The effect of low-input herbicide use on the mean gross margins on crops grouped as cereals, breaks or overall crops in TALISMAN, 1991–1996, as a mean of both rotations (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Herbicide	
Cereal crops				
Boxworth (346 d.f.)	803.6	799.0 (99)	800.2 (100)	5.73*
Drayton (352 d.f.)	564.5	634.5 (112)	616.3 (109)	6.04***
High Mowthorpe (350 d.f.)	860.7	845.0 (98)	852.2 (99)	7.91***
Cross site (1048 d.f.)	742.9	759.5 (102)	756.3 (102)	3.83***
Break crops				
Boxworth (169 d.f.)	444.1	458.9 (103)	440.2 (99)	11.30**
Drayton (176 d.f.)	476.3	486.9 (102)	496.1 (104)	11.65
High Mowthorpe (174 d.f.)	704.6	692.1 (98)	704.7 (100)	8.31
Cross site (519 d.f.)	541.7	546.0 (101)	547.0 (101)	6.08
All crops				
Boxworth (515 d.f.)	683.7	685.6 (100)	680.2 (100)	5.36***
Drayton (528 d.f.)	535.1	585.3 (109)	576.2 (108)	5.59***
High Mowthorpe (524 d.f.)	808.7	794.0 (98)	803.1 (99)	5.96***
Cross site (1567 d.f.)	675.8	688.3 (102)	686.5 (102)	3.26***

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

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Table 2.3.12. The effect of Low Herbicide treatment on volunteer wheat populations and on yield of oilseed rape (OSR) and volunteer wheat in Standard Rotation I at Boxworth, 1991.

Sub-treatment	Volunteer wheat (plants/m²)	OSR yield (t/ha @ 91% d.m.)	Volunteer wheat yield (t/ha @ 85% d.m.)	OSR gross margin (£/ha)
All High	60.0	0.83	3.56	50
Low Herbicide	82.8	0.49	6.96	-28
SED (6 d.f.)	12.85	0.136*	0.256*	36.2

* $P < 0.05$.

Table 2.3.13. The effect of Low Herbicide treatment on weed populations and yield of spring oilseed rape in Standard Rotation Phase I at Boxworth, 1994.

Sub-treatment	Total weed number (plants/m²)	Oilseed rape yield (t/ha @ 91% d.m.)	Gross margin (£/ha)
All High	44.0	0.91	346.5
Low Herbicide	64.7	0.63	330.7
SED (24 d.f.)	9.94*	0.1002	18.0

* $P < 0.05$.

Table 2.3.14. The effect of Low Herbicide treatment on weed populations and yield of spring wheat in Alternative Rotation Phase I at Boxworth, 1996.

Sub-treatment	Total weed number (plants/m²)	Spring wheat yield (t/ha @ 85% DM)	Gross margin (£/ha)
All High	934	5.37	787.5
Low Herbicide	1196	4.28	661.4
SED (24 d.f.)	8.0	0.182*	22.79*

* $P < 0.05$.

Table 2.3.15. The effect of Low Herbicide treatment on weed populations, yield and gross margin of winter barley cv. Fighter in Standard Rotation Phase 2 at High Mowthorpe, 1993.

Sub-treatment	Total weed number (plants/m²)	Winter barley yield (t/ha @ 85% DM)	Gross margin (£/ha)
All High	37.5	7.32	715.8
Low Herbicide	43.2	6.70	665.8
SED (16 d.f.)	-	0.149*	14.46*

* $P < 0.05$.

Table 2.3.16. The effect of Low Herbicide treatment on weed populations, yield and gross margin of winter wheat cv. Hereward in Alternative Rotation Phase 2 at High Mowthorpe, 1995.

Sub-treatment	Total weed number (plants/m²)	Winter wheat yield (t/ha @ 85% DM)	Gross margin (£/ha)
All High	13.1	8.01	1070
Low Herbicide	32.4	7.47	1035
SED (24 d.f.)	-	0.220*	33.1

* $P < 0.05$.

Table 2.3.17. The effect of Low Herbicide treatment on weed populations, yield and gross margin of winter wheat cv. Buster in Standard Rotation Phase 2 at High Mowthorpe, 1996.

Sub-treatment	Total weed number (plants/m²)	Winter wheat yield (t/ha @ 85% DM)	Gross margin (£/ha)
All High	136.7	6.88	703.9
Low Herbicide	256.4	5.82	641.3
SED (24 d.f.)	-	0.180*	18.39*

* $P < 0.05$.

Table 2.3.18. The effect of Low Herbicide treatment on weed populations, yield and gross margin of spring barley cv. Cooper in Alternative Rotation Phase 1 at High Mowthorpe, 1996.

Sub-treatment	Total weed number (plants/m²)	Spring barley yield (t/ha @ 85% DM)	Gross margin (£/ha)
All High	3.5	5.16	683.5
Low Herbicide	74.7	4.83	663.6
SED (24 d.f.)	-	0.101*	10.58

* $P < 0.05$.

THE IMPACT OF LOW-INPUT HERBICIDE USE ON WEED SEEDBANKS

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Introduction

Populations of buried, viable seed – known as the seedbank – have a vital role in arable ecology and agronomy (Brenchley, 1918; Roberts & Rickets, 1979; Mortimer, 1990). Seed of most weed species can live in the soil for many years, germinating after cultivation if the environmental conditions are conducive. The seedbank flora is therefore a better indicator of past and of potential weed problems than the visible weed flora in any season. In the TALISMAN project, the purpose of seedbank work was to assess the effects of Alternative Rotations (Chapter 2.1) and reduced herbicide inputs on the role of the seedbank, both as a source of future weed problems and as a store of arable species diversity.

Seedbank populations tend to fluctuate over time in both total seed number and in the proportions of species. Additions result from weeds depositing seed locally and from long-range dispersal of seed carried in the air or by animals or farm machinery. Single plants of some weed species can generate thousands of seeds (Salisbury, 1942) so even a small weed population, if unchecked, can lead to a massive increase in the seedbank in one or two seasons. Shedding of seed is encouraged by harvesting activity; the populations lying on the soil are then incorporated by cultivation. Losses occur either by death through age, disease, predation or as a result of germination. Many weed species have hard seed coats and are long-lived, and so are much more resistant to fungi and invertebrate pests than are seeds of, say, natural grassland communities (Brenchley, 1918; Chippendale & Milton, 1934). Moreover, germination in any year is a low proportion of the total seedbank population, typically 1/10th or 1/100th, giving weed populations typically in the range 10 to 1,000/m^2. Even if there are no additions for a few years, populations of the main weeds will decline slowly but rarely to extinction.

The seedbank in arable land is controlled by cultivation, by use of herbicide or by competition from the crop. The effects of type and time of cultivation have been widely appreciated (Froud-Williams *et al.*, 1983). In most modern practice, herbicide first, then competition, are the main means of control. Multi-site experiments on reducing herbicide inputs in cereal rotations had already begun and overlapped with the first half of TALISMAN. They showed that adequate control of broad-leaved weed seedbanks in cereals was achieved by annual applications of half doses of herbicide applied prophylactically (Proven *et al.*, 1991; Davies *et al.*, 1993; Wright *et al.*, 1993). The aim of seedbank studies in TALISMAN was to assess the consequence of changing several factors at the same time. At a given herbicide input, certain combinations of rotation, crop type and nitrogen might encourage a greater build up of seedbank populations than was found previously in the Boxworth Project (Greig-Smith *et al.*, 1992) or the herbicide studies (references cited above) where the crops were mainly winter wheat.

In the TALISMAN experiments, the effect of using less herbicide can be examined through the paired All High and Low Herbicide sub-treatment regimes. The effects of competition can be examined indirectly by comparing the Standard Rotations consisting of predominantly autumn-sown cereals (providing intense competition to weeds) with the Alternative Rotations comprising mostly spring-sown cereals, legumes or linseed, which provide competition not only of a weaker nature but later in the season. The results can be assessed broadly by comparing total numbers of seeds and seedbank species. Two other features of the seedbank are also important. One is the balance of species, and particularly whether conditions

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encourage one or a few economically damaging dominants at the expense of species diversity. The other is the aggressiveness of the different weed species. For instance, cleavers (*Galium aparine*) are potentially more damaging to a later crop than the same number of poppies (*Papaver* spp.) or round-leaved fluellen (*Kickxia spuria*). There is some experimental information on how many individuals of one species equals how many of another, but aggressiveness varies among ecotypes and races of a species, and depends also on local conditions.

Methods

Seedbanks were measured in a specific set of the TALISMAN treatments to enable the effects of the Current Commercial Practice (CCP) and Low Input Approach (LIA) regimes of nitrogen and herbicide use to be assessed in the Standard and Alternative Rotations at each site. Rotation and nitrogen level were main treatments, set out in a randomised block design, three of the four replicates of which were sampled for seedbank analysis. Herbicide input was at sub-treatment level, set out in a split plot design (Chapter 2.1).

Three sets of samples were collected at Boxworth, Drayton and High Mowthorpe: the first set in spring 1991 (i.e. at the first sowing of the Alternative Rotation), the second in autumn 1993 and the final set in autumn 1996. All Phases of each Rotation were not sampled at each site. At Boxworth, Standard Rotation Phase II and Alternative Rotation Phase I were sampled, whilst at Drayton and High Mowthorpe Phase I of the Standard and Alternative Rotations were sampled. At the sub-plot level, samples were taken from the All High and Low Herbicide sub-treatments (Chapter 2.1). Soil cores (2.5 cm diameter) to a depth of 0.2 m were taken from each of three fixed quadrats per sub-plot and bagged separately. The samples were sent to SCRI where they were stored at -20°C until required for analysis. After being thawed, each sample was thoroughly mixed and one 200 ml sub-sample extracted and analysed for weed seed content by sieving and flotation in calcium chloride (Roberts & Ricketts, 1979). Floating seeds which were firm and resistant to gentle pressure were assumed to be viable and removed for identification and counting (Lawson *et al.*, 1988). Some taxa could not be identified with certainty to species and are grouped as genera (e.g. mayweeds, *Matricaria* spp., and meadow grass, *Poa* spp.).

Seed counts are expressed per unit field area to the depth sampled (seeds/m^2 to 0.2 m depth) for comparison with weed counts taken at the same quadrats. So a mean seedbank abundance of, say, 600/m^2 cited here means that there were estimated to be 600 seeds in a volume of soil measuring 0.2 m deep below a square metre of field. Seed counts were subjected to analysis of variance after square-root transformation to normalise distributions. Analysis of variance was carried out using the factorial design described (GENSTAT, Chapter 2.1).

Seedbank population size

Initial seedbank populations

The initial seedbank populations were between 1,000 and 2,000/m^2 at all three sites. Three or four species made up most of the seedbank, and though (except for meadow grass) these differed among the sites, all the main species present initially were common representatives of the arable weed flora. Other species were mostly in low numbers. The total number of species was 10 at Boxworth, 14 at High Mowthorpe and 20 at Drayton. Other species would possibly have been present at the sites, but at frequencies too low to be detected.

Though these initial numbers for the total seedbank and the dominants appear large compared with weed populations above ground, they are, however, at the low end of the range of seed population density found in arable seedbanks, and indicate that the management regimes had effectively suppressed weeds in previous years. Nevertheless, a substantial weed population would result if only a moderate proportion of these seedbank seeds were to germinate.

Broad changes over the six years of the rotation

Over the next six cropping years, the treatments and site factors acted on these initial seedbanks to cause sometimes very large changes in seed number and species. Rotation and herbicide input had very strong subsequent effects. Nitrogen treatments caused few statistically significant effects and are not considered further here. Over six years, the range of rotation and herbicide treatments caused a 1,000-fold variation in total seedbank population. The full-rate herbicide regimes in the Standard Rotation kept seedbanks close to the initial values (**Fig. 2.4.1**).

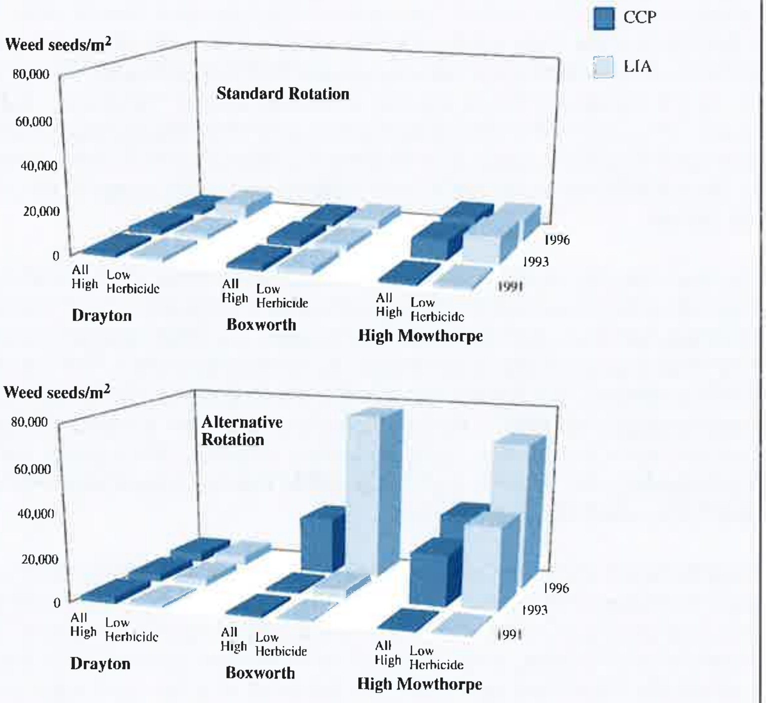

Figure 2.4.1. Summary of the effect of rotation and herbicide regime on seedbank abundance in TALISMAN.

Relaxation of herbicide use in the low-input regime caused the seedbank to increase (**Fig. 2.4.1**), but the rate of increase and final size of the populations were very different among the sites. At Drayton, the seedbank populations increased slightly but no treatment effects were statistically significant; after six years, seedbanks were still typical of those in conventionally managed arable rotations, even in Alternative Rotations with reduced herbicide use. At Boxworth, populations had not changed by Year 3, and were still much the same in Standard Rotations after six years, but increased significantly ($P < 0.001$) to very high values in Alternative Rotations after six years. At High Mowthorpe, populations increased to high values by Year 3, and then further at Year 6 ($P < 0.001$). The final seedbank populations at Boxworth and High Mowthorpe in the combination of Alternative Rotation and low-input herbicide, ranged from 25,000/m² to 90,000/m². These values were ten to a hundred times larger than those found initially and in the most intensely managed treatments in 1996.

Species responsible for the changes

The effects on individual species or genera need to be known for a deeper agronomic and biological interpretation of the experiment. Altogether, between 10,000 and 100,000 seeds were examined in the seedbank analysis in TALISMAN. As an example of part of this data set, the findings for individual species at Boxworth are summarised in **Table 2.4.1**. Boxworth is an instructive example since the seedbank there showed a complex set of responses which had features of both of the other sites.

At Boxworth

Seedbank counts (untransformed) for taxa detected at Boxworth are arranged in decreasing order of the values in the Alternative Rotation, Low Herbicide sub-treatment after six years (**Table 2.4.1**). Twenty-seven taxa were found in total and a maximum of 20 in any one combination of rotation and year. The column under 1991 shows the general mean seedbank counts for the small initial seedbank. '*Brassica* spp.' is probably volunteer oilseed rape (*Brassica napus*). The columns under 1993 show the means for Standard and Alternative Rotations. Small changes occurred in several taxa present initially, and several new taxa were detected, but the total seedbank populations were still small. The analysis of variance on the transformed data (see above Methods) indicated effects of rotation on only three out of the 16 species detected, and all these were significantly smaller ($P < 0.05$) in the Alternative Rotation, the three being *Brassica* spp., prickly sowthistle (*Sonchus asper*) and chickweed (*Stellaria media*). There were no other treatment differences, so the further subdivisions in the range of treatments are not shown.

The four columns under 1996 in **Table 2.4.1** show means for the Standard and Alternative Rotations and for the two herbicide treatments in each rotation. In the Standard Rotation, small or moderate increases occurred between 1991 and 1996 in several taxa, especially in the Low Herbicide sub-treatment. The total seedbank in this treatment, though two and a half times larger than the initial one, was still small by arable standards. Potential problems lie in the accumulation of seed of species such as fat-hen (*Chenopodium album*), black-grass (*Alopecurus myosuroides*) and cleavers, but it is possible that such increases were spurious, simply the result of sampling error.

The Alternative Rotation caused substantial, statistically significant ($P < 0.05$, $P < 0.01$) increases in the abundance of seven out of the 20 species found by Year 6. The very large total seedbank consisted mostly of scarlet pimpernel (*Anagallis arvensis*) and fat-hen, both of which were present in very high populations. Statistically significant enhancement occurred of other taxa such as charlock (*Sinapis arvensis*), black-bindweed (*Fallopia convolvulus*), knotgrass (*Polygonum aviculare*), round-leaved fluellen, and chickweed (*Stellaria media*). The two taxa that rose to dominance were present in low numbers initially, but others such as charlock and round-leaved fluellen were not detected initially. They were most likely present in the seedbank at frequencies too low to be detected with the sampling intensity used.

Reduced herbicide significantly increased the seedbank of the two dominant taxa and of several others in both rotations. There were indications of enhancing effects of Alternative Rotations and low-input herbicide use on several other species, but none of these effects was statistically significant. In the Alternative Rotations, therefore, the seedbank after six years contained a massive potential weed problem. Although scarlet pimpernel is not a vigorous competitive weed, other of the species are, including fat-hen and charlock. In addition to these, cleavers increased from nothing (probably present but below the detectable level) to small to moderate populations that could nevertheless give rise to problems in any of the treatments.

At Boxworth, therefore, the All High herbicide regime in the autumn-sown crops of the Standard Rotation effectively stopped net gain in the seedbank over six years. Some species declined whereas others increased slightly. Competition from the autumn-sown crops also very largely covered for any opportunities arising from reducing the herbicide applied to these crops. In contrast, the All High herbicide regime in the Alternative Rotation allowed germination of seed and subsequent additions to the seedbank of a range of species which are mostly spring-germinators. They were stimulated by the cultivation of soil in spring and, especially with reduced herbicide, were able to reproduce in great numbers, having faced only weak competition from the crops. This observation is also confirmed in the findings relating to weed plant populations (Chapter 2.3).

At Drayton

In the first sample, fool's parsley (*Aethusa cynapium*), meadow grass, speedwell (*Veronica arvensis*) and knotgrass (*Polygonum aviculare*), in decreasing order, constituted 75% of the small seedbank population. Subsequently, the seedbank in the Low Herbicide sub-treatments increased over time to twice the initial value; but none of the treatments caused statistically significant differences in the abundance of the main species. Speedwell was the most common species, having seedbanks of 1,000 to 2,000/m^2 in all main treatments; meadow grass and fool's parsley had seedbanks of this order in at least one treatment. Some minor species, such as volunteer winter wheat (*Triticum aestivum*), also increased in abundance during the experiment. Several species not detected initially were present after three and six years, notably cut-leaved geranium (*Geranium dissectum*), but none was significantly affected by rotation, nitrogen or herbicide.

Scarlet pimpernel and fat-hen, the two species that were most strongly enhanced by the Alternative Rotation at Boxworth, were present in low numbers but not stimulated by any treatment at Drayton. One other of the species at Boxworth enhanced by the Alternative Rotation - black-bindweed - was present only in the Alternative Rotation at Drayton, but still in low abundance and not consistently among replicates. At Drayton, therefore, six years of Alternative Rotation and low-input herbicide use had not caused any statistically significant increase in the seedbank abundance nor any major shift in the prevalent species. Seedbanks in all treatments were still typical of conventionally managed arable rotations.

At High Mowthorpe

The number of species and maximum seedbank populations were of a similar magnitude to those at Boxworth, but differed from them in two main respects. The first was that the total seed number increased over time in all treatments, not just in the Alternative Rotations. Very large increases in common weed taxa such as poppy, cleavers, meadow grass, chickweed and shepherd's purse (*Capsella bursa-pastoris*), occurred throughout the site and were apparent in both 1993 and 1996. Moderate increases also occurred in about ten other arable weed species. This suggests that even the full use of herbicide and the competition from autumn-sown crops in the most intense regime was not enough to prevent weeds from returning very large amounts of seed to the seedbank.

The second difference from Boxworth was that the seedbank, and most treatment effects, were dominated by one taxon, poppy. This was the only taxon to be significantly affected by the Alternative Rotation in 1993, being largely responsible for the three-fold greater seedbank ($P < 0.01$). By 1996, the seedbank of the Alternative Rotation had increased further to very high values, but poppy and charlock (the latter present only at low populations) were the only taxa to show a significant increase in the Alternative Rotation. The population of poppy was estimated at 22,000/m^2 in the All High sub-treatment of the Alternative Rotation and 55,000/m^2 in the corresponding Low Herbicide sub-treatment. Several other species, notably common fumitory (*Fumaria officinalis*) and shepherd's purse had higher means in the Alternative Rotation but effects were not statistically significant.

Poppy can germinate over a large part of the year, though is most stimulated by cultivation in the spring. The only other species enhanced by the Alternative Rotation, charlock, is also a spring germinator. Of the species enhanced at Boxworth by the Alternative Rotation, scarlet pimpernel and round-leaved fluellen were absent, fat-hen was scarce and not stimulated by any treatment, whereas black-bindweed was not significantly more abundant in the Alternative Rotation than the Standard. Apart from poppy, therefore, most of the additions to the seedank were generalist weed species, notably cleavers, that germinate and reproduce whenever the management is relaxed. One of the very few significant effects of nitrogen treatment occurred at High Mowthorpe, when reduced nitrogen increased the populations of cleavers ($P < 0.05$).

The conclusion for High Mowthorpe is that none of the treatments succeeded in preventing seedbank populations rising from the initial low numbers, whereas the least intense treatments provided opportunities for poppy to multiply excessively, and others such as cleavers and chickweed to reach potentially damaging levels (each > 2,000 seeds/m^2). It is likely that the majority of the other weeds were suppressed as much by poppy and cleavers as by the crops themselves. Most of the species that had increased to large populations by 1996 were present at very low frequency in the first sample. For instance, the site mean for *Papaver* spp., 60/m^2 at the beginning, had increased about 1,000-fold in the Low Herbicide sub-treatment of the Alternative Rotation. The main exception was cleavers which were not detected at the beginning but were likely to have been present in low abundance. As in the Alternative Rotations at Boxworth, the treatments at High Mowthorpe left potentially very damaging seedbank populations of several important long-lived weeds.

Was herbicide input the dominant site-effect?

The inconsistencies between sites in reponse to the treatment could have several possible causes, including the local management as well as other site factors such as the initial seedbanks, the soil and the weather. Perhaps all contributed, but these other local factors can probably be eliminated as the principal discriminants of seedbank change. The starting seedbank abundance, for instance, was similarly low at all sites. Although only four taxa were common to all sites, there were sufficient instances of one taxon being present at two sites to suggest that the differing starting seedbanks were not responsible for the subsequent differences in total seedbank. For example, poppy was present at Drayton and High Mowthorpe, but formed massive seedbanks only at the latter.

The local weather and soil are likely to have affected seedbank dynamics to a degree. High Mowthorpe was somewhat extreme, having the lightest (silty clay loam) soil and the coolest and wettest climate. Of the other two sites, Drayton has the heavier clay soil and Boxworth the drier climate. However, great differences in total seedbank occurred at Boxworth and High Mowthorpe between randomised plots just several metres apart, suggesting that treatments had more effect on total seedbank populations than sites *per se*. There is also evidence that the seedbank at Drayton is not always as unresponsive as in TALISMAN. Moderate to high total seedbank populations of 14,000/ m^2, three times the highest site mean at Drayton in this experiment, and similar to seed populations in the standard rotation at High Mowthorpe, were found at Drayton in another study (Wright *et al.*, 1993).

Of the management factors, crop type differed much less between sites than herbicide input. All the crops of the Standard Rotation were autumn-sown and individual crops were the same at each site in each year, except in year 6 when winter barley was grown at High Mowthorpe and winter wheat was grown at the other two sites. Alternative Rotations had two autumn-sown crops and three spring-sown crops in the first five years. The years in which these crops were grown were the same across all three sites, although the actual crops sometimes differed. In the final year, Drayton had another winter crop whereas the other sites had spring crops. The extra autumn-sown crop would provide greater competition to weeds and allow more opportunity for herbicide spraying, but this alone would not have caused the great difference in the Alternative Rotation between Drayton and the other sites.

The clearest discriminant between sites and treatments was the number of herbicide units applied, most applied at Drayton and least at High Mowthorpe (Chapter 2.3). Certain generalisations about the consequence of reducing herbicide dose and reducing competition are possible. Where herbicide was already applied effectively at high doses, as at Drayton, inputs could be reduced with little or no net effect on the weed seedbanks. This was equally true in the Alternative Rotation where competition from the crops was reduced. At High Mowthorpe at the other extreme, herbicide use was insufficient to control the seedbank, even in the most intense treatments. In these circumstances, the lower competition from crops in the Alternative Rotation encouraged massive seedbank populations to form. The other site, Boxworth, had comparably extreme responses between the treatments. Herbicide dose could be reduced but only in the Standard Rotation when winter-sown crops provided strong competition. The less-intense competition in the Alternative Rotations here allowed the seedbank to amplify, especially with low-input herbicide use (see also Chapter 2.3).

Seedbank species diversity

Several aspects of seedbank species diversity need to be considered. The number of species (species richness) gives a general indication of the effect of treatments on floral diversity. Other factors include the frequency with which a species occurs in a sample and the balance between dominants and less common species. The various methods of arranging species and their frequency and abundance give clues as to how a seedbank interacts with a treatment. Knowledge is also useful of the species' functions, such as those governing germination, dormancy, flowering, competitive effects and fecundity.

The importance of sampling volume

Ecological sampling has shown that the number of different coexisting species increases with the area of study site. By taking more samples spread over a site, there will be greater chance of finding rarer species.

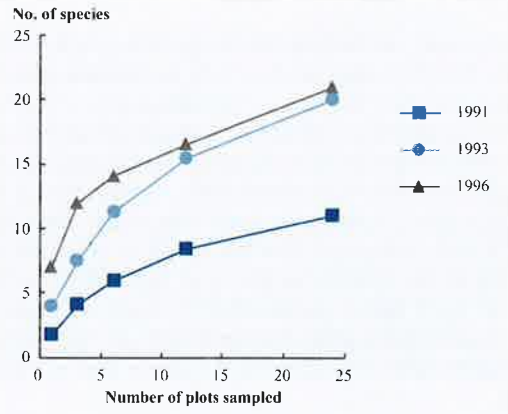

Figure 2.4.2. The relationship between the number of plots sampled and the number of seedbank species detected in TALISMAN at Boxworth.

The commoner species will still be found in most samples, so the actual number of different species detected increases as a diminishing returns curve (**Fig. 2.4.2**). When comparing species richness between treatments, it is essential therefore to do so for the same volume of soil sampled.

Sampling curves give broad-scale insights about how species richness changes with time at a site or treatment. In **Fig. 2.4.2**, the curves are systematically based on the treatments at Boxworth, rather than obtained by randomly sampling from among the plots. The data points representing species richness at the minimum sample size are simply the mean number of species found per plot (n = 24, 600 ml soil sample). The data points at the maximum number of samples represent the total number of taxa found in the 24 plots at the site (n = 1, 14.4 litres of soil sampled). Intermediate points show the mean number of species in three plots (all combinations of rotation, nitrogen, herbicide), six plots (combinations of rotation, herbicide), and twelve plots (rotation only). The whole curve rises between 1991 and 1993, consistent with the increase in species in **Table 2.4.2**. However, only the lower part of the curve increases between 1993 and 1996. This indicates that the total number of species detected stabilised in 1993 at the scale of the rotation and the whole site, but more species became detectable in 1996 in smaller volumes of soil (as a result of increased abundance of existing species). A further point is that the curves did not level off completely at high sample number, implying that more species would have been detected if more samples had been taken. However, the main aim of the sampling was to estimate economically damaging weed seed populations; a sampling method aimed at detecting rare seedbank species would have incurred considerable extra cost.

The curves for the data from High Mowthorpe were similar to those of Boxworth, except that 25 species were found in the 24 plots. The curves for Drayton, though a similar shape to those for other sites, decreased over time. The high degree of weed control at this site must have prevented all but a few common species from seeding, whereas seed of species occurring initially in low numbers decayed to undetectable levels.

Change in species richness during the experiment is summarised in **Table 2.4.2**. There was almost a doubling between the lowest value in the most herbicide-intense treatment (Drayton, Standard Rotation) to the highest value in the least-intense treatment (High Mowthorpe, Standard Rotation). On average, two to three more species were added each year over six years of the low-input herbicide regimes at Boxworth and High Mowthorpe.

Divergence of sites and treatments over time

By 1996, fifty-three taxa had been found at the sites combined, considerably more than at any individual site. Only four - *Brassica* spp. (probably oilseed rape), black-bindweed, annual meadow grass and knotgrass - were common to all sites, but in 1993 and 1996, these taxa were generally low in abundance and contributed little to the changes in total seedbank. Sites had come to support groups of taxa that differed not just in the dominants but in a large part of the less abundant flora also.

Principal co-ordinate analysis was used to show how far the species complement differed within and between sites. The first stage in this form of analysis was to compare all pairs of plots for presence and absence of species and to assign a measure of similarity between zero (no species in common) and one (all species in common). A statistical program then arranges all plots in a graphical space, where plots close together have a similar, and those far apart a less similar, group of species. The principal co-ordinate graphs for 1991 and 1996 (**Fig. 2.4.3**) show an expansion of the data points over time, indicating that the species complement between sites became less similar, to an extent that the sites formed separate groupings in 1996. Drayton was the most tightly clustered site in 1996, indicating plots within that site were more similar to each other than were plots at other sites, a pattern that agrees with the smaller number of species at Drayton and the lack of significant effects of treatment.

The greater spread of data-points for 1996 compared with 1991, especially at Boxworth and High Mowthorpe, was caused by effects of treatment on the species number and complement. Effects of rotation were statistically significant only at Boxworth ($P < 0.001$), where each 600 ml plot sample contained 1 to 3 species in the Standard Rotation and 5 to 7 species in the Alternative Rotation. However, reducing the herbicide input increased species per plot at all sites, commonly by 1 to 3 species ($P < 0.05$). The plots at sites in 1996 that were most different from plots at other sites were usually of the Low Herbicide treatment, and are represented by the circled groups of co-ordinates in the lower part of **Fig. 2.4.3**. The combinations of site and treatment had therefore acted on the initial seedbank to produce assemblages with few species in common. The main taxa in the circled plots are listed in the boxes below the graphs.

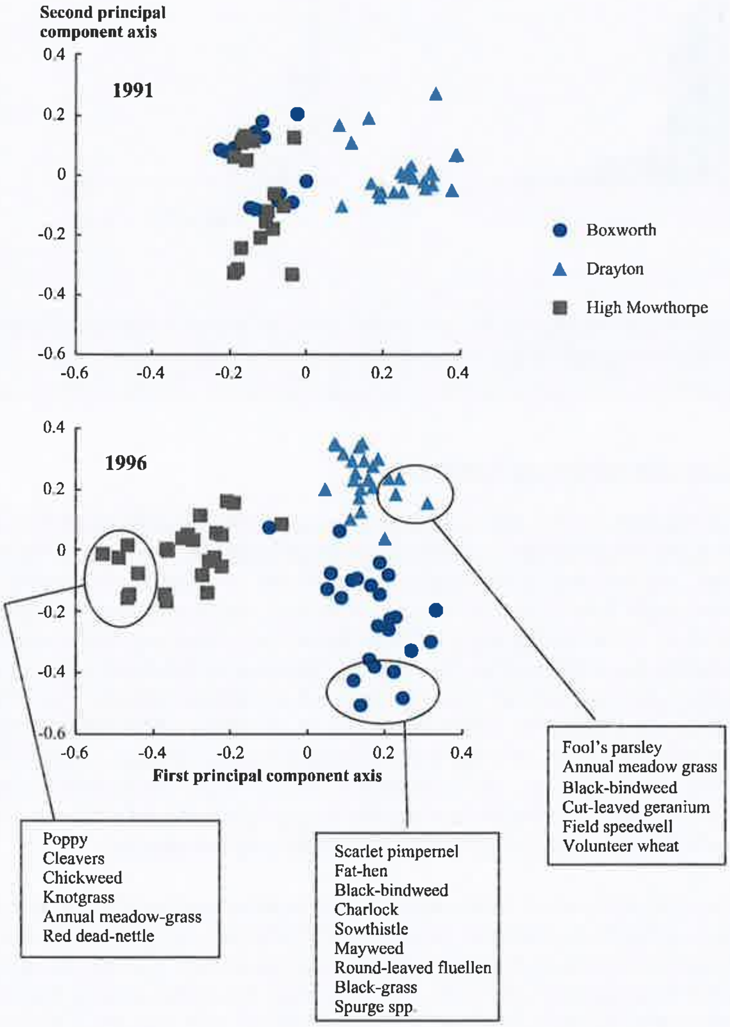

Figure 2.4.3. Principal co-ordinate analysis based on presence/absence of seedbank species in TALISMAN during 1991 and 1996. The species listed in the boxes are typical of the circled data points.

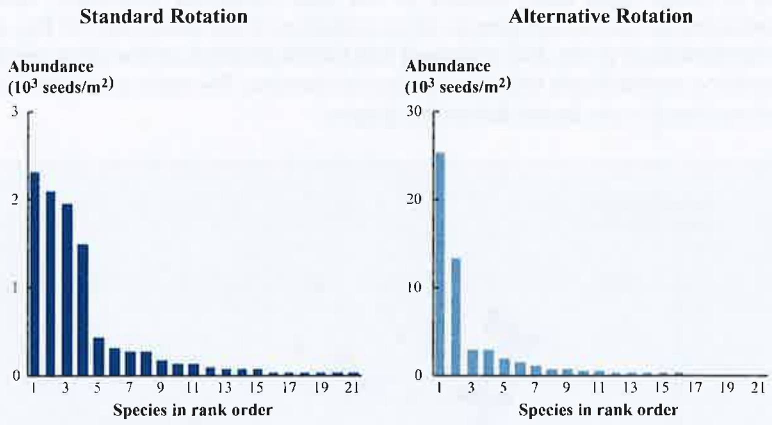

Figure 2.4.4. Examples of species/abundance rankings to show different degrees of species dominance in TALISMAN at High Mowthorpe, 1996.

Dominance and balance of species

Arable seedbanks, in common with other ecosystems, usually consist of a few dominants and other species in much lower abundance. The balance between the dominants and the rest is an important indicator of seedbank diversity. Two seedbanks might have a similar number of species but very different degrees of dominance, as shown in **Fig. 2.4.4**. At High Mowthorpe, four species were present in much higher populations than the other 17. However, in the Alternative Rotation at the same site, one species (poppy) dominated, whilst cleavers were half as abundant as the poppy. The absolute seedbank abundance was much greater in the Alternative Rotation but the two seedbanks also differed in the relative abundance of the species. The seedbanks can therefore be compared by the number of species, the absolute abundance of seeds per unit field area and some measure of the evenness in the spread of seed among the species.

One of the commonly used indices of evenness is calculated as $-\Sigma p \ln p$ where p is the fraction of the total seed in any one species (Kempton, 1979). The value of plnp is calculated for each species in turn, then the total summed. This evenness index increases if more species are found in the seedbank or if the seed is distributed more evenly among them. The maximum possible value in any set of treatments would have the largest number of species found in the experiment, and each would have the same number of seed; the distribution in **Fig. 2.4.4** would then form a horizontal line. The minimum value would occur where there was no seed or where all seed was of one species.

In **Fig. 2.4.5**, values of the evenness index are compared with species number and total seed abundance for all rotation and herbicide treatments. Each co-ordinate represents averages of samples from six replicate plots (N levels combined); abundance is presented per unit field area, and species number is reference to a 600 ml sample. The curved line shows the maximum value of the evenness index with change in species number. If any treatment is on or near this line, all species in the seedbank have the same or a similar number of seeds irrespective of total seed number. Treatments further away from this line on the bottom plane of the graph have a seedbank increasingly dominated by one or two species. The vertical lines from data points are drawn to show where the co-ordinates lie with respect to the bottom plane.

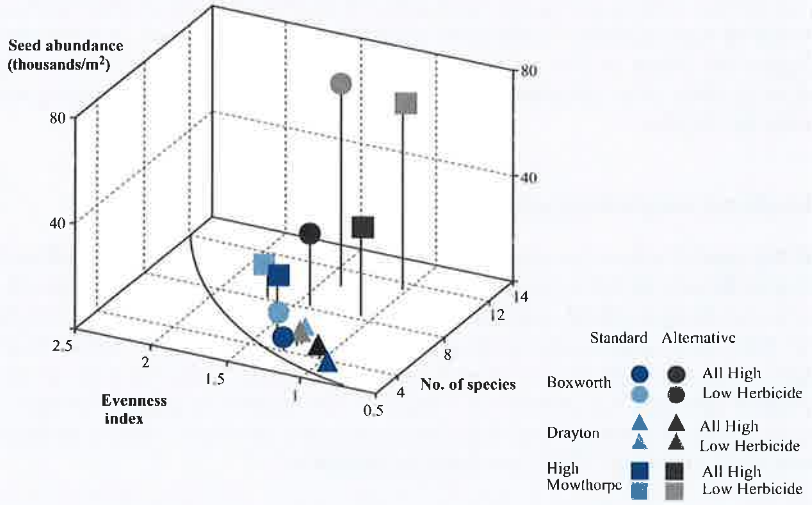

Figure 2.4.5. Three-dimensional plot of species number, evenness index (see text) and seed abundance. Values are averages per plot within rotation-herbicide regimes. The curve shows the maximum possible value of the evenness index at a given species number.

The lie of the data points in **Fig. 2.4.5** suggests there was optimum evenness achieved in the Standard Rotation at High Mowthorpe. Both the All High sub-treatment of the Alternative Rotation and Low Herbicide sub-treatment of the Standard Rotation at Boxworth were also close to the optimum. All the co-ordinates at Drayton were below the optimum, having high evenness and low seedbank abundance but low species number. The Alternative Rotation at High Mowthorpe was above the optimum, having high species number but low evenness (domination by poppy) and high abundance.

The association between species number and seed abundance

The arrangement of co-ordinates in **Fig. 2.4.5** indicates the difficulty of achieving diversity without a potential weed problem, that is high species number together with low or moderate seed abundance.

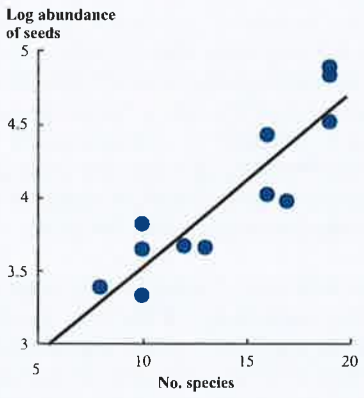

Figure 2.4.6. The relationship between the total number of species detected in TALISMAN rotation-herbicide regimes and the log abundance of seeds (all sites and rotation treatments). The fitted line is $y = 0.119x+2.33$, $r^2 = 0.81$.

More detailed investigation of the distribution of seed among the species revealed that the Low Herbicide treatments formed an approximately lognormal species-abundance distribution. When herbicide inputs were reduced, the distribution widened, such that whereas new species were detected, the existing dominant species increased considerably (on a non-log scale). The relation between number of species detected in a rotation and the log number of seeds was largely consistent for all sites and rotation treatments; those treatments with over four herbicide units applied annually form the lower co-ordinates (**Fig. 2.4.6**).

The population dynamics underlying the association in **Fig. 2.4.6** are not yet understood. The rotations and low-herbicide treatments that provide spatial and temporal opportunities for the rarer species must provide them in much greater degree for some of the common ones. Progress will depend on identifying opportunities that stimulate the rarer weed species without encouraging the commoner ones.

Functional weighting of species

All the species were treated equally in the above analysis. Single seeds of wild oat (*Avena fatua*), cleavers, poppy, round-leaved fluellen, cut-leaved geranium and bristly ox-tongue (*Picris echioides*) were equally weighted. Given this condition, the maximum value on the curve of evenness on species number occurred when species number was in the range 6 to 9 in a 600 ml sample of soil, or 20 in a rotation treatment as a whole (12 × 600 ml). The maximum species number, 13 or 14 in a 600 ml sample, was achieved only in the presence of one or two very dominant species and high seedbank populations.

The optimum conditions would be different, however, if the criteria for weighting species depended on ecological function, competitive effect, ease of control or a rareness factor. For instance, poppy is a much less competitive weed than wild oat or cleavers, so could be given much less weighting than them. Even if every two poppy seeds were counted as one, the optimum species number (that maximising evenness in **Fig. 2.4.5**) would shift slightly to a higher species number. Conversely, if rarer species were counted as more than one, their presence would also increase the optimum species number in **Fig. 2.4.5**.

The limitation to this approach is that the weighting criteria are of a different nature. Some such as competitiveness against the crop and ease of control by selective herbicide can be measured experimentally. Ecological criteria, such as niche, can at least be quantified in terms of resource use. Others, such as the value of rareness, are largely subjective, unless a price is put on them so they can be compared with farm profits.

Links between seedbank and weed flora

Contribution of weed populations to final seedbank

The results presented earlier show that the total seedbank population either remained stable or increased during the experiment. This maintenance or increase would have occurred despite a continuous decline of seedbank populations through decay and predation. Additions to the seedbank were therefore likely in most plots, the new seed being the result of seed drop by the weed flora or seed transported into the plots. Since some treatments lying only a few metres apart differed very considerably in their seedbank populations and dynamics, seed transport to and between plots probably occurred only at a low rate throughout the experiment. The final seedbank populations were therefore likely to have originated from reproduction and seed drop by the weeds within the plots.

The large and varied weed seed populations in the Low Herbicide sub-treatments of the Alternative Rotation well illustrate the dependence of the final seedbank taxa on the preceding weed populations (**Table 2.4.3**). Most of the abundant weed species in the summer of 1996 were also high ranking in the autumn seedbank. The correspondence is particularly good at Boxworth, where the five highest ranking taxa are the same in the weed flora and seedbank, though the rank order differed slightly. At Drayton and High Mowthorpe, four out of the top five weed taxa were in the top five of the seedbank.

Considering all the main weed taxa reported in **Table 2.4.3**, only one was not found in the seedbank. This exception was charlock at Drayton in 1996, also not found in the seedbank there in any other year. However, charlock was only in low abundance as a weed, and might not have shed seed in great enough quantity to be detected. Where all other discrepancies occurred, the species was present in the seedbank but not as a weed in 1996. At Boxworth, the only substantive seedbank species missing from the weed flora was round-leaved fluellen, a plant of slight stature that might have been missed. At Drayton, wild oat at 5th rank in the seedbank was absent at the summer weed count but had been present as a weed early in the year (and in previous years) and had been controlled by herbicide in 1996. At High Mowthorpe, seedbank taxa previously recorded as weeds were annual meadow grass (3rd in the 1996 seedbank, last recorded 1995), and shepherd's purse (6th, last recorded 1994). Therefore, the main seedbank taxa were also the most prevalent weeds above ground, either in the summer of 1996 or in a previous year.

Potential future weed problems

Although consistent in the most abundant taxa, the weed flora and seedbank differed in several important respects. The dominants in the less-intense treatments at Boxworth and High Mowthorpe were present in the seedbank in much greater numbers than the weed counts alone would suggest. For instance, Drayton and High Mowthorpe had similar weed counts, but the seedbank in autumn was many times larger at High Mowthorpe (**Table 2.4.3**). The greater use of herbicide, coupled with greater competition from the crop at Drayton, suppressed the weeds present in summer and all but prevented them from seeding, while the less intensive management at High Mowthorpe allowed the weeds to reproduce and provide a considerable return to the already substantial seedbanks of poppy especially, but also cleavers and a few other species.

By 1996 in the Alternative Rotations, ratios of autumn seedbank to summer weeds were approximately 50:1 for fat-hen and 100:1 for scarlet pimpernel at Boxworth, and 2000:1 for poppy and 200:1 for cleavers and several other taxa at High Mowthorpe. The reproductive capacity of such species, if unchecked, is such that these ratios could arise following a single seeding year (Salisbury, 1942). However, the build up was more likely to have occurred over several years, since among the plots and treatments in a site, the size of these species' seedbanks was closely related to the plant population during the whole experiment. For example, the poppy seedbank at autumn 1996 was linearly related to the number of poppy plants counted (per unit field area) during the whole six years of the experiment (850 seeds to one plant). Notably, the seed/plant ratio was very low in the Standard Rotation which must have suppressed the plants' fecundity as well as seedling establishment. By allowing seeding of what initially were small populations of certain species, the Alternative Rotations at these two sites had resulted in a massive future weed problem. Most of the species concerned are long-lived. Even if all subsequent seedlings were killed or prevented from seeding further, the resultant losses to the seedbank would be trivial for many years.

A further important difference in weed flora and seedbank lay in the many seedbank species that were rarely or not recorded as weeds. For example, comparison of **Tables 2.4.1 & 3** (Boxworth) shows that taxa such as spurge (*Euphorbia* spp.), chickweed, prickly sow-thistle (*Sonchus asper*) and several others were present in moderate abundance in the seedbank but were not present, or not in quantity to be worth counting as weeds, in 1996. These discrepancies could have arisen simply because species at low abundance or in a fragmented distribution can easily be missed in any sampling scheme. All on this list but spurge had been found at least somewhere on the site in low abundance. A comparable set of moderately abundant seedbank species that were not major weeds during the experiment was also found at Drayton and High Mowthorpe. However, the low-input herbicide regime at Drayton had reduced the number of such potential weeds presently in low abundance, whereas the comparatively lower herbicide usage in the Alternative Rotations at Boxworth and High Mowthorpe had increased their number.

Conclusions

This six-year experiment 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 agrochemical consumption by introducing both spring-sown crops and reduced herbicide input failed at two sites (Boxworth & High Mowthorpe) in terms of the very high weed seedbank populations that accumulated. There appeared a fine balance between suppression and release of the seedbank, such that below a certain level of management intensity, the seedbank amplified to very high populations of long-lived species.

The aims of TALISMAN were to determine how far agrochemical inputs could be reduced without an economic loss to the farm. The approach, and much of the existing data, could also be used to assess the effect of the range of inputs on arable seedbank diversity in the broad sense that includes species number, evenness and function. However, the ecological criteria for such an aim and the 'value' of different species need to be determined before progress can be made.

Given a definite set of criteria, the challenge is now to identify the minimum inputs that would achieve control of weed species and assemblages in systems that are inherently very sensitive to 'relaxation' of herbicide use. Routinely reducing the herbicide rates or omitting applications is unlikely to be an option if dominance by one or two weed species is to be prevented. Herbicide use in spring crops in particular is limited by fewer approved active ingredients and shorter spraying windows than in winter crops. Moreover, the application of a single regime for a run of years is unlikely to be the best option for reducing inputs in the long term. Wright *et al.* (1993) and Davies *et al.* (1993) suggested avoiding a continuous run of autumn- or spring-sown crops and having a flexible approach to reducing herbicide dose-rates and preventive treatments. The experience of low-input herbicide use in TALISMAN supports this view.

Acknowledgements

We owe our thanks to Mr H M Lawson for establishing this seedbank study and giving his advice on the analysis.

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Table 2.4.1. Change of soil seedbanks over time and among treatments in TALISMAN at Boxworth (seeds/m²).

Taxa		1991	1993		1996			
		General	Standard	Alternative	Standard Rotation		Alternative Rotation	
		Mean	Rotation	Rotation	All High	Low Herbicide	All High	Low Herbicide
Anagallis arvensis	Scarlet pimpernel	56	170	920	300	600	10,900	39,400
Chenopodium album	Fat-hen	56	140	110	300	1,200	6,300	20,000
Sinapis arvensis	Charlock	0	28	28	0	60	1,330	4,220
Alopecurus myosuroides	Black-grass	14	0	390	330	440	1,060	2,670
Fallopia convolvulus	Black-bindweed	14	0	110	0	0	610	2,000
Polygonum aviculare	Knotgrass	0	0	56	0	0	110	1,830
Kickxia spuria	Round-leaved fluellen	0	28	140	0	60	4,330	1,280
Matricaria spp.	Mayweed	0	0	83	0	56	170	1,220
Euphorbia spp.	Spurge	0	0	0	0	0	110	670
Galium aparine	Cleavers	0	28	83	170	830	560	560
Plantago major	Greater plantain	0	0	0	0	0	0	560
Stellaria media	Chickweed	0	470	83	0	110	56	560
Sonchus asper	Prickly sow-thistle	0	560	110	440	170	0	440
Brassica spp.	Volunteer oilseed rape	1,320	1,030	280	280	390	220	170
Capsella bursa-pastoris	Shepherd's purse	14	140	28	170	56	56	170
Veronica hederifolia	Ivy-leaved speedwell	0	0	0	0	110	0	170
Epilobium spp.	Willowherb	0	0	0	0	0	0	110
Avena sterilis	Winter wild oat	0	0	0	390	330	170	56
Picris echioides	Bristly oxtongue	0	0	0	0	0	56	56
Papaver spp.	Poppy	0	56	83	0	0	110	0
Poa spp.	Meadow grass	190	306	56	0	56	0	0
Other spp. (6)		70	84	28	0	0	0	0
Total		1,734	3,040	2,588	2,380	4,468	26,148	76,142

Table 2.4.2. Total numbers of species of weed seeds recorded at the TALISMAN sites.

	1991	1993	1996
Boxworth			
Whole site	11	20	21
Standard Rotation	10	15	13
Alternative Rotation	7	16	20
Drayton			
Whole site	16	17	14
Standard Rotation	10	15	11
Alternative Rotation	14	13	12
High Mowthorpe			
Whole site	14	24	25
Standard Rotation	12	21	20
Alternative Rotation	11	24	22

Table 2.4.3. Comparison of weed flora and seedbank populations for the most abundant weed taxa in the Low Herbicide sub-treatments of the Alternative Rotations in 1996. Weed flora taxa are ranked by abundance; the far right column shows the corresponding abundance rank for the seedbank.

Taxa		Weed flora on 2 May 1996 (plants/m^2)	Seedbank in autumn 1996	
			Seeds/m^2	Rank
Boxworth				
Chenopodium album	Fat-hen	390	20,000	2
Sinapis arvensis	Charlock	385	4,220	3
Anagallis arvensis	Scarlet pimpernel	310	39,400	1
Fallopia convolvulus	Black-bindweed	34	2,000	5
Matricaria spp.	Mayweed	13	1,220	8
Veronica arvensis	Speedwell	13	170	16
Galium aparine	Cleavers	12	560	10
Alopecurus myosuroides	Black-grass	11	2,670	4
Polygonum aviculare	Knotgrass	4	1,830	6
Drayton				
Aethusa cynapium	Fool's parsley	38	1,280	2
Chenopodium album	Fat-hen	31	111	6
Polygonum aviculare	Knotgrass	8	56	10
Fallopia convolvulus	Black-bindweed	7	389	4
Veronica arvensis	Speedwell	5	1,610	1
Poa spp.	Meadow grass	3	390	3
Sinapis arvensis	Charlock	1	0	-
High Mowthorpe				
Papaver spp.	Poppy	27	54,800	1
Galium aparine	Cleavers	13	2,170	2
Veronica arvensis	Speedwell	9	780	9
Stellaria media	Chickweed	8	1,280	4
Fallopia convolvulus	Black-bindweed	6	1,220	5
Fumaria officinalis	Common fumitory	6	1,060	7
Sonchus spp.	Sowthistle	3	940	8
Lamium purpureum	Red dead-nettle	2	278	14
Senecio vulgaris	Groundsel	1	56	18

DISEASE CONTROL: THE AGRONOMIC AND ECONOMIC EFFECTS OF REDUCING FUNGICIDE USE

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Introduction

The value of fungicides for disease control in winter wheat, winter barley and spring barley has been well established since the late 1970s (Cook & Jenkins, 1988). On winter wheat, two-spray programmes were profitable in about 80% of experiments and performed more reliably than single sprays. Both disease resistance and the 'responsiveness' of plant varieties to fungicides affected the profitability of treatments (Cook & Jenkins, 1988). During the period 1985-1989, diseases of winter wheat caused estimated losses of £113 million/annum (8% of production) after fungicide treatment, excluding losses from take-all (*Gaeumannomyces graminis*) which were about £43 million/annum (Cook *et al.*, 1991). The benefits from fungicides were worth £217 million/annum and this could be increased by a further £40 million/annum by improved timing of fungicides (Cook *et al.*, 1991). The development of very effective fungicides has enabled reduced dose strategies to be adopted and principles of defining optimum dose have been established (Paveley *et al.*, 1998).

Winter barley also gave profitable yield responses after two-spray programmes of fungicides. The first spray in the spring at stem extension – first node stage (GS 30-31) (Tottman, 1987) – is more important than the second treatment at flag-leaf emergence to ear emergence stage (GS 39-59) (Cook & Jenkins, 1988) as late-season disease problems are very variable in importance (Gladders & Hims, 1994) and flag leaves may contribute less to yield than in other cereals. Spring barley has given very large yield responses to fungicide where severe powdery mildew (*Blumeria graminis*) was controlled and single treatments may be adequate, provided fungicide resistance does not impair disease control (Clark, 1992).

Cultivar resistance has made a substantial contribution to disease control (Priestley & Bayles, 1988) but its full potential has not been exploited as farmers often give higher priority to agronomic factors than to high disease resistance.

In combinable break crops, disease problems are of considerable importance, particularly in winter oilseed rape (Fitt *et al.*, 1997) and field beans (Gladders, 1988; Gladders *et al.*, 1991). Diseases in these crops show considerable regional and seasonal variation (Fitt *et al.*, 1997) and control strategies are still being developed (Gladders, 1998). Fungicides may not be cost-effective in break crops when disease pressure is low. Crop rotation and varietal resistance are also important elements in reducing the risk of yield loss from a wide range of potential pathogens.

This chapter considers the effects of reducing fungicide treatments on disease control, yield and gross margins in rotations involving six years of cropping at the three contrasting sites in the TALISMAN project. This project provided the opportunity to examine in detail the effects of reducing fungicide dose in a wide range of crops and diverse conditions, a significant progression from the Boxworth Project (see Chapter 1.1).

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

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The design of TALISMAN (Chapter 2.1) allowed evaluation of reduced fungicide inputs on individual crops and also enabled cumulative effects of rotation, nitrogen treatments and pesticides on soil- and trash-borne diseases such as take-all and eyespot (*Tapesia* spp., imperfect stage *Pseudocercosporella herpotrichoides*) respectively, to be monitored.

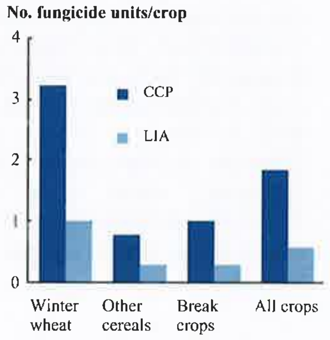
Fungicide treatments were selected to represent the most commonly used products as indicated by the most recent Pesticide Usage Survey (Thomas *et al.*, 1997) or local practice when new products became available. Full label-recommended rates were used in the Current Commercial Practice (CCP) regime and compared with the Low Input Approach (LIA), where treatments were omitted or used at up to 50% of CCP rate if a yield loss of more than 10% was expected. The CCP regime had optimal nitrogen application and half this rate was applied to LIA (Chapter 2.2). As fungicides with increased levels of fungicidal activity became commercially available during the course of the project, the opportunity was taken to more rigorously reduce the doses applied in LIA compared with CCP.

Disease control in cereals followed guidelines laid down in the ADAS Managed Disease Control programmes (Anon., 1986). Treatments were applied when there was a risk of disease development in specific crops. This was determined by regular monitoring of crops throughout the growing season at intervals of 7-10 days and local knowledge guided by the Technical Management Team of ADAS Consultants. Managed disease control programmes continue to evolve, to take account of changes in crop plant varieties or varietal resistance to diseases and the effectiveness of current or new fungicides. Decisions are made at certain key growth stages and the most important criteria are summarised in **Tables 2.5.1-3**. Critical decisions are at flag leaf emergence (GS 39) for winter wheat, stem extension (GS 30) and flag leaf emergence (GS 39) for winter barley and stem extension (GS 30) for spring barley. Routine treatment would usually be considered at these timings if some disease is present.

Disease assessments were carried out when fungicide treatments were applied and post-spraying to evaluate the effects of treatment when differences were apparent. The mean severity of foliar diseases, expressed as the percentage leaf area affected, was derived by samples of 10 tillers per sub-plot. Stem-base and root disease were assessed as samples of 25 plants (spring) or 25 tillers per sub-plot. The mean incidence and/or severity (% leaf area affected or disease index for stem diseases) was calculated and analysed as appropriate.

Fungicide inputs

Winter wheat received the highest fungicide inputs, averaging 3.1 units in CCP and 1.0 in LIA (**Fig. 2.5.1**). In all references to pesticide units, one unit is defined as one active ingredient applied at full label recommended rate; a formulated mixture with two active ingredients equals two units when applied at the full label rate. There were no differences in fungicide inputs between first and second winter wheat crops. Break crops and other cereals (barley, triticale) averaged 1.0 and 0.8 units, respectively, under CCP. Substantial reductions in fungicide were achieved with the LIA regime on all crops, and over all 70 crops, LIA treatments averaged 0.6 units compared with 1.8 in CCP (a 68% reduction) (**Fig. 2.5.1**).



Crop	*Number of crops*
Winter wheat	28
Other cereals	18
Break crops	24
All crops	70

Figure 2.5.1. Mean number of fungicide units applied to winter wheat and other crop groups, TALISMAN 1990–96. One unit = one active ingredient at full label recommended rate.

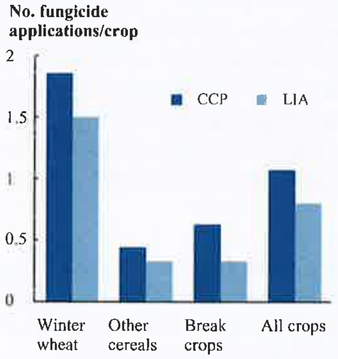


Figure 2.5.2. Mean number of fungicide applications to winter wheat and other crop groups, TALISMAN 1990–96.

There were some savings from reducing the number of spray applications, particularly for other cereals (i.e. cereals excluding winter wheat) (**Fig. 2.5.2**) and this was most marked between CCP and LIA for break crops, where approximately half of the crops treated under CCP received treatment in LIA. On wheat, there was a reduction in the number of applications from 1.9 spray rounds in CCP to 1.5 in LIA (**Fig. 2.5.2**). Savings from not treating winter wheat crops were more modest and all winter wheat crops received fungicide in CCP and 93% were treated in LIA, a much higher proportion than for either break crops or other cereals (**Fig. 2.5.3**). There was a reduction in the total number of fungicide active ingredients applied in LIA compared with CCP (**Fig. 2.5.4**) in all crop types and this resulted in a 24% reduction overall.

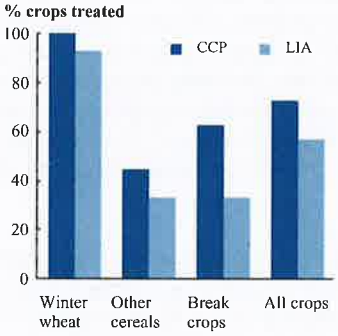


Figure 2.5.3. Percentage of winter wheat and other crop groups treated with fungicide, TALISMAN 1990–96.

The most commonly used fungicide active ingredients were propiconazole and chlorothalonil, which were used predominantly as single formulated products applied alone or in tank mixtures on cereals (**Table 2.5.4**). There was limited use of formulated mixtures of fungicides. Both epoxiconazole and tebuconazole became available only during the course of the project and replaced propiconazole in the latter stages. Chlorothalonil and benomyl were the most frequently used active ingredients on break crops, reflecting a major use against foliar diseases on field beans (**Table 2.5.5**).

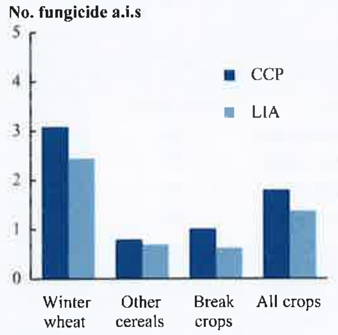


Figure 2.5.4. Mean number of fungicide active ingredients (a.i.s) applied to winter wheat and other crop groups, TALISMAN 1990–96.

There were lower fungicide inputs in the Alternative Rotations than in the Standard Rotations (**Table 2.5.6**). At Boxworth, six fewer fungicide units were applied under CCP to Phase II than to Phase I of the Standard Rotation. At High Mowthorpe, more fungicides were used on the Alternative Rotation than at Drayton, where fungicides were not used on triticale.

Yields and gross margins

The Low Fungicide and All High pesticide sub-treatments (Chapter 2.1) gave similar first and second wheat yields at Boxworth, Drayton and High Mowthorpe (**Table 2.5.7**). Results were remarkably consistent for all three sites when averaged for all wheat crops, with only a one per cent reduction in yield compared with All High (**Table 2.5.7**). Winter barley and spring wheat gave lower yields (95% and 96%, respectively) under Low Fungicide than All High, but the differences were not significant (**Table 2.5.7**). Spring barley and triticale were within one per cent of the yields of the All High, although these differences were also non-significant.

Low Fungicide appeared to increase yield of winter oilseed rape at Boxworth by 0.41 t/ha compared with All High ($P < 0.001$) and reduced the yield of spring rape by 0.28 t/ha at the same site ($P < 0.05$) (**Table 2.5.8**). The yields of all these crops were poor and the differences were not associated with diseases or disease control.

Beans, linseed and spring oats showed positive or negative differences of up to five per cent in yield in Low Fungicide compared with All High, but the differences were all non-significant (**Table 2.5.8**). Differences between the All Low and Low Fungicide sub-treatments suggested that factors other than diseases influenced the response to the All Low sub-treatments.

Gross margins for Low Fungicide were significantly higher than the All High sub-treatments for first wheats at Boxworth ($P < 0.001$) and High Mowthorpe ($P < 0.001$) and cross-site means ($P < 0.001$) (**Table 2.5.9**) and for second wheats at Drayton ($P < 0.001$). Gross margins were also higher when averaged over all wheats at Drayton ($P < 0.001$) and High Mowthorpe ($P < 0.001$), and in the cross-site analyses ($P < 0.001$). Differences in gross margin for Low Fungicide on both winter and spring barley, triticale and spring wheat were not significantly different from All High. Margins were lower for All Low on spring wheat ($P < 0.001$) and higher for All Low on triticale ($P < 0.001$), but probably reflect differences from treatments other than fungicide (**Table 2.5.9**).

Low Fungicide improved gross margins for winter oilseed rape only at Boxworth ($P < 0.001$), but had no effect on margins in spring oilseed rape (**Table 2.5.10**). On winter beans, Low Fungicide improved gross margins at Boxworth and the cross-site means ($P < 0.001$) compared with All High but the Low Fungicide regime had no effect on gross margin for spring beans (**Table 2.5.10**). Differences between All High and Low Fungicide were also non-significant for spring linseed and spring oats.

Low Fungicide gave a higher gross margin than All High for all cereals (averaged over three sites) of £16/ha and differences were significant at Drayton ($P < 0.001$) and High Mowthorpe ($P < 0.001$) but not at Boxworth (**Table 2.5.11**). Break crops showed a mean increase in gross margin from Low Fungicide over All High of £35/ha at Boxworth ($P < 0.01$), but differences for Drayton and High Mowthorpe and cross-site means were not significant. However, averages over all crops showed that Low Fungicide had significantly improved gross margins at Boxworth ($P < 0.001$), High Mowthorpe and in overall cross-site means by £16/ha ($P < 0.001$) (**Table 2.5.11**). Low Fungicide was more cost-effective than All Low at Boxworth ($P < 0.001$) and High Mowthorpe ($P < 0.001$). However, the All Low was superior to Low Fungicides at Drayton for both cereals ($P < 0.001$) and all crops ($P < 0.001$) but not for break crops (**Table 2.5.11**).

There was a larger effect of nitrogen treatments than pesticide sub-treatments on the yield of winter wheat and LIA nitrogen yielded 0.92 t/ha less than CCP nitrogen (7.97 t/ha). The Low Fungicide sub-treatment of winter wheat gave marginally less yield (0.07 t/ha) than the All High treatment and both were higher yielding than All Low by 0.43 and 0.53 t/ha, respectively, at CCP N and by 0.31 and 0.35 t/ha at LIA N (**Fig. 2.5.5**). The use of Low Fungicide improved gross margins over the All High regime under both CCP and LIA nitrogen treatments by £21 and £27/ha, respectively, and gave the highest gross margins of all the pesticide sub-treatments (**Fig. 2.5.5**). This benefit from Low Fungicide was consistent for cereal crops, occurring across all sites and all years, except in 1992 at Drayton when Low Fungicides gave a £0.80/ha lower margin than All High.

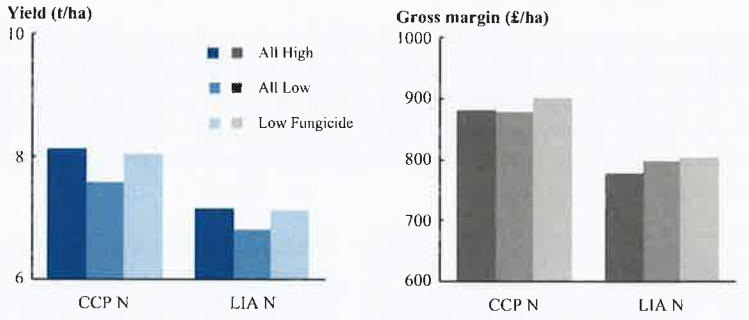


Figure 2.5.5. Mean yield and gross margin of winter wheat in relation to nitrogen and fungicide inputs, TALISMAN 1990–96. SEDs (651 d.f.) for comparisons within each nitrogen/pesticide group: yield 0.050; gross margin 5.89.

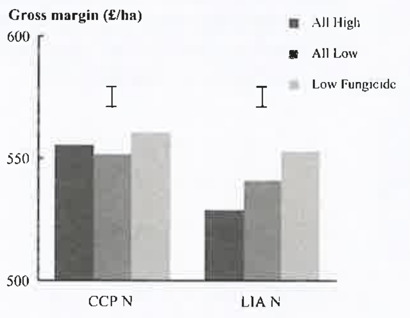


Figure 2.5.6. Mean gross margin of break crops in relation to nitrogen and fungicide inputs, TALISMAN 1990–96. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

The Low Fungicide sub-treatment gave the highest gross margins for break crops of all the pesticide sub-treatments under both CCP and LIA N, though the differences were most apparent under the LIA N treatment, which improved gross margins by £25/ha compared with £5/ha under CCP N. Gross margins for break crops were much lower than for winter wheat and were highest in Low Fungicide at CCP N (£560/ha) (**Fig. 2.5.6**). The improved gross margins from Low Fungicides occurred at all three sites in both seasons when break crops were grown, except at Drayton in 1991 when Low Fungicides gave a lower return of £15/ha compared with All High. In 1991, the lower returns from Low Fungicide were associated with poor disease control in field beans and probable yield enhancement from prochloraz (applied to CCP only) on winter oilseed rape (Stafford *et al.*, 1995). The gross margins of pesticide sub-treatments differed in relation to site and year, but did not differ within nitrogen treatment. Differential nitrogen treatments were not applied to field beans and, therefore, differences in nitrogen response reflected soil residues.

Examination of the consistency of the benefits of Low Fungicide sub-treatments compared with All High has been carried out under both CCP N and LIA N. Positive benefits in gross margin were recorded in 44 out of 66 crops at CCP N and in 45 out of 66 crops at LIA N. Positive benefits in gross margin from Low Fungicide occurred on first and second winter wheat crops under both CCP N and LIA N and were found in 23 out of 28 crops. Yields were higher in 20 out of 66 crops at CCP N and in 23 out of 66 crops at LIA N. Gross margins were higher for Low Fungicide than All High in 5 years out of 6 (not 1991 - see above comments for Drayton) for Standard Rotations and in three years out of six for Alternative Rotations. At LIA N, annual gross margins were improved by Low Fungicide inputs for all rotations except Alternative Rotations in 1994 and 1996. In 1994 and 1996, there was very little disease in crops grown in the Alternative Rotations, such that no fungicides were applied to spring barley at High Mowthorpe in 1996. At LIA N, there appears to be the opportunity to reduce fungicides still further and hence improve margins by saving the cost of fungicide.

Effects of diseases on yield

There were few cases where diseases contributed to significant yield differences between treatments. At Drayton in 1996, a build-up of sooty moulds (*Alternaria* spp. and *Cladosporium* spp.) late in the season contributed to the lower yield (7.75 t/ha) in the Low Fungicide sub-treatment compared with All High (7.96 t/ha) sub-treatments of winter wheat. There was a large response to nitrogen, which averaged 1.28 t/ha (**Fig. 2.5.7**).

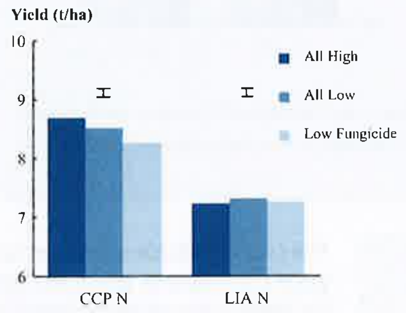


Figure 2.5.7. Effect of fungicide and nitrogen treatment on yield of winter wheat cv. Hussar, Standard Rotation Phase I, Drayton 1996. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

Similar significant effects were also apparent in the winter wheat of Standard Rotation II at Drayton in 1996; pesticide sub-treatment means were 8.14 t/ha (All High), 7.76 t/ha (All Low) and 7.88 t/ha (Low Fungicide). A yield reduction in the Low Fungicide sub-treatment in spring oilseed rape at Boxworth in 1993, however, was not associated with a specific disease problem and was confounded by the presence of wheat volunteers (**Table 2.5.8**).

Diseases and disease control

Disease severity was generally low and only occasionally affected more than 10% of leaf area. Under these conditions, the LIA approach provided adequate control without jeopardising yield. There were a few cases where reduced fungicide dose resulted in impaired disease control and data are presented for All Low and Low Fungicide sub-treatments in comparison with the All High under CCP and LIA N.

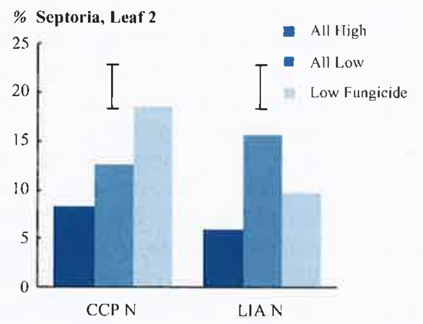


Figure 2.5.8. Control of *Septoria* spp. in relation to fungicide and nitrogen treatments, winter wheat cv. Riband, Standard Rotation I, Drayton 1992. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

Septoria leaf spot (*Septoria* spp.) affected 18.4% of leaf area on 4 July in winter wheat cv. Riband following half rate fungicide application of propiconazole (14 May) and propiconazole + fenpropimorph + chlorothalonil (12 June) to CCP nitrogen treatments at Drayton in 1992. Full-rate fungicide was more effective ($P < 0.05$) and resulted in 8.1% of leaf area of Leaf 2 affected by septoria compared with 18.4% in Low Fungicide (**Fig. 2.5.8**). Disease severity was lower under LIA nitrogen except for the All Low treatment. Crop lodging in CCP nitrogen treatments accounted for the lack of yield responses at the site.

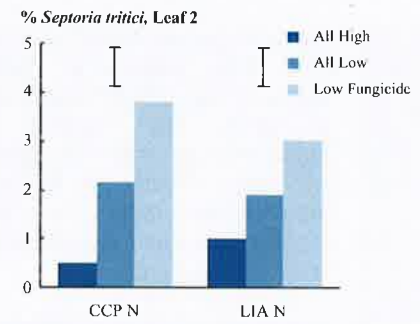


Figure 2.5.9. Control of *Septoria tritici* in relation to fungicide and nitrogen treatments, winter wheat cv. Riband, Standard Rotation II, Drayton 1993. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

Rather more consistent differences between All High, All Low and Low Fungicides were apparent for *Septoria tritici* on leaf 2 of winter wheat at Drayton on 19 July 1993 (0.7%, 2.0% and 3.4%, respectively). Reducing fungicide dose (cyproconazole + prochloraz on 6 May, propiconazole + fenpropimorph on 14 June and propiconazole on 23 June) from full to half rate impaired disease control ($P < 0.05$) (**Fig. 2.5.9**). Nitrogen rate had little effect on disease severity in 1993, though only low levels of disease developed in this case.

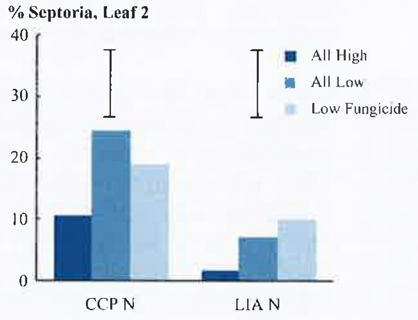


Figure 2.5.10. Control of *Septoria* spp. on winter triticale cv. Lasko, Alternative Rotation II, in relation to nitrogen and fungicide treatment, Drayton 1992. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

A single full-rate application of propiconazole to All High on winter triticale on 8 June 1992 at Drayton gave partial control of *Septoria* spp. on leaf 2 by 4 July under CCP nitrogen (10.5% leaf area affected), but appeared to be more effective (1.4% leaf area affected) under the lower disease pressure experienced on the LIA nitrogen (**Fig. 2.5.10**). Fungicides were not used on the Low Fungicide or the All Low sub-treatments and these differences in disease severity were not significant and there were no effects on yield.

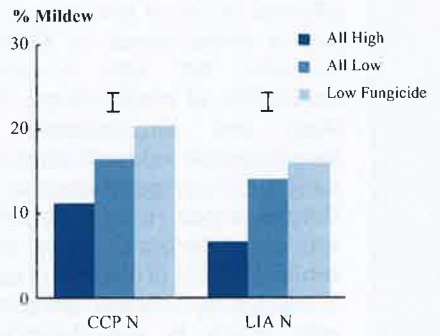


Figure 2.5.11. Control of powdery mildew in spring oats (leaf 2, GS 73), Alternative Rotation II, Drayton 1991. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

Moderate powdery mildew infection in spring oats cv. Keeper (Alternative Rotation II) at Drayton on 26 July 1991 (GS 73) was contained on leaf 2 by full-rate propiconazole applied on 28 June, but half-rate fungicide in Low Fungicide (18.0% leaf area affected) and All Low (13.8% leaf area affected) gave unsatisfactory control ($P < 0.01$) under both CCP and LIA nitrogen treatments compared with All High (8.9%) (**Fig. 2.5.11**). At the same time, there was less mildew on leaf 3 (5.4%) in the LIA N treatment than there was at CCP N (10.1%) ($P < 0.05$). The absence of yield effects was attributed to the relatively late development of mildew at this site.

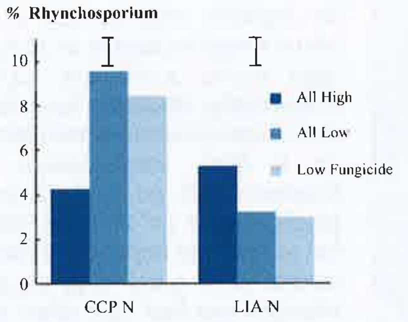


Figure 2.5.12. Control of rhynchosporium on leaf 3 (GS 59, 18 June) in spring barley cv. Hart, Alternative Rotation I, at High Mowthorpe 1993. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

Rhynchosporium secalis was the main foliar disease in spring barley cv. Hart at High Mowthorpe in 1993. The mixture of propiconazole and tridemorph was more effective at full-rate than half-rate under CCP N, but the opposite trend was detected at LIA N (**Fig. 2.5.12**).

It generally proved more difficult to achieve good control of diseases in break crops. This was typified by chocolate spot results from Drayton on 9 July 1991 where there were no significant differences between full- (5.4% leaf area affected) and half-rate (6.9% leaf area affected) treatment with benomyl and chlorothalonil applied on 21 June to winter beans.

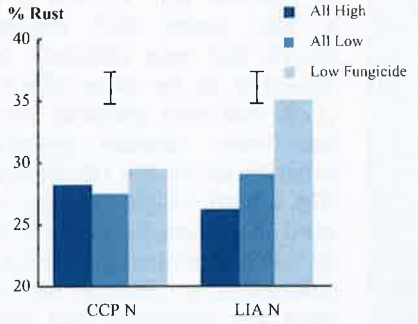


Figure 2.5.13. Rust severity in spring beans cv. Troy in relation to fungicide and nitrogen treatments, Alternative Rotation I, Drayton 1991. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

There were few cases where disease control was considered unsatisfactory within the TALISMAN experiment. A notable exception was the failure to control rust in spring beans cv. Troy in Alternative Rotation I at Drayton in 1991. Full- and half-rate applications of metalaxyl and chlorothalonil to control downy mildew (*Peronospora viciae*) on 10 July were unable to contain subsequent rust (*Uromyces viciae-fabae*) infection. Rust developed uniformly in the experiment and significant differences were detected despite small differences in severity. There was more mid-plant rust ($P < 0.05$) in Low Fungicide (32.3%) than in All High (27.2%) or All Low (28.2%) sub-treatments on 8 August (**Fig. 2.5.13**).

In winter oilseed rape at Boxworth in 1991, partial control of phoma leaf spot (reduced from 55% plants affected to 39%) was achieved from a single full-rate application of prochloraz applied on 28 January to All High (no fungicide was applied to Low Fungicide or All Low sub-treatments), following an assessment on 18 January showing 45% of plants were affected (**Table 2.5.12**). Subsequently, leaf spotting declined and very low levels of canker were found in July.

In February 1991, at Drayton, more phoma leaf spot was found in the LIA nitrogen treatment than in CCP nitrogen (**Table 2.5.13**). Prochloraz was applied at full rate to All High only on 19 February and reduced disease severity ($P < 0.05$) by 3 April, but there were no differences in phoma-induced canker at harvest or subsequent effects on yield. As observed in other experiments on winter oilseed rape, however, prochloraz-treated plots had a higher yield than the untreated, which may be due to physiological effects of the fungicide (Stafford *et al.*, 1995).

Effects of rotation and integrated control

Integrated control strategies used within TALISMAN included selection of disease-resistant cultivars and delaying sowing to reduce risks of early foliar diseases, eyespot and take-all. Spring cropping replaced some winter cropping in the Alternative Rotation, with a view to reducing disease risk and, hence, the requirement for fungicide sprays. In general, the weather patterns experienced during the TALISMAN project were not conducive to the development of severe stem-base and root diseases at the end of the season. Selected examples are presented to illustrate the complex interactions which need to be considered when planning rotations and management strategies.

In 1991/92, winter wheat cvs Beaver and Riband were sown following break crops on 9 October and cv. Hereward was sown on 22 October in the Alternative Rotation I (ARI) at Boxworth. Propiconazole and chlorothalonil were used at full and half rates on 22 May on cvs Beaver in Standard Rotation I and Riband in Standard Rotation II. In cv. Hereward, full- and half-rate prochloraz was applied against eyespot on 19 May, together with full- and half-rate propiconazole (with chlorothalonil on the CCP treatment only).

Hereward showed the highest incidence of eyespot on 27 April (GS 32) and this was well controlled by prochloraz, giving Hereward the lowest eyespot index at the end of the season (**Table 2.5.14**). Take-all was very low on cv. Hereward in the spring and there was rather more infection on cv. Riband than on cv. Beaver, differences which were still apparent ($P < 0.001$) on 14 July (GS 85). Whilst there was less mildew in the LIA plots, differences for *S. tritici* reflected differences in varietal susceptibility, being most severe on Riband ($P < 0.001$). The NIAB disease ratings were 3 for Riband and 5 for Beaver for *S. tritici*, whilst both varieties had a rating of 7 for mildew resistance and Hereward was rated 6 for both diseases.

The benefits of integrated control at Boxworth in 1992 did not result in higher yield or gross margin for Hereward compared with Riband. The benefits of later drilling for disease control were probably outweighed by the yield penalty from later crop establishment as Riband yielded 6.59 t/ha and Hereward 6.03 t/ha.

In the following year (1992/93) at Boxworth, eyespot was again common in the spring. Winter wheat cv. Hereward sown on 2 October 1992 and spring wheat cv.Tonic sown on 3 March 1993 received propiconazole at full and half rate in CCP and LIA on 9 June, whereas prochloraz was applied to cv.Hereward in CCP only on 13 May (GS 33). Eyespot affected 33.7% of cv. Hereward tillers at the third node stage but there was much less eyespot in the spring wheat ($P < 0.001$) and there were no differences between pesticide treatments (**Table 2.5.15**). However, by July, there were indications that prochloraz had given partial control of eyespot, reducing the eyespot index from 37.3 in the All Low to 20.2 in All High, meaned across all rotations ($P < 0.001$) (**Table 2.5.16**). There were significant differences in the eyespot index at the milky-ripe stage (GS 75) between rotational means (Standard Rotation I, 42.3; Standard Rotation II, 39.2 and Alternative Rotation II, 10.9; $P < 0.001$), but no differences between nitrogen means. Control of *S. tritici* was also demonstrated, with the All High sub-treatment showing 0.9% leaf area affected on leaf 2 at the milky-ripe stage compared with 2.7% in both All Low and Low Fungicide.

The cumulative effects of rotation and agronomic practice on disease were only occasionally apparent. The incidence of eyespot (% plants) at Boxworth in the spring showed no treatment differences in 1995 and 1996 within rotations, although more tillers were affected in CCP (48%) than LIA (32%) in Standard Rotation II in 1995 ($P < 0.05$). The establishment of eyespot during the winter was avoided by sowing spring wheat cv. Axona on 11 March 1996 so that on 3 April, Axona had 1% of plants with eyespot compared with 72% on Hereward (sown 2 October). The dry weather in both 1995 and 1996 restricted the development of eyespot and take-all in cereal crops and their effects on yield were slight.

At Boxworth, in July 1995, there were significant differences ($P < 0.05$) in the eyespot index between nitrogen treatments for Standard Rotation I (10.6 for CCP and 18.1 for LIA) and Alternative Rotation I (4.4 for CCP and 12.8 for LIA), but no differences between pesticide regimes. No fungicides were used for eyespot control in this case. CCP nitrogen gave small, but significant, increases in green leaf area on the upper leaves compared with LIA nitrogen. On cv. Hereward, *S. tritici* affected 5.1% of leaf 5 at GS 77 (10 July 1995), significantly higher ($P < 0.01$) than 1.0% in LIA nitrogen plots. In 1996, an interaction ($P < 0.01$) between pesticide and nitrogen treatments was detected for severe eyespot at GS 77 (13 July 1996) in Standard Rotation I, despite fungicides being confined to a single spray of tebuconazole on 14 May. The All High sub-treatment had 5.0% severe eyespot at CCP N and 2.5% at LIA N, compared with 0% and 5.0% in the All Low and 12.5% and 3.8% in the Low Fungicide sub-treatments.

On cv. Axona, nitrogen effects ($P < 0.05$) were apparent for powdery mildew, which affected 17.2% of leaf 3 on 12 July (GS 71) in CCP N, and 5.8% in LIA N and for *S. tritici* on the flag leaf of the same cultivar (GS 81) on 26 July (2.0% CCP N, 0.4% LIA N, $P < 0.001$). Internodal fusarium was also higher ($P < 0.05$) after CCP N on cv. Axona on 26 July with 43% tillers affected compared with 19% after LIA N.

The cumulative effects of rotation were limited within the project and of less importance than within-season differences created by sowing date, cultivar, nitrogen and pesticide use. Take-all and eyespot remain important diseases for which cultural control measures are valuable. Their impact on yield of winter wheat was realised in 1998 when take-all was particularly severe after a mild winter.

There were slight differences in gross margins for Low Fungicide compared with All High between Phases I and II of the Standard Rotation at CCP N, which were not significant in Phase I but significant for Phase II at £26/ha ($P < 0.05$). At LIA N, Low Fungicide gave improved ($P < 0.05$) gross margins of £25/ha (Phase I) and £40/ha (Phase II), respectively. These differences between the Phases reflect seasonal variations in crop growth, disease pressure and weather factors. Low Fungicides did not affect gross margins in either of the Alternative Rotations compared with All High. These rotational means indicate that Low Fungicide strategies are reliable and have a low risk of reducing gross margins (indeed, they may improve gross margins).

Discussion

The general conclusion that fungicide rates may be reduced without detriment to gross margins can be drawn from the project as a whole. The results confirm the observations made in the Boxworth Project (Greig-Smith *et al.*, 1992) that reduced pesticide applications can produce better gross margins (Jarvis, 1992) and that this principle applies to a wide range of crops and rotations. In the Boxworth Project, disease pressure was low and differences in yield loss between Full Insurance and Supervised strategies were not more than 2% (Yarham & Symonds, 1992). The number of fungicide active ingredients applied was reduced from 9.8 in Full Insurance to 4.7 in Supervised and 4.6 in the Integrated areas in the Boxworth Project. The gross margins for winter wheat were £477/ha for Supervised, £454/ha for Full Insurance and £423/ha for Integrated treatment areas, although it could be argued that crop-walking costs should have reduced the Supervised gross margin by £10/ha (Jarvis, 1992). TALISMAN was able to manipulate dose rates to a greater extent than the Boxworth Project and achieved improved gross margins where pesticides were reduced by more than 75%. In addition, concerns that inherently lower-yielding fields formed part of the Supervised area in the Boxworth Project have been overcome by using a replicated experimental design in TALISMAN.

In many cases, both CCP and LIA plots received fungicide treatments and it is not possible to gauge the extent of disease control achieved by the reduced rate treatments in the absence of an untreated control. However, if benefits were seen in the gross margins of the Low Fungicide compared with All High sub-treatments, then additional benefits from the higher rate were not deemed to be cost-effective. There may be opportunity to reduce rates still further with benefits equating to reduced expenditure on fungicide. Farmers are generally risk averse and will continue to use slightly higher doses than the (retrospective) optimum, realising (from the shape of the fungicide dose-response curves) that the penalty of using too low a dose is greater than using a supra-optimal dose (Paveley *et al.*, 1998). Further advances in predicting disease severity and risk of yield will be needed if further reductions in doses are to be achieved and widely adopted.

Some caution is needed before extrapolating from these results to arable cropping in general, as indicated in the RISC project where half-rate fungicides on wheat reduced gross margins at full-rate fertiliser (Easson *et al.*, 1998). Disease pressure was low in many of the TALISMAN crops. At Boxworth no significant foliar disease epidemics occurred, for example, in winter wheat, and stem-base diseases failed to develop after early stem extension. The results are consistent with those reported for RISC in Northern Ireland on barley and with specific projects to identify optimum dose rates for cereal fungicides (Paveley *et al.*, 1998). Negative gross margins at CCP N with a Low Fungicide regime were noted for winter and spring barley, spring oats and winter oilseed rape, which suggests that further exploration of managing reduced inputs is required. A feature of current farming practice is the failure to recognise the savings in fungicide use that can be achieved by integration of cultivar resistance and fungicide dosage. TALISMAN experiments utilised a range of cultivars and some differences in disease severity were noted, albeit confounded by differences in previous cropping and sowing date. The limited scale of such comparisons does not allow major conclusions to be drawn about the undoubted benefits of cultivar resistance (Priestley & Bayles, 1988). An integrated approach using cultural control (Yarham, 1988) and pesticides can sustain gross margins even if there is some reduction in yield (Jordan, 1990).

Since TALISMAN was initiated, there have been changes in the use of fungicides on farms and this can be quantified using MAFF Pesticide Usage Survey data. Propiconazole and flutriafol were used at about 80% of the label rate in 1990, and morpholine fungicides such as fenpropimorph and fenpropidin were used in mixtures at less than full label rate (**Table 2.5.17**). By 1996, more active 'azole' fungicides such as epoxiconazole and tebuconazole, supported by research and development on appropriate dose rate (Clark, 1997; Paveley *et al.*, 1998), were being used at half the full label rate. Fungicides have been used most reliably in two- or three-spray programmes and the optimum varies according to the pathogen involved (Clark, 1997). Between 1990 and 1996, the dose of older fungicide products also declined by about 20% for azoles such as propiconazole and flutriafol and by rather more in the case of morpholine fungicides. This has been offset by increases in the number of spray rounds per crop (**Table 2.5.18**) and the number of active ingredients used each season (**Table 2.5.19**), which provide the appropriate spectrum of disease control and a balance between protectant and eradicant activity. There have been relatively minor changes in the percentage of crops which received fungicides during the period 1990-1996 (**Table 2.5.20**).

Similar trends are apparent for other arable crops, where older products have shown some reduction in mean dose whilst newer products such as carbendazim/flusilazole and tebuconazole are used at well below the full label rate on oilseed rape (**Table 2.5.21**). The situation is somewhat different to that on wheat because many products are recommended as split dose (two-spray) programmes and therefore the full-rate treatments are not generally used. On field beans, where there have been limited recent technical advances with new fungicides against the main disease, chocolate spot. Fungicide rates have shown small decreases (**Table 2.5.21**). When the number of fungicide units was calculated for each year of TALISMAN, the ratio of LIA:CCP decreased on cereals from 0.33 in 1991/92 to 0.23 in 1995/96 and on break crops from 0.32 in 1990/91 to 0.25 in 1995/96 – reflecting use of more active chemistry and better identification of low-risk disease situations. These findings are in line with reductions of 20-40% on cereals and 6-20% as seen in general usage in MAFF Pesticide Usage Surveys (**Tables 2.5.17 & 2.5.21**).

It has been argued that LIA pesticide regimes were similar to current on-farm practice, which has moved increasingly towards reduced dose applications, and therefore do not challenge pesticide use. Overall, TALISMAN achieved a 68% reduction in fungicide use (**Fig. 2.5.1**) in LIA, by reducing the number of spray rounds and the number of active ingredients as well as by reducing dose. Where fungicides were used in LIA, the mean rate of use was 41% of full label rates. The impact of this can be seen in **Table 2.5.22**, which clearly shows farmers are using many more active ingredients than were used in TALISMAN. The net effect being that average farm use is estimated to be 2.8 fungicide units per wheat crop compared with 1.0 unit in LIA. Indeed, farm practice is close to the CCP regime. The Pesticide Usage data are averages and therefore mask the proportion of farms which might already be close to the LIA regime. Nevertheless, it appears there is considerable scope for pesticide use to be managed more effectively on commercial crops.

The main arable crops are almost always treated with fungicide, notable exceptions being linseed and triticale (**Table 2.5.20**). Whilst linseed production is supported by area payments, yield is of secondary importance, particularly when responses to fungicides have been difficult to predict. As triticale generally shows good resistance to many of the foliar diseases that are significant on wheat, fungicide treatments are more difficult to justify and are used infrequently (**Table 2.5.20**).

In the RISC project in Northern Ireland, the major effects on yield and gross margins followed reduction in nitrogen application (Chapter 4.1). Fungicides could be reduced to half-rate at full rate nitrogen on both winter and spring barley. However, in winter wheat, half rate fungicides reduced yield by 13.6% and gross margins by £73/ha (Easson *et al.*, 1998). This provides a cautionary experience in extrapolating the reduced pesticide approach to situations of high disease pressure. On potatoes, the omission of a seed treatment resulted in significant increases in four tuber-borne diseases and stem canker within the crop. Reduced-rate strategies can be effective in potato blight programmes (Easson *et al.*, 1998), but are considered risky and untested under serious blight pressure.

In oilseed rape, diseases have shown marked seasonal and regional variations with particularly low disease pressure in the early 1990s (Fitt *et al.*, 1997) when winter oilseed rape was grown in TALISMAN. With the combination of low disease pressure and canker resistant varieties such as Libravo, fungicides would not now be expected to produce profitable responses (Gladders, 1998). Highly effective fungicides are available for control of rust in spring beans and reduced rate strategies are effective if sprays are applied at the onset of the epidemic (ADAS, unpublished data). Fungicides were omitted from all break crops at High Mowthorpe in 1993/94 and from LIA at Boxworth in 1990/91 and recent developments with disease forecasting should underpin improved decision making in the future (Fitt *et al*., 1997).

Interactions between disease and nitrogen encountered in cereal crops (e.g. oat powdery mildew and *S. tritici*) were consistent with effects investigated for *S. tritici* (Leitch & Jenkins, 1995) and yellow rust (Bryson *et al*., 1997) on winter wheat. Higher nitrogen use produces larger crop canopies, which could result in an environment more conducive to the spread and development of foliar diseases. However, it appears that tissue nutrient status is the most important factor for some interactions and, in the case of yellow rust, the interaction of disease and nitrogen was such that increased disease severity cancelled out the yield response to nitrogen (Bryson *et al*., 1997). In winter barley, benefits obtained in gross margin and yield by delaying spring nitrogen application from March to April have been attributed to later vegetative growth and production of more open crop canopies, which were less conducive to disease (Jordan & Stinchcombe, 1986).

Interactions between diseases and weeds may occur. There is a possibility that eyespot was influenced by larger weed populations producing a more humid environment at the stem base rather than affecting spore dispersal (Soleimani *et al*., 1996). Differences in eyespot between All Low and Low Fungicide sub-treatments were not significant at Boxworth, suggesting that weeds had little effect at that site. However, studies of effects of cover crops on *S. tritici* might suggest that weed cover has the potential to reduce spread of the pathogens (Bannon & Cooke, 1998) and this interaction merits further study.

The environmental impact of fungicides has received less attention than insecticides. Some adverse effects are reported, such as those of benzimidazole fungicides on earthworms, but other fungicides are considered suitable for use in integrated control programmes (Hassan, 1987). The effects of fungicides and other agrochemicals on soil microorganisms are considered in Chapter 3.3.

The Low Fungicide approach has been applied successfully within TALISMAN across a wide range of crops and site-season combinations. It had little impact on yield and resulted in savings in fungicide costs which improved gross margins, particularly in winter wheat. The results are consistent with other research on fungicide rates (Paveley *et al*., 1998) and nitrogen responses (Chambers & Chalmers, 1994) and therefore provide a solid basis for extension into on-farm practice. The results should not be taken simply as a message that fungicides should be used at reduced rates. Indeed, recent work with the new strobilurin fungicides suggests that high rates of use are required to maximise the benefits from these materials. Results from TALISMAN support the view that use of technical knowledge and skills can safely lead to manipulation of dose and treatment and improve profitability. There is still scope to improve decision making in arable cropping and such improvements should enable many farmers to reduce pesticide use still further.

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Table 2.5.1. Action thresholds currently in use for some of the major diseases of winter cereals in the UK.

Disease	Pathogen	Crop	Action threshold
Brown rust	*Puccinia recondita*	Winter wheat	Disease obvious from GS 30-31 to GS 39. During GS 39-55, spray very susceptible varieties if brown rust present in local area
Eyespot	*Tapesia* spp.	Winter wheat	> 20% tillers affected at GS 30-31 with lesions penetrating 2 or more leaf sheaths
Powdery mildew	*Blumeria (Erysiphe) graminis*	Winter wheat	Mildew active and affecting younger leaves at GS 30-31, or any green leaves GS 37-50
Septoria leaf blotch/glume blotch	*Stagonospora nodorum (Septoria nodorum)*	Winter wheat	Follow septoria leaf spot guidelines
Septoria leaf spot	*Mycosphaerella graminicola (Septoria tritici)*	Winter wheat	Septoria present on older leaves at GS 30-32. A 'wet period' of 4 or more days with at least 1mm rain on a single day with > 5mm rain in the two weeks prior to flag leaf emergence (GS37-59). Further treatment 3 weeks after a GS39-45 spray if wet weather continues
Yellow rust	*Puccinia striiformis*	Winter wheat	Disease obvious from GS 30-31 to GS 55. Spray at first appearance in highly susceptible varieties (NIAB 4 or less), or if spreading from early foci on moderately resistant varieties
Brown rust	*Puccinia hordei*	Winter barley	Disease found on upper 3 leaves during GS 30-59 especially susceptible varieties (NIAB rating <6)
Eyespot	*Tapesia* spp.	Winter barley	> 20% tillers with lesions penetrating 2 or more leaf sheaths GS 30-31
Leaf blotch	*Rhynchosporium secalis*	Winter barley	> 10% leaf area affected in autumn or present on youngest leaves (Jan-Mar) at GS 30-31, then on any of upper 3 leaves from GS31-59
Powdery mildew	*Blumeria (Erysiphe) graminis*	Winter barley	Autumn treatments especially on light or medium soils if active on youngest leaves. From GS 30-31 if mildew is active on youngest expanded leaf, or 3 upper leaves during GS31-59
Net blotch	*Pyrenophora teres*	Winter barley	> 10% lower leaf area affected in autumn or if found readily at GS 30-31 or if on any of upper 3 leaves GS 39-69
Yellow rust	*Puccinia striiformis*	Winter barley	Disease on upper leaves on susceptible varieties or spreading from foci on more resistant varieties

Table 2.5.2. Action thresholds currently in use for some of the major diseases of spring cereals in the UK.

Disease	Pathogen	Crop	Action threshold
Brown rust	*Puccinia hordei*	Spring barley	At first symptoms (NIAB rating ≤ 4) or when found readily on upper 3 leaves
Eyespot	*Tapesia* spp.	Spring barley	Use winter barley criteria particularly for early sown crops
Leaf blotch	*Rhynchosporium secalis*	Spring barley	Disease present on susceptible varieties up to GS 59 on upper leaves
Net blotch	*Pyrenophora teres*	Spring barley	Disease obvious on upper leaves from GS 39
Powdery mildew	*Blumeria (Erysiphe) graminis*	Spring barley	First signs of mildew on susceptible varieties, treat other varieties when disease spreads
Yellow rust	*Puccinia striiformis*	Spring barley	At first symptoms in susceptible varieties, or when spreading in more resistant varieties
Crown rust	*Puccinia coronata*	Spring oats	As soon as infection found on upper 3 leaves on susceptible varieties: other varieties if disease is spreading up to GS 45
Powdery mildew	*Blumeria (Erysiphe) graminis*	Spring oats	Mildew obvious on lower leaves up to GS 45

Table 2.5.3. Action thresholds currently in use for some of the major diseases of break crops in the UK.

Disease	Pathogen	Crop	Action threshold
Dark leaf spot and pod spot	*Alternaria brassicae*	Winter & Spring oilseed rape	Alternaria on upper leaves or pods from early flowering up to 3 weeks pre-harvest
Light leaf spot	*Pyrenopeziza brassicae*	Winter oilseed rape	As soon as symptoms are found up to early stem extension
Phoma leaf spot and canker	*Leptosphaeria maculans* (*Phoma lingam*)	Winter oilseed rape	> 20% plants with phoma leaf spot in autumn on susceptible cultivars (NIAB disease resistance rating <6) or > 40% plants affected on other cultivars, apply second spray at early stem extension
Chocolate spot	*Botrytis* spp.	Beans	Active spotting present during flowering
Rust	*Uromyces viciae-fabae*	Beans	Symptoms found up to 5 weeks before harvest
Alternaria	*Alternaria linicola*	Linseed	Symptoms found during flowering
Grey mould	*Botrytis cinerea*	Linseed	Active infection found during flowering

Table 2.5.4. Fungicide units applied to TALISMAN cereal crops 1990–1996. One unit equals one full-rate application of one active ingredient.

Crop (no. grown)	Disease targeted	Active ingredient applied	Fungicide units applied		
			CCP	LIA*	
Winter wheat (28)	*S. tritici*, mildew	Propiconazole	24.0	9.5	(60)
	Septoria spp.	Chlorothalonil	19.0	4.0	(79)
	S.tritici	Chlorothalonil + flutriafol	8.0	2.0	(75)
	S.tritici	Tebuconazole + triadimenol	8.0	2.0	(75)
	S.tritici	Epoxiconazole	6.0	1.5	(75)
	Foliar diseases	Tebuconazole	5.0	2.5	(50)
	Mildew	Fenpropimorph	4.0	2.0	(50)
	Septoria spp., eyespot	Prochloraz + cyproconazole	4.0	2.0	(50)
	Eyespot	Prochloraz	4.0	1.5	(63)
	S.tritici, mildew	Tridemorph + triadimenol	2.0	1.0	(50)
	Mildew	Fenpropidin	2.0	0	(100)
Total			86.0	28.0	(67)
Mean			3.1	1.0	(68)
Winter triticale (8)[1]	*Septoria* spp.	Propiconazole	2.0	0	(100)
Total			2.0	0	(100)
Mean			0.3	0	(100)
Spring barley (6)[2]	Rhynchosporium, mildew	Propiconazole + tridemorph	4.0	2.0	(50)
Total			4.0	2.0	(50)
Mean			0.7	0.3	(50)
Winter barley (2)	Eyespot	Carbendazim + flusilazole	4.0	1.5	(63)
	Mildew	Fenpropimorph	2.0	0.8	(60)
Total			6.0	2.3	(62)
Mean			3.0	1.1	(63)
Spring wheat (2)	*S.tritici*	Propiconazole	1.0	0.5	(50)
	Mildew	Tridemorph	1.0	0.5	(50)
Total			2.0	1.0	(50)
Mean			1.0	0.5	(50)
All cereal crops (46)					
Total			100.0	33.3	(67)
Mean			2.2	0.7	(68)

* Figures in parentheses are percentage reductions in LIA compared with CCP.

[1] Includes two crops which failed to establish owing to slug damage.

[2] Sown after the failed winter triticale crops.

Table 2.5.5. Fungicide units applied to TALISMAN break crops 1990–1996. One unit equals one full-rate application of one active ingredient.

Crop (no. grown)	Disease targeted	Active ingredient applied	Fungicide units applied		
			CCP	LIA*	
Winter oilseed rape (6)[1]	Phoma leaf spot, light leaf spot	Prochloraz	3.0	0	(100)
Total			3.0	0	(100)
Mean			0.5	0	(100)
Spring oilseed rape (2)[2]	Sclerotinia stem rot	Iprodione + thiophanate-methyl	2.0	0	(100)
Total			2.0	0	(100)
Mean			1.0	0	(100)
Winter beans (6)	Chocolate spot	Benomyl	5.0	2.0	(60)
	Chocolate spot	Chlorothalonil	5.0	2.0	(60)
Total			10.0	4.0	(60)
Mean			1.7	0.7	(59)
Spring beans (5)	Chocolate spot	Benomyl	4.0	1.0	(75)
	Foliar disease	Chlorothalonil	2.0	0.5	(75)
	Chocolate spot, downy mildew	Chlorothalonil + metalaxyl	1.0	0.5	(50)
Total			7.0	2.0	(71)
Mean			1.4	0.4	(71)
Linseed (3)	Nil	Nil	0	0	(0)
Total			0	0	(0)
Mean			0	0	(0)
Spring oats (2)[3]	Powdery mildew	Fenpropimorph	1.0	0.5	(50)
	Foliar diseases	Propiconazole	1.0	0.5	(50)
Total			2.0	1.0	(50)
Mean			1.0	0.5	(50)
All break crops (24)					
Total			24.0	7.0	(71)
Mean			1.0	0.3	(70)

* Figures in parentheses are percentage reduction in LIA compared with CCP.

[1] Includes two crops which failed to establish due to slug damage.

[2] Sown after the failed winter oilseed rape crops.

[3] Grown as a break crop at Drayton.

Table 2.5.6. Total fungicide units applied in the Standard and Alternative Rotations of TALISMAN, 1990–1996 (One unit equals one full-rate application of one active ingredient).

Rotation/Site	Rotation Phase I			Rotation Phase II		
	CCP	LIA*		CCP	LIA*	
Standard Rotation						
Boxworth	14.0	3.5	(75)	8.0	2.5	(69)
Drayton	16.0	6.0	(63)	15.0	6.0	(60)
High Mowthorpe	16.0	5.0	(69)	16.0	5.3	(67)
Average	15.3	4.8	(69)	13.0	4.6	(65)
Alternative Rotation						
Boxworth	9.0	2.5	(72)	-	-	-
Drayton	4.0	1.0	(75)	4.0	0.5	(88)
High Mowthorpe	10.0	3.3	(67)	12.0	4.3	(64)
Average	7.7	2.3	(70)	8.0	2.4	(70)

* Figures in parentheses are percentage reductions in LIA compared with CCP.

Table 2.5.7. The effect of low-input fungicide use on the mean yields of cereal crops in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Fungicide	
First winter wheat				
Boxworth (172 d.f.)	7.01	6.68 (95)	6.92 (99)	0.063***
Drayton (80 d.f.)	8.07	7.79 (97)	7.96 (99)	0.091***
High Mowthorpe (176 d.f.)	8.37	7.60 (91)	8.35 (100)	0.080***
Cross-site (428 d.f.)	7.76	7.27 (94)	7.70 (99)	0.045***
Second winter wheat				
Boxworth (111 d.f.)	7.43	7.21 (97)	7.38 (99)	0.064***
Drayton (80 d.f.)	7.22	6.93 (96)	7.16 (99)	0.132*
High Mowthorpe (32 d.f.)	7.79	6.88 (88)	7.54 (97)	0.112***
Cross-site (223 d.f.)	7.42	7.05 (95)	7.33 (99)	0.059***
All winter wheat				
Boxworth (283 d.f.)	7.18	6.90 (96)	7.10 (99)	0.046***
Drayton (160 d.f.)	7.64	7.36 (96)	7.56 (99)	0.080***
High Mowthorpe (208 d.f.)	8.25	7.45 (90)	8.19 (99)	0.069***
Cross-site (651 d.f.)	7.64	7.19 (94)	7.57 (99)	0.036***
Spring barley				
Drayton (40 d.f.)	5.96	5.65 (95)	5.93 (99)	0.224
High Mowthorpe (78 d.f.)	5.34	5.35 (100)	5.40 (101)	0.184
Cross-site (119 d.f.)	5.55	5.45 (98)	5.58 (101)	0.178
Winter triticale				
Drayton (120 d.f.)	5.25	5.19 (99)	5.28 (101)	0.083
Winter barley				
High Mowthorpe (32 d.f.)	7.95	7.67 (97)	7.58 (95)	0.200
Spring wheat				
Boxworth (47 d.f.)	5.92	5.25 (89)	5.69 (96)	0.135***

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

Table 2.5.8. The effect of low-input fungicide use on the mean yields of break crops in TALISMAN, 1991–1996 (t/ha @ 85% d.m. or 91% d.m. for oilseeds).

Crop & Site	Pesticide sub-treatment[1]			SED
	All High	All Low	Low Fungicide	
Winter oilseed rape				
Boxworth (24 d.f.)	0.83	0.51 (61)	1.24 (149)	0.157***
Drayton (16 d.f.)	2.59	2.31 (90)	2.38 (92)	0.259
High Mowthorpe (31 d.f.)	3.58	3.24 (91)	3.64 (102)	0.114**
Cross-site (71 d.f.)	2.50	2.18 (87)	2.61 (104)	0.093***
Spring oilseed rape				
Boxworth (24 d.f.)	0.91	0.55 (60)	0.62 (69)	0.100*
Drayton (16 d.f.)	0.23	0.36 (154)	0.39 (169)	0.088
Cross-site (40 d.f.)	0.62	0.46 (75)	0.52 (85)	0.069
Winter beans				
Boxworth (48 d.f.)	4.08	4.19 (103)	4.19 (103)	0.083
Drayton (32 d.f.)	4.01	4.03 (101)	3.96 (99)	0.095
High Mowthorpe (32 d.f.)	4.86	4.67 (96)	4.94 (102)	0.086**
Cross-site (112 d.f.)	4.29	4.29 (100)	4.35 (101)	0.051
Spring beans				
Boxworth (17 d.f.)	1.74	1.46 (84)	1.79 (103)	0.231
Drayton (32 d.f.)	3.23	2.89 (90)	3.20 (99)	0.087***
High Mowthorpe (32 d.f.)	4.46	4.25 (95)	4.45 (100)	0.108
Cross-site (81 d.f.)	3.32	3.04 (92)	3.32 (100)	0.075**
Spring linseed				
Boxworth (24 d.f.)	2.48	2.43 (98)	2.52 (102)	0.061
High Mowthorpe (31 d.f.)	1.72	1.74 (102)	1.81 (105)	0.056
Cross-site (55 d.f.)	2.02	2.02 (100)	2.09 (104)	0.041*
Spring oats				
Drayton (32 d.f.)	4.93	4.62 (94)	4.66 (95)	0.116

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

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Table 2.5.9. The effect of low-input fungicide use on the mean gross margins of cereal crops in TALISMAN, 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Fungicide	
First winter wheat				
Boxworth (172 d.f.)	717.8	724.0 (101)	732.6 (102)	7.16***
Drayton (80 d.f.)	753.3	810.2 (108)	769.3 (102)	10.07***
High Mowthorpe (176 d.f.)	1022.1	974.5 (95)	1055.5 (103)	10.26***
Cross-site (428 d.f.)	846.6	841.4 (99)	869.1 (103)	5.42***
Second winter wheat				
Boxworth (111 d.f.)	945.6	950.7 (101)	961.6 (102)	8.01
Drayton (80 d.f.)	606.4	701.8 (116)	650.0 (107)	13.18***
High Mowthorpe (32 d.f.)	759.9	750.8 (99)	778.6 (103)	11.59***
Cross-site (223 d.f.)	793.1	827.6 (104)	819.4 (103)	6.36***
All winter wheat				
Boxworth (283 d.f.)	808.9	814.7 (101)	824.2 (102)	5.63**
Drayton (160 d.f.)	679.8	756.0 (111)	709.7 (104)	8.30***
High Mowthorpe (208 d.f.)	969.7	929.8 (96)	1000.1 (103)	8.68***
Cross-site (651 d.f.)	827.3	836.4 (101)	851.1 (103)	4.16***
Spring barley				
Drayton (40 d.f.)	384.9	425.7 (111)	381.4 (99)	22.44
High Mowthorpe (78 d.f.)	608.6	633.3 (104)	620.1 (102)	17.89
Cross-site (119 d.f.)	534.0	564.1 (106)	540.5 (101)	14.07
Winter triticale				
Drayton (120 d.f.)	470.6	542.1 (115)	479.1 (102)	8.62***
Winter barley				
High Mowthorpe (32 d.f.)	820.4	844.2 (103)	806.2 (98)	19.98
Spring wheat				
Boxworth (47 d.f.)	776.6	720.3 (93)	766.2 (99)	17.10***

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

*** $P < 0.001$.

Table 2.5.10. The effect of low-input fungicide use on the mean gross margins of break crops in TALISMAN, 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment[1]			SED
	All High	All Low	Low Fungicide	
Winter oilseed rape				
Boxworth (24 d.f.)	50.0	-1.0 (na)	181.0 (na)	41.90***
Drayton (16 d.f.)	373.0	361.0 (97)	338.0 (91)	68.90
High Mowthorpe (31 d.f.)	829.0	797.1 (96)	847.6 (102)	23.41
Cross-site (71 d.f.)	484.1	450.9 (93)	524.9 (108)	23.23**
Spring oilseed rape				
Boxworth (24 d.f.)	346.5	345.2 (100)	324.8. (94)	18.04
Drayton (16 d.f.)	324.1	369.3 (114)	354.1 (109)	15.80
Cross-site (40 d.f.)	336.9	355.5 (106)	337.4 (100)	12.43
Winter beans				
Boxworth (48 d.f.)	620.8	674.0 (109)	659.9 (106)	13.41**
Drayton (32 d.f.)	566.3	616.5 (109)	565.6 (100)	15.78***
High Mowthorpe (32 d.f.)	744.9	724.8 (97)	763.1 (102)	11.73**
Cross-site (112 d.f.)	641.7	672.0 (105)	662.5 (103)	8.00***
Spring beans				
Boxworth (17 d.f.)	328.5	380.1 (116)	347.8 (106)	22.42
Drayton (32 d.f.)	485.9	474.9 (98)	498.4 (103)	13.51***
High Mowthorpe (32 d.f.)	679.3	664.8 (98)	679.5 (100)	15.92
Cross-site (81 d.f.)	519.1	522.4 (101)	528.7 (102)	9.54
Spring linseed				
Boxworth (24 d.f.)	698.0	686.8 (98)	702.3 (101)	6.31**
High Mowthorpe (31 d.f.)	565.2	581.7 (103)	576.3 (102)	7.29
Cross-site (55 d.f.)	618.3	623.8 (101)	626.7 (101)	4.99
Spring oats				
Drayton (32 d.f.)	504.4	491.0 (97)	484.7 (96)	12.11

[1] Cross-nitrogen means. 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.
** $P < 0.01$.
*** $P < 0.001$.

Table 2.5.11. The effect of low-input fungicide use on the mean gross margins on crops grouped as cereals, breaks or overall crops in TALISMAN 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Fungicide	
Cereal crops				
Boxworth (346 d.f.)	803.6	799.0 (99)	814.6 (101)	5.73*
Drayton (352 d.f.)	564.5	634.5 (112)	582.2 (103)	6.04***
High Mowthorpe (350 d.f.)	860.7	845.0 (98)	881.1 (102)	7.91***
Cross-site (1048 d.f.)	742.9	759.5 (102)	759.3 (102)	3.83***
Break crops				
Boxworth (169 d.f.)	444.1	458.9 (103)	479.3 (108)	11.30**
Drayton (176 d.f.)	476.3	486.9 (102)	473.7 (100)	11.65
High Mowthorpe (174 d.f.)	704.6	692.1 (98)	716.5 (102)	8.31
Cross-site (519 d.f.)	541.7	546.0 (101)	556.5 (103)	6.08
All crops				
Boxworth (515 d.f.)	683.7	685.6 (100)	702.8 (103)	5.36***
Drayton (528 d.f.)	535.1	585.3 (109)	546.0 (102)	5.59***
High Mowthorpe (524 d.f.)	808.7	794.0 (98)	826.2 (102)	5.96***
Cross-site (1567 d.f.)	675.8	688.3 (102)	691.7 (102)	3.26***

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

Table 2.5.12. Incidence of phoma leaf spot and yield of winter oilseed rape cv. Libravo (Standard Rotation II), Boxworth 1991.

Variate	All High	All Low	Low Fungicide	SED
% plants affected by phoma leaf spot (22/02/91)	39	55	54	6.37* (12 d.f.)
Yield of winter oilseed rape (t/ha)	0.83	0.51	1.24	0.157*** (24 d.f.)

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

Table 2.5.13. Control of phoma leaf spot and effect on yield in winter oilseed rape cv. Cobra (Standard Rotation I), Drayton 1991.

Variate	All High	All Low	Low Fung	SED (8 d.f.)	CCP N	LIA N	SED (8 d.f.)
% leaf area with phoma leaf spot, 18 February	2.1	2.1	1.4	0.48	1.6	2.1	0.04*
% leaf area with phoma leaf spot, 3 April	1.3	3.9	2.5	0.55	2.3	2.8	0.31
Yield (t/ha)	2.59	2.31	2.38	0.26	2.55	2.41	0.10

* $P < 0.05$.

Table 2.5.14. Effect of rotation and crop cultivar on diseases of winter wheat at Boxworth, 1992. SR = Standard Rotation, Phase I or II; AR = Alternative Rotation, Phase I or II; W.OSR = winter oilseed rape.

Winter wheat cultivar	1990/91 Crop	% tillers with eyespot GS 32	% tillers with take-all GS 32	% mildew leaf 1† GS 77	% *S. tritici* leaf 1† GS 77	Eyespot index GS 85	% tillers with take-all GS 85
Beaver SR I, CCP	W.beans	20.0	11.3	19.3	0.4	8.1	34.2
Beaver SR I, LIA	W.beans	15.0	10.0	13.1	2.1	11.4	29.2
Riband SR II, CCP	W.OSR	23.8	22.5	10.6	5.1	14.4	45.0
Riband SR II, LIA	W.OSR	25.0	18.8	2.7	4.7	19.0	48.3
Hereward AR I, CCP	Linseed	35.0	0.0	11.4	0.6	2.5	5.6
Hereward AR I, LIA	Linseed	38.8	1.3	6.3	0.4	3.1	5.8
SED		6.80* (33 d.f.)	4.25*** (33 d.f.)	1.93*** (45 d.f.)	0.67*** (51 d.f.)	2.62*** (50 d.f.)	1.72*** (50 d.f.)

† Angular transformed data presented.
* $P < 0.05$.
*** $P < 0.001$.

Table 2.5.15. Effect of rotation, nitrogen and pesticide treatments on eyespot incidence on 6 May (28 May for cv. Tonic) at Boxworth 1993. SR = Standard Rotation, Phase I or II; AR = Alternative Rotation, Phase I or II.

Treatment	Nitrogen	% tillers with eyespot at GS 33		
		All High	All Low	Mean
Hereward SR I	CCP	36.0	44.7	40.4
Hereward SR I	LIA	42.6	35.6	39.1
Hereward SR II	CCP	45.5	45.4	45.5
Hereward SR II	LIA	43.5	56.3	49.9
Tonic AR I	CCP	12.2	14.1	13.2
Tonic AR I	LIA	13.6	14.8	14.2
Mean		32.2	35.2	33.7
SED (18 d.f.)	7.64 rotation/nitrogen x pesticide or 8.59 at same level of rotation/nitrogen			

Table 2.5.16. Effect of rotation, nitrogen and pesticide treatments on eyespot index (GS 75) at Boxworth 1993. SR = Standard Rotation, Phase I or II; AR = Alternative Rotation, Phase I or II.

Treatment	Nitrogen	Pesticide sub-treatment		
		All High	All Low	Low Fungicide
Hereward SR I	CCP	24.9	46.8	42.9
Hereward SR I	LIA	38.5	51.1	49.7
Hereward SR II	CCP	25.3	45.0	49.9
Hereward SR II	LIA	18.5	49.5	50.0
Tonic AR I	CCP	5.3	12.6	10.3
Tonic AR I	LIA	8.7	18.1	10.1
Mean		20.2	37.2	35.5
SED (51 d.f.)	5.13 (rotation x nitrogen x pesticide); 2.09*** (rotation/pesticide)			

*** $P < 0.001$.

Table 2.5.17. Fungicide use and dose on wheat in 1990 and 1996.*

Fungicide	**1990**		**1996**			
	Treated area x 10^3 ha	**Mean dose kg a.i./ha**	**Treated area x 10^3 ha**	**Mean dose kg a.i./ha**	**% reduction 1990 vs. 1996**	**Full label rate kg a.i./ha**
Chlorothalonil	317	0.537	1294	0.392	27	0.50-1.00
Cyproconazole	N/A	N/A	354	0.045	-	0.08
Cyproconazole/ prochloraz	N/A	N/A	302	0.256	-	0.46
Epoxiconazole	N/A	N/A	651	0.066	-	0.125
Flutriafol	517	0.095	487	0.075	21	0.125
Fenpropidin	385	0.410	948	0.248	40	0.75
Fenpropimorph	1018	0.407	314	0.294	28	0.56-0.75
Flusilazole	N/A	N/A	325	0.115	-	0.20
Propiconazole	643	0.103	104	0.079	23	0.125
Tebuconazole	N/A	N/A	600	0.119	-	0.250
Tebuconazole/ triadimenol	N/A	N/A	370	0.198	-	0.375

* Data from MAFF Pesticide Usage Surveys (Davis *et al.*, 1991; Thomas *et al.*, 1997).

Table 2.5.18. Number of spray rounds of fungicides, 1990 and 1996.*

Crop	**1990 England & Wales**	**1996 Great Britain**
Wheat	2.1	2.5
Winter barley	1.9	2.1
Spring barley	1.2	1.3
Triticale	-	0.6
Oilseed rape	1.2	1.7
Linseed	0.2	0.2
Field beans	1.0	1.3

* Data from MAFF Pesticide Usage Surveys (Davis *et al.*, 1991; Thomas *et al.*, 1997).

Table 2.5.19. Number of fungicide active ingredients applied per crop, 1990 and 1996.*

Crop	**1990 England & Wales**	**1996 Great Britain**
Wheat	4.3	5.6
Winter barley	3.4	4.9
Spring barley	2.0	2.7
Triticale	-	0.8
Oilseed rape	1.7	2.9
Linseed	0.3	0.4
Field beans	2.0	2.6

* Data from MAFF Pesticide Usage Surveys (Davis *et al.*, 1991; Thomas *et al.*, 1997).

Table 2.5.20. Crops (%) sprayed with fungicides, 1990 and 1996.*

Crop	1990 England & Wales	1996 Great Britain
Wheat	96.8	97.2
Winter barley	95.7	94.1
Spring barley	87.7	79.1
Triticale	7.7	19.3
Oilseed rape	76.4	70.4
Linseed	17.3	9.8
Field beans	68.6	79.7

* Data from MAFF Pesticide Usage Surveys (Davis *et al.*, 1991; Thomas *et al.*, 1997).

Table 2.5.21. Fungicide use and dose on oilseed rape and field beans in 1990 and 1996.*

	1990		1996			
Fungicide	Treated area x 10^3 ha	Mean dose kg a.i./ha	Treated area x 10^3 ha	Mean dose kg a.i./ha	% reduction 1990 vs. 1996	Full label rate kg a.i./ha
Oilseed rape						
Carbendazim	75	0.333	156	0.268	20	0.25-0.50
Carbendazim/ flusilazole	N/A	N/A	94	0.162	-	0.50 or 0.25 x2
Prochloraz	160	0.327	66	0.280	14	0.495 or 0.315 split dose
Tebuconazole	N/A	N/A	100	0.117	-	0.250
Field beans						
Carbendazim	39	0.347	68	0.325	6	0.55 or 0.275 x2
Chlorothalonil	59	0.770	99	0.685	11	1.50

* Data from MAFF Pesticide Usage Surveys (Davis *et al.*, 1991; Thomas *et al.*, 1997).

Table 2.5.22. Comparison of fungicide use on winter wheat in TALISMAN with farm practice in 1996.

Fungicide component	TALISMAN		Pesticide Usage Survey*
	CCP	LIA	1996
Number of spray rounds	1.86	1.50	2.5
Number of active ingredients	3.1	2.4	5.6
% crops sprayed	100	93	97
Mean % label dose	100	41	50
Number of fungicide units/crop	3.1	1.0	2.8

* Data from MAFF Pesticide Usage Survey (Thomas *et al.*, 1997).

INVERTEBRATE PEST CONTROL: THE AGRONOMIC AND ECONOMIC IMPLICATIONS OF REDUCING INSECTICIDE AND MOLLUSCICIDE USE

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Introduction

Insecticide and molluscicide use in TALISMAN entailed treatment decisions against most of the major invertebrate pests of combinable crops found in the UK (Gratwick, 1992). In cereals, aphids and slugs were the most commonly encountered problems. A wider range of pests occurred in the break crops: slugs, cabbage stem flea beetle, pollen beetle and cabbage seed weevil in oilseed rape; flax flea beetle in linseed and black bean aphid in field beans (**Table 2.6.1**). TALISMAN realistically reflected many of the crucial insecticide and molluscicide treatment decisions facing farmers of combinable crops in the UK. The consequences of adopting a low-input approach for invertebrate pest control have, therefore, been extensively and uniquely studied in TALISMAN over a long-term period, in contrasting sites and crop rotations (Chapter 2.1).

Use of insecticides and molluscicides in TALISMAN was governed by action thresholds wherever these were available for given pest/crop combinations. Such thresholds were available for many of the major pests of arable crops (**Table 2.6.1**), enabling treatment decisions to be based on the assessment of pest populations in each crop. In principle, low numbers of pests may be tolerated in a crop but there is a point at which the numbers and activity of a pest justify pesticide use on economic grounds. When a pest population reaches a certain threshold, pesticide use becomes cost-effective as all of the various financial costs associated with the application of a pesticide are repaid by the reduction of further losses in crop yield or quality arising from the pest attack.

Insecticide and molluscicide use in TALISMAN was dictated by the needs of the Current Commercial Practice (CCP) treatment regime. This was always determined by frequent crop monitoring and, in many instances, in conjunction with the use of action thresholds if they were available for the crop/pest situation in question. The corresponding treatment decisions in the Low Input Approach (LIA) regime were comprised of three options: a) omit treatment; b) apply a reduced-rate treatment, at least 50% less than the label recommended rate used in the CCP; or c) apply treatment at full label rate when pest attacks were serious enough to threaten the survival of the crop.

In this chapter, insecticide and molluscicide use in CCP is referred to as the 'All High' pesticide sub-treatment in which all categories of pesticides were applied according to the CCP regime. In comparison, references to the 'Low Insecticide' sub-treatment indicate that only insecticides and molluscicides were applied according to LIA rules, with herbicides and fungicides applied according to the normal CCP regime. In addition, data from the 'All Low' sub-treatment in which all categories of pesticides (i.e. herbicides, fungicides and insecticides/molluscicides) were applied according to LIA rules, is also presented for reference purposes.

In the majority of cases, there was no interaction between nitrogen and insecticide/molluscicide inputs; therefore, to simplify the presentation of data, cross-nitrogen means of the pesticide sub-treatments are generally shown and referred to in this Chapter.

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.

Insecticide and molluscicide use

The full dose-rates for insecticides and molluscicides, as recommended on the manufacturers' labels (label rate), were always applied in the CCP regime. It is well known that, in recent years, there has been an increasing trend for farmers to apply pesticides at less than their label rates. In TALISMAN CCP, it was decided at the outset to follow manufacturers' label rates as there was uncertainty about 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 judged. This issue is also discussed in Chapter 2.1. Cutting dose-rates has become more widespread amongst herbicides and fungicides than with insecticides and molluscicides (see Chapters 2.3 and 2.5). Examination of data from recent MAFF Pesticide Usage Surveys (Davis *et al.*, 1993; Thomas *et al.*, 1997) reveals that there is only limited evidence to indicate widespread adoption of rate-reducing practices with the most commonly applied insecticides and molluscicides in TALISMAN (**Table 2.6.2**). According to the most recent survey, the two most commonly used insecticides, cypermethrin and dimethoate, continue to be applied at, or very near, their label recommended rates. However, there was some evidence that methiocarb and pirimicarb were being applied at less than their label rates but there was only a limited increase in this practice in 1996 compared with 1992 levels (**Table 2.6.2**). It can be concluded from this evidence that the insecticide and molluscicide label rates applied in TALISMAN CCP were a fair representation of on-farm commercial practices.

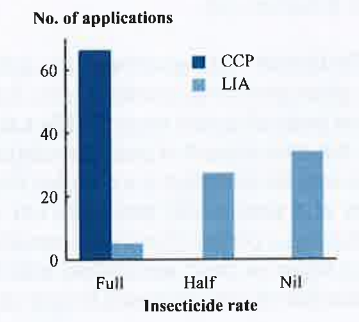

Figure 2.6.1. Insecticide (including molluscicide) use in TALISMAN treatment regimes, 1990–1996. CCP: Current Commercial Practice. LIA: Low Input Approach.

Seventy crops were grown during the six cropping years of TALISMAN; this included four crops (two of winter oilseed rape and two of winter triticale) which failed to establish, owing to slug damage. The 'failed' winter oilseed rape was subsequently replaced by spring rape and the 'failed' triticale replaced by spring barley. Under CCP, an average of 0.7 and 1.1 insecticide applications (including molluscicides) were made to individual cereal and break crops, respectively (**Tables 2.6.3 & 2.6.4**). A total of 66 applications of insecticides and molluscicides was made to CCP during the course of TALISMAN. In contrast, there were 32 corresponding applications in LIA (i.e. 52% of applications were omitted), of which 27 (41%) were applied at half-rate or less and five (7%) applied at full label rate (**Fig. 2.6.1**). In terms of pesticide units applied (where 1.0 unit = one full rate application and 0.5 units = one half-rate application), this represented a reduction in insecticide and molluscicide use of 76% in the cereal crops and 65% in the break crops (**Tables 2.6.3 & 2.6.4**). Thus, in the majority of instances, reductions in insecticide and molluscicide use were obtained through omitting applications rather than by cutting the dose-rates.

Overall, reducing dose-rates in LIA did not cause economic losses. However, omitting certain insecticides did so in four (6%) of the 66 insecticide/molluscicide treatment decisions ($P < 0.05$). Specifically, losses in yield ($P < 0.05$) (and associated reductions in gross margins) resulted from omitting dimethoate against aphids in three crops of winter wheat and from omitting pirimicarb against black bean aphid in one crop of spring beans (see aphid section below). Although, as mentioned above, slug attacks caused the loss of four crops, this was not related to differences in molluscicide use between the CCP and LIA treatment regimes (see slug section below).

The Alternative Rotations were considered to have an inherently low demand for nitrogen and pesticides, as they contained a large proportion of spring-sown crops. This contrasted with the Standard Rotations, which included only winter (i.e. autumn-sown) crops (Chapter 2.1). However, when comparing insecticide and molluscicide use in the Standard and Alternative Rotations, the average number of pesticide units applied was not consistently lower in the Alternative Rotation (**Table 2.6.5**). When insecticide use on winter crops was compared with that of spring crops, insecticide demand was, as expected, lower in spring crops than in winter crops, irrespective of rotation (**Table 2.6.6**). The number of spring crops (16 out of 30 crops) in the Alternative Rotations was insufficient to substantially reduce the overall demand for insecticides and molluscicides in comparison with the Standard Rotations. Furthermore, the Alternative Rotation was disadvantaged by the relatively heavy demand for insecticides/molluscicides at Drayton, which was exacerbated by slug attacks in the winter triticale.

Overall, insecticide and molluscicide use was consistently greater in the Standard and Alternative Rotations at Drayton than at either Boxworth or High Mowthorpe (**Table 2.6.5**). This was owing to the high risk of slug attack at Drayton and the frequent need to treat against certain other pests: notably, cereal aphids in the summer and aphids as vectors of barley yellow dwarf virus (BYDV) in the autumn.

Yields and gross margins

Sixty-six crops were taken to harvest in the six-year term of TALISMAN. Statistically significant ($P < 0.05$) losses in yield caused by invertebrate pests occurred in the following four crop/pest combinations: spring beans/black bean aphid at Drayton; winter wheat/grain aphid and rose-grain aphid in two crops at High Mowthorpe and in one crop at Boxworth. Details of these cases are documented in the individual pest sections below. In each instance, the yield loss sustained resulted from the omission of an insecticide in the LIA compared with a full-rate application in the CCP.

Summary yield and gross-margin data indicate the comparative performance of each type of crop grown in TALISMAN, grouped according to each type of cereal crop (**Tables 2.6.7 & 8**) or break crop (**Tables 2.6.9 & 10**), as site and cross-site means. Additionally, to provide an overview of financial performance in relation to insecticide use, average gross margins were analysed for amalgamations of cereals, breaks and all crops grown at individual sites and cross-sites (**Table 2.6.11**). The overall number of each type of crop grown, and their relative position in the rotations, are detailed in Chapter 2.1.

Overall, crop yields were largely unaffected by the adoption of the Low Input Approach with insecticides and molluscicides. The average yield of the Low Insecticide sub-treatment was less than that of the All High pesticide sub-treatment in the winter wheat (all) and winter beans at High Mowthorpe and spring beans at Drayton ($P < 0.05$) (**Tables 2.6.7 & 9**). The reductions in the average yield of winter wheat at High Mowthorpe and spring beans at Drayton were both associated with aphid infestations (see aphid section below). However, the reduction in average yield of the Low Insecticide sub-treatment of the winter beans at High Mowthorpe cannot be fully explained. The only pest problem associated with the two crops of winter beans at High Mowthorpe was a late-season infestation of black bean aphid in 1991. These aphids were controlled by applying full-rate pirimicarb to the CCP only but there was no significant yield response to this treatment.

The yield of the spring oilseed rape was disappointingly low as the two crops grown (as replacements for failed winter oilseed rape) both suffered from poor establishment and from pigeon damage. Yield of the spring rape crops was extremely variable and, at Drayton (**Table 2.6.9**), the 47% increase in the yield of the Low Insecticide sub-treatment compared with the All High sub-treatment was neither statistically significant nor associated with pest attack.

Average gross margins of the Low Insecticide sub-treatment of the various cereal and break crops grown in TALISMAN often exceeded those of the All High pesticide sub-treatment (**Tables 2.6.8 & 10**). Amongst the break crops, the average gross margin of the Low Insecticide sub-treatment of the winter beans at Boxworth was greater than the corresponding All High pesticide sub-treatment, although this was not associated with savings in insecticide use. However, reductions in average gross margins of the Low Insecticide compared with the All High sub-treatment occurred in the winter beans at Drayton and High Mowthorpe. At Drayton, a damaging late-season attack of black bean aphid in 1991 was responsible for the reduction in gross margin, following the application of pirimicarb to the CCP only. The relatively lower average gross margin of the Low Insecticide sub-treatment of the High Mowthorpe winter beans was also connected with a late-season infestation of black bean aphid in 1991.

None of the cross-site average gross margins of the Low Insecticide sub-treatment for the individual cereal or break crops differed from their respective All High sub-treatments. However, when crops were grouped into the following general categories: a) break crops; b) cereal crops; c) 'all crops', some statistically significant differences emerged (**Table 2.6.11**). The average gross margins of the Low Insecticide sub-treatment of the cereals and 'all crops' categories at Drayton were greater than their corresponding All High sub-treatments by 5% and 4% respectively ($P < 0.05$).

An overview of the cross-site/year average gross margins of amalgamated cereal and break crops (**Table 2.6.11**) indicated that the reduction of insecticide and molluscicide use in the Low Input Approach resulted in a small increase of 1% (£5/ha) in the LIA gross margin, compared with the CCP. The average LIA gross margins of the amalgamated cereal and break crops did not fall below that of the CCP, except at High Mowthorpe where a reduction of 1% (£5/ha) was noted. This reduction was attributed to the problems experienced with aphids in winter wheat at High Mowthorpe in 1992. It was concluded that the reduction in insecticide and molluscicide use through the implementation of the Low Input Regime was cost-effective. The generally low cost of insecticides and molluscicides compared with other variable inputs dictates that the financial savings to be gained from reducing their use are likely to be small. Nevertheless, the TALISMAN results indicate the potential for small but fairly consistent financial savings to be gained from minimising insecticide and molluscicide use in combinable arable crops.

Slug attacks

Slugs were the most troublesome and damaging invertebrate pest experienced in TALISMAN, causing problems at Boxworth and at Drayton. Both of these sites are on heavy clay soils and when seedbed preparation is hampered by a wet autumn, seedbeds may remain in a rough, cloddy and loose condition which favours slug activity (Glen *et al.*, 1992).

Slug attacks accounted for the failure of two crops of winter oilseed rape (Boxworth and Drayton) and two crops of winter triticale (Drayton). However, there were no significant differences in the scale of attack between treatments; the CCP and LIA regimes were both equally affected by slug damage, virtually irrespective of the control measures applied. Overall, a cumulative total of eight full-rate CCP applications of methiocarb was applied to these crops before they were abandoned owing to unacceptable losses of plants during emergence and establishment. In comparison, a total of two half-rate and one full-rate applications of methiocarb was made in the LIA. Despite the relatively heavy use of methiocarb, equally serious levels of slug damage were sustained in both the CCP and LIA regimes. Each crop was abandoned owing to non-viable plant populations, unrelated to treatment. None of the omitted or reduced-rate LIA applications of methiocarb in any of the other crops resulted in a measurable loss in yield.

An example of the scale of slug damage encountered can be seen in the plant establishment counts of the winter triticale in the Alternative Rotation at Drayton, damaged by slugs in autumn 1992. Full-rate methiocarb slug pellets (as Draza) were applied to this crop on 10 November 1992 and on 4 December 1992 in response to an on-going slug attack which was destroying plants. When assessed in January 1993, plant populations were, on average, 44 plants/m^2 greater in the treated plots than in the untreated All Low and Low Insecticide sub-treatments (**Table 2.6.12**). However, despite the molluscicide treatments, plant populations were unacceptably low and variable on both treated and untreated plots. In view of the non-viable plant population, triticale crops were replaced by spring barley.

The slug problems experienced in TALISMAN reflect the general difficulties in gaining effective control of slugs once an attack is underway. The field slug (*Derocerus reticulatum*) is the most common slug pest species encountered in the UK. Chemical control measures currently rely on the use of molluscicide pellets which are broadcast onto the soil surface before or after drilling, or sown in mixture (admixed) with the seed. Several molluscicides are available for use in the UK, the three major active ingredients being methiocarb, metaldehyde and thiodicarb. Pre-emergence attacks are the most difficult to control. Oilseed rape and winter wheat crops frequently suffer from pre-emergence damage when slugs feed on the seeds or emerging shoots during the early stages of germination. In winter wheat, slug feeding at this time typically results in 'grain hollowing', leading to poor plant establishment and crop failure owing to unacceptably thin or patchy crops. Chemical control tends to be more effective when slugs are active on the soil surface where they encounter slug pellets broadcast to the soil surface (Green *et. al.*, 1992). However, in certain conditions, slugs remain entirely below the surface where their feeding is difficult to control using slug pellets, even when applied in admixture with the seed.

Standard advice emphasises the need to integrate chemical and cultural measures for successful slug control. Effective cultural control measures include the preparation of well-consolidated seedbeds with a fine tilth where there are fewer air spaces in the soil structure in which the slugs can move and feed. Sowing seed at a depth of 4–5 cm has also been shown to reduce slug damage compared with seed sown closer to the soil surface, where slug activity is often greater (Glen *et al.*, 1990).

The results from TALISMAN realistically illustrated the practical difficulties encountered in controlling slugs: heavy expenditure on molluscicides is not always cost-effective. Owing to the difficulties in reliably forecasting and controlling slug attacks, molluscicides are often applied as a routine, preventive measure. However, serious attacks cannot always be prevented with the currently available molluscicides, irrespective of high- or low-input strategies.

Aphid attacks

In terms of yield and financial losses, aphids were the most damaging invertebrate pests encountered in TALISMAN. Economically damaging attacks were experienced in the following crops:

Spring beans cv. Troy, Alternative Rotation Phase I, Drayton, 1991;
Winter wheat cv. Riband, Standard Rotation Phase II, High Mowthorpe, 1992;
Winter wheat cv. Hereward, Alternative Rotation Phase II, High Mowthorpe, 1992;
Winter wheat cv. Hereward, Alternative Rotation Phase I, Boxworth, 1995.

Black bean aphid

An infestation of black bean aphid developed on the spring beans in the Alternative Rotation (Phase I) at Drayton in 1991, and the treatment threshold was exceeded in June. Pirimicarb was applied, only to the CCP, on 10 July 1991. Eight days after treatment, the aphid infestation was lower in the treated CCP than in the untreated LIA (**Fig. 2.6.2**) ($P < 0.05$). Subsequently, an average yield loss of 0.61 t/ha (18%) was associated with the omission of pirimicarb in the Low Insecticide sub-treatment compared with the treated All High sub-treatment ($P < 0.05$). The corresponding gross margin for the All High sub-treatment was consequently £101/ha greater ($P < 0.05$) than the Low Insecticide sub-treatment (**Fig. 2.6.2**).

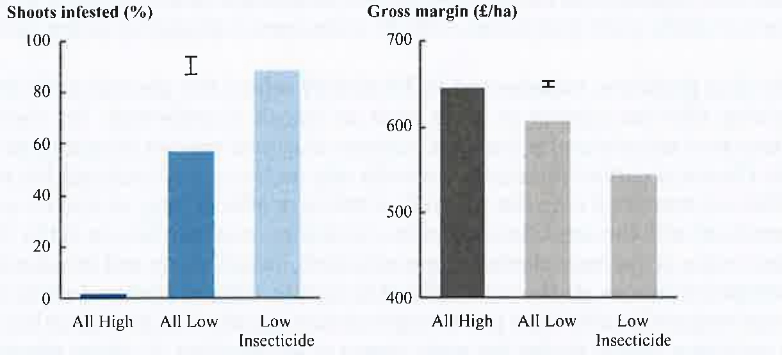

Figure 2.6.2. The effect of insecticide treatment on numbers of black bean aphids and the gross margins of spring beans at Drayton in 1991. Full rate pirimicarb applied only to the All High sub-treatment on 10/7/91. Shoot infestation assessed 8 days after treatment. Error bars denote SEDs for comparisons between pesticide sub-treatments.

Cereal aphids

Yield losses experienced from cereal aphids in winter wheat are well illustrated by a late-season attack of grain aphid and rose-grain aphid in the two crops of winter wheat at High Mowthorpe in 1992 (Standard Rotation II and Alternative Rotation II). When assessed at the early-dough growth stage (GS 83, Tottman & Broad, 1987), the action threshold was exceeded. Dimethoate was applied, therefore, to the CCP on 8 July 1992. However, the LIA was not treated as the crop was thought to be beyond the latest growth stage (GS 77, late milky-ripe) at which an economic yield response might be obtained from the application of an insecticide.

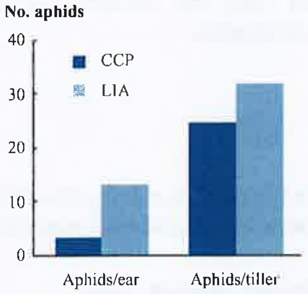

Figure 2.6.3. The effect of insecticide treatment on the numbers of cereal aphids in winter wheat (Standard Rotation II) at High Mowthorpe in 1992, assessed 11 days after treatment.

Dimethoate was effective in reducing the number of aphids (mainly grain aphids) feeding on the ears but less so against aphids (mainly rose-grain aphids) feeding on the lower leaves of winter wheat (cv. Riband) of Standard Rotation II at High Mowthorpe in 1992 (**Fig. 2.6.3**). Consequently, a highly cost-effective yield increase averaging 0.42 t/ha (5%, $P < 0.05$) occurred in the All High compared with the untreated Low Insecticide sub-treatment (**Fig. 2.6.4**). A similar increase of 0.45 t/ha (5%, $P < 0.05$) was noted in the winter wheat (cv. Hereward) of Alternative Rotation Phase II in 1992. Gross margins reflected these yield responses. At the CCP nitrogen rate, the All High sub-treatment exceeded the untreated Low Insecticide sub-treatment by £94/ha and £76/ha in Standard Rotation Phases I and II respectively (**Fig. 2.6.4**). Cost-effective, late-season yield responses from controlling cereal aphids have been reported in other recent work (e.g. Oakley et al., 1996). These findings have illustrated that the potential yield benefits from controlling cereal aphids do not cease at a specific growth stage of the crop (e.g. late milky-ripe). The control of foliar diseases of wheat using highly effective broad-spectrum fungicides prolongs the duration of green-leaf area, delays crop senescence and extends the period during which crops may be vulnerable to aphid attack. Evidently, the latest 'cut-off' date for aphicide sprays needs to be adjusted according to the duration of green-leaf area and the yield potential of individual crops.

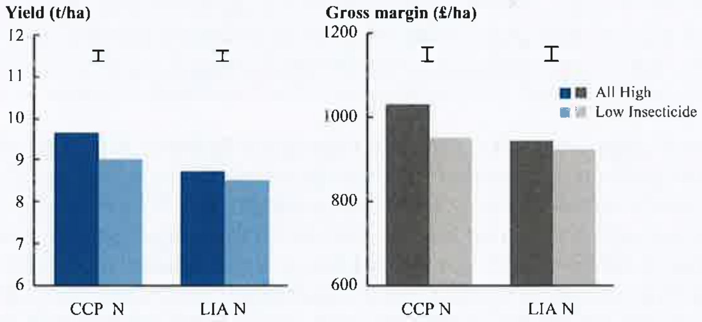

Figure 2.6.4. The effect on yield and gross margin of controlling cereal aphids in winter wheat (Standard Rotation II) at High Mowthorpe in 1992. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

The infestation of cereal aphids in the winter wheat in Standard Rotation II at High Mowthorpe in 1992 was the only example of a significant interaction ($P < 0.05$) between invertebrate pest infestation and nitrogen treatment in TALISMAN. These data indicated that the effect of a cereal aphid infestation may be more damaging in wheat crops grown under optimum nitrogen conditions (CCP) than where nitrogen supply is limited (LIA) (**Fig. 2.6.4**). This finding is in general agreement with a recently completed MAFF-funded study at ADAS Boxworth in which the effect of nitrogen on the development of grain aphid populations in winter wheat was investigated (Duffield *et al.*, 1997).

At Boxworth, in 1995, in winter wheat cv. Hereward in Alternative Rotation Phase I, grain aphid was the predominant species present. Dimethoate was applied to the CCP on 17 July at which time the crop was at the late milky-ripe growth stage (GS 79). Aphid numbers were reduced effectively by this treatment (**Fig. 2.6.5**). A yield increase of 0.39 t/ha (6%) was recorded in the treated All High compared with the untreated Low Insecticide sub-treatment ($P < 0.05$). However, there was no interaction between yield response to insecticide treatment and the two levels (CCP vs. LIA) of nitrogen treatment. Compared with the All High sub-treatment, the gross margins of the Low Insecticide treatment were subsequently reduced ($P < 0.05$) by £69/ha and £59/ha in the CCP and LIA nitrogen treatments respectively (**Fig. 2.6.5**).

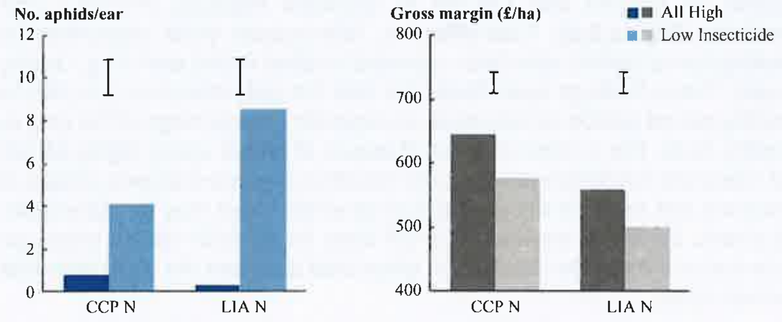

Figure 2.6.5. The effect of insecticide treatment on aphid numbers and the gross margins of winter wheat (Alternative Rotation I) at Boxworth, 1995. Full rate dimethoate applied only to the All High sub-treatment on 17/7/95. Aphid infestation assessed 8 days after treatment. Error bars show SEDs for comparisons within each nitrogen/pesticide group.

At Drayton in 1994, a crop of spring oats (Alternative Rotation, Phase I) suffered a late-season build-up of grain aphid and rose-grain aphid. An average of 64% tillers was infested by late June. Dimethoate was applied to the CCP on 30 June (GS 61, anthesis) but was omitted on the LIA. The dimethoate appeared to have little persistence in this instance as a week later aphid numbers were again above threshold. A second spray of dimethoate was applied at full rate to the CCP and at half rate to the LIA on 8 July (GS 73, early milk). Both full and half rates of dimethoate resulted in similar levels of control. There were no statistically significant differences in yield.

Conclusions

Insecticide use in low-input arable rotations entails a higher risk and lower safety margin than conventional practice, and requires a high degree of knowledge and management. TALISMAN has highlighted the consequences of failure in controlling invertebrate pest attacks. However, economically damaging, sporadic, pest attacks can have a long-lasting effect on the attitude of the practitioner. Also, the low cost of insecticides, compared with the high cost of pest damage, weighs heavily in favour of the preventive use of insecticides. Any reluctance on the part of crop protection consultants or farmers to adopt the non-routine use of insecticides combined with action thresholds reflects the potentially large financial losses, the low cost of treatment and technical uncertainty of many action thresholds.

However, the instances of invertebrate damage arising from the LIA strategy of insecticide and molluscicide use should be kept in perspective. Of the 66 insecticide and molluscicide treatments applied in TALISMAN, statistically significant yield losses occurred from omitting only four (6%) of the applications. No financial losses arose from applying reduced rates of insecticide or molluscicides. Compared with omitting applications, reducing insecticide dose-rates was a financially safer option, although the potential environmental benefits may not be as great. Clearly, great caution and expertise is required in deciding where and when dose-rates may safely be cut. When pest pressure becomes abnormally high, reduced rate insecticides or molluscicides may not be robust enough to obtain a commercially acceptable standard of control as full-rate use may also fail (e.g. slugs).

TALISMAN has shown that profitable reductions in insecticide use are possible, provided they are targeted selectively. Minimisation of insecticide and molluscicide use through the implementation of the TALISMAN Low Input Regime was cost-effective. The generally low cost of insecticides and molluscicides, compared with other variable costs, dictates that the financial savings to be gained from reducing their use are likely to be small. Nevertheless, the TALISMAN results indicate the potential for small but consistent financial savings to be gained from minimising insecticide and molluscicide use in combinable arable crops and this should be exploited within the industry.

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Table 2.6.1. Action thresholds currently in use for some of the major invertebrate pests of arable crops in the UK.

Pest Common Name	Latin name	Crop	Action threshold
Grain aphid	*Sitobion avenae*	Winter wheat	66% of tillers infested from flowering up to two weeks until the loss of active green leaf area.
Rose-grain aphid	*Metopolophium avenae*	Winter wheat	As for grain aphid.
Slugs	Mainly *Derocerus reticulatum*	Winter wheat	3-4 slugs per baited refuge trap over a 1-4 day trapping period.
Wheat bulb fly	*Delia coarctata*	Winter wheat	2.5 million eggs/ha.
Orange wheat blossom midge	*Sitodiplosis mosellana*	Winter wheat	One adult midge per six ears of wheat (feed crops) or one/three ears (milling crops).
Cabbage stem flea beetle	*Psylliodes chrysocephala*	Winter oilseed rape	Five larvae/plant in the autumn (60% leaf petioles damaged).
Cabbage seed weevil	*Ceutorhynchus assimilis*	Oilseed rape	Two adult weevils per plant during flowering.
Pollen beetle	*Meligethes* spp.	Oilseed rape	15 adults/plant at green-yellow bud in winter crops or 3/plant at green-yellow bud in spring crops.
Black bean aphid	*Aphis fabae*	Field beans	5% plants infested (on headland) before flowering.

Table 2.6.2. Insecticide use and dose rates on wheat in 1992 and 1996 (data from Davis *et al*., 1993 and Thomas *et al*., 1997).

Active ingredient	Area treated (ha)		Tonnes a.i. applied		Grams a.i./ha		% of full label rate*	
	1992	1996	1992	1996	1992	1996	1992	1996
Cypermethrin	832,751	1,200,709	19.76	27.74	23.7	23.1	95	92
Deltamethrin	140,363	71,974	0.73	0.37	5.2	5.1	104	103
Dimethoate	258,843	227,314	83.52	78.28	322.7	344.4	95	101
Methiocarb	71,273	69,983	12.02	10.49	168.6	149.9	77	68
Pirimicarb	78,828	67,202	7.97	5.76	101.1	85.7	72	61

* If a range of label rates was available, the average rate was used in this calculation.

Table 2.6.3. Insecticide and molluscicide units applied to TALISMAN cereal crops 1990–1996. One unit equals one full-rate application of one active ingredient.

Crop (no. grown)	Pest targeted	Active ingredient applied	Pesticide units applied		
			CCP	LIA*	
Winter wheat (28)	Summer aphids	Dimethoate	14.0	3.5	(75)
	Slugs	Methiocarb	7.0	2.0	(71)
	Aphids/BYDV	Cypermethrin	6.0	1.0	(83)
		Deltamethrin	2.0	0	(100)
Total			29.0	6.5	(78)
Mean			1.04	0.23	(78)
Winter triticale (8) [1]	Slugs	Methiocarb	11.0	2.0	(82)
	Aphids/BYDV	Cypermethrin	4.0	1.5	(63)
		Deltamethrin	2.0	0	(100)
Total			17.0	3.5	(79)
Mean			2.13	0.44	(79)
Spring barley (6) [2]	Slugs	Methiocarb	2.0	2.0	(0)
Total			2.0	2.0	(0)
Mean			0.33	0.33	(0)
Winter barley (2)	Aphids/BYDV	Cypermethrin	1.0	0	(100)
Total			1.0	0	(100)
Mean			0.50	0	(100)
Spring wheat (2)	Nil	Nil	0	0	(0)
Total			0	0	(0)
Mean			0	0	(0)
All cereal crops (46)					
Total			49.0	12.0	(76)
Mean			1.07	0.26	(76)

* Figures in parentheses are percentage reductions in LIA compared with CCP.

[1] Includes two crops which failed to establish due to slug damage.

[2] Sown after the failed winter triticale crops.

Table 2.6.4. Insecticide and molluscicide units applied to TALISMAN break crops 1990–1996. One unit equals one full-rate application of one active ingredient.

Crop (no. grown)	Target pest	Active ingredient applied	Pesticide units applied		
			CCP	LIA*	
Winter oilseed rape (6)[1]	Slugs	Methiocarb	6.0	3.5	(42)
	Flea beetle	Deltamethrin	2.0	1.0	(50)
	Pollen beetle	Alphacypermethrin	1.0	0	(100)
	C. seed weevil	Triazophos	1.0	0	(100)
Total			10.0	4.5	(55)
Mean			1.67	0.75	(55)
Spring oilseed rape (2)[2]	Pollen beetle	Deltamethrin	1.0	0.5	(50)
Total			1.0	0.5	(50)
Mean			0.50	0.25	(50)
Winter beans (6)	B. bean aphid	Pirimicarb	1.0	0	(100)
Total			1.0	0	(100)
Mean			0.17	0	(100)
Spring beans (5)	B. bean aphid	Pirimicarb	2.0	0	(100)
Total			2.0	0	(100)
Mean			0.40	0	(100)
Linseed (3)	Flea beetle	Alphacypermethrin	1.0	0.5	(50)
Total			1.0	0.5	(50)
Mean			0.33	0.17	(48)
Spring oats (2)[3]	Summer aphids	Dimethoate	2.0	0.5	(75)
Total			2.0	0.5	(75)
Mean			1.00	0.25	(75)
All break crops (24)					
Total			17.0	6.0	(65)
Mean			0.71	0.25	(65)

* Figures in parentheses are percentage reduction in LIA compared with CCP.

[1] Includes two crops which failed to establish due to slug damage.

[2] Sown after the failed winter oilseed rape crops.

[3] Grown as a break crop at Drayton.

Table 2.6.5. Total insecticide and molluscicide units applied in the Standard and Alternative Rotations of TALISMAN, 1990–1996. One unit equals one full-rate application of one active ingredient.

Rotation/Site	Rotation Phase I			Rotation Phase II		
	CCP	LIA*		CCP	LIA*	
Standard Rotation						
Boxworth	5.0	1.0	(80)	4.0	1.0	(75)
Drayton	10.0	3.0	(70)	9.0	3.5	(61)
High Mowthorpe	5.0	1.0	(80)	4.0	1.0	(75)
Average	6.7	1.7	(75)	5.7	1.8	(68)
Alternative Rotation						
Boxworth	2.0	0.5	(75)	-	-	-
Drayton	13.0	3.3	(75)	9.0	2.8	(69)
High Mowthorpe	2.0	0.5	(75)	3.0	0.5	(83)
Average	5.7	1.4	(75)	6.0	1.6	(73)

* Figures in parentheses are percentage reductions in LIA compared with CCP.

Table 2.6.6. The effect of winter- and spring-sown crops on insecticide and molluscicide units applied in TALISMAN, 1990–1996.

Crop	Number grown[1]	Mean no. units applied per crop[2]		% reduction of LIA cf. CCP
		CCP	LIA	
Winter crops	50	1.160	0.250	78
Spring crops	20	0.400	0.175	56
All crops	70	0.943	0.257	73

[1] Includes four failed crops.

[2] One unit equals one full-rate application of one active ingredient.

Table 2.6.7. The effect of low-input insecticide use on the mean yields of cereal crops in TALISMAN, 1991–1996 (t/ha @ 85% d.m.).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Insecticide	
First winter wheat				
Boxworth (172 d.f.)	7.01	6.68 (95)	6.90 (98)	0.063***
Drayton (80 d.f.)	8.07	7.79 (97)	8.23 (102)	0.091***
High Mowthorpe (176 d.f.)	8.37	7.60 (91)	8.22 (98)	0.080***
Cross-site (428 d.f.)	7.76	7.27 (94)	7.70 (99)	0.045***
Second winter wheat				
Boxworth (111 d.f.)	7.43	7.21 (97)	7.49 (101)	0.064***
Drayton (80 d.f.)	7.22	6.93 (96)	7.37 (102)	0.132*
High Mowthorpe (32 d.f.)	7.79	6.88 (88)	7.64 (98)	0.112***
Cross-site (223 d.f.)	7.42	7.05 (95)	7.48 (101)	0.059***
All winter wheat				
Boxworth (283 d.f.)	7.18	6.90 (96)	7.14 (100)	0.046***
Drayton (160 d.f.)	7.64	7.36 (96)	7.80 (102)	0.080***
High Mowthorpe (208 d.f.)	8.25	7.45 (90)	8.11 (98)	0.069***
Cross-site (651 d.f.)	7.64	7.19 (94)	7.62 (100)	0.036***
Spring barley				
Drayton (40 d.f.)	5.96	5.65 (95)	5.60 (94)	0.224
High Mowthorpe (78 d.f.)	5.34	5.35 (100)	5.40 (101)	0.184
Cross-site (119 d.f.)	5.55	5.45 (98)	5.47 (99)	0.178
Winter triticale				
Drayton (120 d.f.)	5.25	5.19 (99)	5.35 (102)	0.083
Winter barley				
High Mowthorpe (32 d.f.)	7.95	7.67 (97)	7.88 (99)	0.200
Spring wheat				
Boxworth (47 d.f.)	5.92	5.25 (89)	5.88 (99)	0.135***

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

* $P < 0.05$.

*** $P < 0.001$.

Table 2.6.8. The effect of low-input insecticide use on the mean gross margins of cereal crops in TALISMAN, 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Insecticide	
First winter wheat				
Boxworth (172 d.f.)	717.8	724.0 (101)	706.8 (99)	7.16***
Drayton (80 d.f.)	753.3	810.2 (108)	779.9 (104)	10.07***
High Mowthorpe (176 d.f.)	1022.1	974.5 (95)	1004.2 (98)	10.26***
Cross-site (428 d.f.)	846.6	841.4 (99)	840.4 (99)	5.42***
Second winter wheat				
Boxworth (111 d.f.)	945.6	950.7 (101)	954.8 (101)	8.01
Drayton (80 d.f.)	606.4	701.8 (116)	642.0 (106)	13.18***
High Mowthorpe (32 d.f.)	759.9	750.8 (99)	745.7 (98)	11.59***
Cross-site (223 d.f.)	793.1	827.6 (104)	807.5 (102)	6.36***
All winter wheat				
Boxworth (283 d.f.)	808.9	814.7 (101)	806.0 (100)	5.63**
Drayton (160 d.f.)	679.8	756.0 (111)	710.9 (105)	8.30***
High Mowthorpe (208 d.f.)	969.7	929.8 (96)	952.5 (98)	8.68***
Cross-site (651 d.f.)	827.3	836.4 (101)	828.5 (100)	4.16***
Spring barley				
Drayton (40 d.f.)	384.9	425.7 (111)	389.7 (101)	22.44
High Mowthorpe (78 d.f.)	608.6	633.3 (104)	614.9 (101)	17.89
Cross-site (119 d.f.)	534.0	564.1 (106)	539.8 (101)	14.07
Winter triticale				
Drayton (120 d.f.)	470.6	542.1 (115)	503.8 (107)	8.62***
Winter barley				
High Mowthorpe (32 d.f.)	820.4	844.2 (103)	816.4 (100)	19.98
Spring wheat				
Boxworth (47 d.f.)	776.6	720.3 (93)	772.1 (99)	17.10***

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

*** $P < 0.001$.

Table 2.6.9. The effect of low-input insecticide use on the mean yields of break crops in TALISMAN, 1991–1996 (t/ha @ 85% d.m. or 91% d.m. for oilseeds).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Insecticide	
Winter oilseed rape				
Boxworth (24 d.f.)	0.83	0.51 (61)	0.87 (105)	0.157***
Drayton (16 d.f.)	2.59	2.31 (90)	2.80 (108)	0.259
High Mowthorpe (31 d.f.)	3.58	3.24 (91)	3.73 (105)	0.114**
Cross-site (71 d.f.)	2.50	2.18 (87)	2.64 (105)	0.093***
Spring oilseed rape				
Boxworth (24 d.f.)	0.91	0.55 (60)	0.74 (82)	0.100*
Drayton (16 d.f.)	0.23	0.36 (154)	0.34 (147)	0.088
Cross-site (40 d.f.)	0.62	0.46 (75)	0.57 (93)	0.069
Winter beans				
Boxworth (48 d.f.)	4.08	4.19 (103)	4.28 (105)	0.083
Drayton (32 d.f.)	4.01	4.03 (101)	4.17 (104)	0.095
High Mowthorpe (32 d.f.)	4.86	4.67 (96)	4.65 (96)	0.086**
Cross-site (112 d.f.)	4.29	4.29 (100)	4.36 (102)	0.051
Spring beans				
Boxworth (17 d.f.)	1.74	1.46 (84)	1.75 (101)	0.231
Drayton (32 d.f.)	3.23	2.89 (90)	2.92 (90)	0.087***
High Mowthorpe (32 d.f.)	4.46	4.25 (95)	4.49 (101)	0.108
Cross-site (81 d.f.)	3.32	3.04 (92)	3.22 (97)	0.075**
Spring linseed				
Boxworth (24 d.f.)	2.48	2.43 (98)	2.50 (101)	0.061
High Mowthorpe (31 d.f.)	1.72	1.74 (102)	1.75 (102)	0.056
Cross-site (55 d.f.)	2.02	2.02 (100)	2.05 (102)	0.041*
Spring oats				
Drayton (32 d.f.)	4.93	4.62 (94)	4.77 (97)	0.116

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

* $P < 0.05$.

** $P < 0.01$.

*** $P < 0.001$.

Table 2.6.10. The effect of low-input insecticide use on the mean gross margins of break crops in TALISMAN, 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Insecticide	
Winter oilseed rape				
Boxworth (24 d.f.)	50.0	-1.0 (na)	60.0 (na)	41.90***
Drayton (16 d.f.)	373.0	361.0 (97)	438.0 (117)	68.90
High Mowthorpe (31 d.f.)	829.0	797.1 (96)	867.5 (105)	23.41
Cross-site (71 d.f.)	484.1	450.9 (93)	520.1 (107)	23.23**
Spring oilseed rape				
Boxworth (24 d.f.)	346.5	345.2 (100)	317.7 (92)	18.04
Drayton (16 d.f.)	324.1	369.3 (114)	349.7 (108)	15.80
Cross-site (40 d.f.)	336.9	355.5 (106)	331.4 (98)	12.43
Winter beans				
Boxworth (48 d.f.)	620.8	674.0 (109)	653.1 (105)	13.41**
Drayton (32 d.f.)	566.3	616.5 (109)	583.4 (103)	15.78***
High Mowthorpe (32 d.f.)	744.9	724.8 (97)	718.9 (97)	11.73**
Cross-site (112 d.f.)	641.7	672.0 (105)	651.9 (102)	8.00***
Spring beans				
Boxworth (17 d.f.)	328.5	380.1 (116)	341.9 (104)	22.42
Drayton (32 d.f.)	485.9	474.9 (98)	434.7 (90)	13.51***
High Mowthorpe (32 d.f.)	679.3	664.8 (98)	678.5 (100)	15.92
Cross-site (81 d.f.)	519.1	522.4 (101)	502.9 (97)	9.54
Spring linseed				
Boxworth (24 d.f.)	698.0	686.8 (98)	702.2 (101)	6.31**
High Mowthorpe (31 d.f.)	565.2	581.7 (103)	568.6 (101)	7.29
Cross-site (55 d.f.)	618.3	623.8 (101)	622.0 (101)	4.99
Spring oats				
Drayton (32 d.f.)	504.4	491.0 (97)	489.8 (97)	12.11

[1] Cross-nitrogen means. 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.
** $P < 0.01$.
*** $P < 0.001$.

Table 2.6.11. The effect of low-input insecticide use on the mean gross margins on crops grouped as cereals, breaks or overall crops in TALISMAN 1991–1996 (£/ha, including area payments).

Crop & Site	Pesticide sub-treatment [1]			SED
	All High	All Low	Low Insecticide	
Cereal crops				
Boxworth (346 d.f.)	803.6	799.0 (99)	800.4 (100)	5.73*
Drayton (352 d.f.)	564.5	634.5 (112)	593.1 (105)	6.04***
High Mowthorpe (350 d.f.)	860.7	845.0 (98)	851.1 (99)	7.91***
Cross-site (1048 d.f.)	742.9	759.5 (102)	748.2 (101)	3.83***
Break crops				
Boxworth (169 d.f.)	444.1	458.9 (103)	454.7 (102)	11.30**
Drayton (176 d.f.)	476.3	486.9 (102)	475.5 (100)	11.65
High Mowthorpe (174 d.f.)	704.6	692.1 (98)	707.8 (101)	8.31
Cross-site (519 d.f.)	541.7	546.0 (101)	546.0 (101)	6.08
All crops				
Boxworth (515 d.f.)	683.7	685.6 (100)	685.2 (100)	5.36***
Drayton (528 d.f.)	535.1	585.3 (109)	553.9 (104)	5.59***
High Mowthorpe (524 d.f.)	808.7	794.0 (98)	803.3 (99)	5.96***
Cross-site (1567 d.f.)	675.8	688.3 (102)	680.8 (101)	3.26***

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

Table 2.6.12. Plant populations of winter triticale (Alternative Rotation I) at Drayton on 7/1/93 following attack by slugs during autumn establishment (nos. plants/m^2).

Main Treatment	Pesticide sub-treatment					Cross-pesticide means
	All High	All Low	Low Herbicide	Low Fungicide	Low Insecticide	
			SED v 37.4, h 33.8			SED 5.3
CCP Nitrogen	127	69	138	136	54	105
LIA Nitrogen	136	86	66	111	91	98
			SED 26.4			
Cross-nitrogen means	132	78	102	124	73	

MONITORING THE EFFECTS OF INSECTICIDES AND MOLLUSCICIDES ON NON-TARGET ARTHROPODS AND NEMATODES

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Introduction

Although TALISMAN was designed primarily to examine the economic and agronomic effects of adopting cropping systems which use low inputs of agrochemicals and nitrogen, the influence of these systems on various invertebrate taxa was also assessed. Pesticides in the form of insecticides, molluscicides and nematicides are by far the most common means of combating invertebrate pests in agricultural and horticultural crops, and there is much concern about the impact of these agrochemicals on non-pest invertebrate species. These non-pest species are important for a number of reasons: they may be predators or parasitoids, particularly of invertebrate pests, they may contribute to the maintenance of soil fertility and they add to the biodiversity of the ecosystem.

TALISMAN provided an opportunity to gain information on the impact of pesticides on invertebrate populations and to complement data collected in the SCARAB study. SCARAB was designed specifically to investigate some of the possible longer-term ecological effects of pesticide use in arable crops, whereas the main objective of TALISMAN was to quantify the agronomic and economic effects (Cooper, 1990). Had TALISMAN been an ecological study, plots would have been much larger and more intensive monitoring would have been undertaken. The limitations of the TALISMAN arthropod monitoring are recognised and the results are reported here to show trends between sites and between years and to complement data from SCARAB.

Arthropods (e.g. insects and spiders) and soil nematodes (microscopic, unsegmented worms) were assessed. The arthropods were compared in the CCP and LIA regimes of nitrogen and pesticide use: i.e. nitrogen and all categories of pesticides applied according to either CCP or LIA rules (Chapter 2.1). Nematode populations were monitored in the All High and Low Herbicide sub-treatments of both the CCP and LIA nitrogen regimes. Owing to the limitations of the design, it was recognised from the start that, at best, only short-term effects of insecticides and molluscicides on non-target species were likely to be detected.

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.

Arthropod monitoring

The arthropod monitoring focused on taxa (taxonomic groups) believed to be of general benefit in arable crop ecosystems. The Carabidae (ground beetles) and Staphylinidae (rove beetles) include many important predatory species which feed upon damaging pests such as aphids (Edwards *et al.*, 1979) and slugs

(Symondson, 1989). Likewise, certain species of spiders, notably those in the Linyphiid family (money spiders), are also known to be useful predators of aphid pests (Sunderland *et al.*, 1985). In contrast, springtails (Collembola), the majority of which are fungal feeders, are near the bottom of the food chain and, as such, are a key group on which the survival of many higher taxa depend. They also play an important role in the decomposition of organic matter, such as dead vegetation, which in turn helps to maintain soil fertility (Hopkin, 1997).

Pitfall trapping

The effects of pesticide treatment on arthropods were assessed using pitfall traps which measure a combination of the abundance and activity of arthropods, modified by behaviour and other possible factors. Indeed, some species or individuals may not be caught on some or all possible occasions because they can avoid the traps or are simply not active when traps are in position. Therefore, pitfall trap data must be interpreted carefully.

At each site, pitfall traps were located in Block I only (the block nearest the field boundary). Four pitfall traps were placed in each plot within the block in a line at right angles to the field boundary, down the centre of the plot, avoiding tram lines and crop strips between the tram lines. The traps were spaced so that the first and fourth were approximately 5 m from the plot ends with the others positioned evenly in-between, i.e. approximately 5, 10, 15 and 20 m from the edge of the plot nearest the field boundary.

Each trap consisted of a plastic beaker, 8.5 cm in diameter and 13.5 cm deep. These were set with their rims level with the soil surface within cylinders of plastic drain pipe (9.5 cm outside diameter, 3 mm wall, 20 cm deep). The drain pipe was used to prevent the sides of the hole collapsing when traps were changed. The trap was filled to a depth of about 50 mm with water containing a few drops of washing-up liquid. The purpose of the washing-up liquid was to reduce the surface tension of the water to ensure that captured individuals were quickly wetted and immersed. Traps were changed every seven days and also on the day of and before any application of insecticide or molluscicide. Trapping resumed the day after any insecticide or molluscicide had been applied and continued for four days. This catch and the one before treatment were identified. The next trapping period lasted until the next regular collection day but the catch was not usually identified. Regular crop monitoring was also undertaken to establish the incidence of invertebrate pests, e.g. aphids and slugs. The decision to apply an insecticide or molluscicide was normally based on established thresholds (Chapter 2.6). Pesticide treatments were applied either as full rate applications on plots managed to Current Commercial Practice (CCP) but omitted, or applied at reduced rates, in the Low Input Approach (LIA) plots.

The catches from all traps in a plot for a trapping period were bulked and stored. In the absence of any pesticide application, alternate weeks' catches were identified. All carabids (ground beetles), staphylinids (rove beetles) and spiders were identified to species. Other major taxa including Acari (mites), Collembola (springtails), Diptera (flies), Hemiptera (e.g. aphids and bugs), Hymenoptera (e.g. bees and wasps), and Thysanoptera (thrips) were also counted. Data were expressed as numbers per plot per day.

Arthropod catches

The major arthropod orders

At Boxworth, mites and springtails were by far the most numerous Arthropod groups recovered and accounted for 93% of all specimens caught (**Table 2.7.1**). In five out of six years, springtails were the most frequently trapped group, comprising between 53% and 70% of the catch in any one year. Extremely large numbers of mites were trapped in 1990/91, and this accounts for their high proportion of the total catch over all years of the experiment.

Springtails were by far the most abundant Arthropod group at Drayton, comprising 81% of the total (**Table 2.7.1**). Within each year, springtails were the most numerous order and provided from 53% to 91% of the total catch of arthropods. At this site, carabid and staphylinid beetles and spiders were identified in 1990/91 only. Thereafter, only the most common species from each of these groups were counted.

Springtails were also the most numerous Arthropod group at High Mowthorpe, and comprised from 31% to 53% of arthropods within any particular year and 42% of arthropods over all six years (**Table 2.7.1**).

Carabid beetles

At Boxworth, the most numerous species caught was *Bembidion obtusum*, followed in decreasing order by *Trechus quadristriatus, Pterostichus melanarius* and *Agonum dorsale* (**Table 2.7.2**). *B. obtusum* was most frequently trapped in four out of six years from 1991/92 to 1994/95. During this period, this beetle comprised between 44% and 76% of all those caught. However, in 1990/91 and 1995/96, *T. quadristriatus* was the most common carabid trapped. With the exception of the six most commonly trapped carabid beetles, none of the other species exceeded 2% of the total catch.

At Drayton, the most numerous carabids were *T. quadristriatus* (32% of total carabids) and *P. melanarius* (22% of total). With the exception of 1993/94, when catches of *T. quadristriatus* were very low, these species were the most abundant ground beetles in all years of the experiment at Drayton (**Table 2.7.2**).

The most numerous species trapped during the experiment at High Mowthorpe were *A. dorsale*, followed by *P. melanarius* and *Nebria brevicollis*. Together, these species accounted for approximately 58% of all carabids caught (**Table 2.7.2**). Within individual years, the most common species varied. In 1990/91 and 1991/92, *A. dorsale* was most frequently recorded but in 1993/94 and 1994/95, *P. melanarius* was most the numerous species. In 1992/93, *N. brevicollis* was caught in greatest numbers and in 1995/96 it was *Pterostichus madidus*.

Staphylinid beetles

Overall, Aleocharinae were the most commonly trapped staphylinid beetles at Boxworth and 36% of all staphylinids belonged to this sub-family (**Table 2.7.2**). Of the named species, *Tachyporus hypnorum* was most frequently trapped and accounted for 24% of the total catch. The next most common species were *Xantholinus linearis* (11% of total catch), *Lathrobium fulvipenne* (8% of total catch) and *Anotylus sculpturatus* (7% of total catch). No other species exceeded 2% of all staphylinids caught at Boxworth.

At Drayton, with the exception of 1990/91, *T. hypnorum* was the only staphylinid beetle consistently identified to species level (**Table 2.7.2**). It comprised 14% of the total catch. Numbers were highest in 1991/1992.

The most numerous species at High Mowthorpe was *T. hypnorum* which comprised 33% of all staphylinids trapped (**Table 2.7.2**). This species was also caught most often in all years except 1992/93 when *Philonthus cognatus* was most common. *P. cognatus* was the second most frequently trapped staphylinid and accounted for 18% of this family. No other staphylinid species accounted for more than 2% of the total catch.

Spiders

At Boxworth, the Lycosidae (wolf spiders) was the most numerous family trapped although only seven species were recorded. However, one of these, *Pardosa palustris*, was by far the dominant spider species, particularly in 1994/95 and 1995/96, and accounted for 48% of all specimens caught (**Table 2.7.2**). Within the Linyphiidae (money spiders), the most common species was *Oedothorax apicatus* followed by *Erigone atra* and *Lepthyphantes tenuis*. These species comprised 21%, 11% and 7% of the total spider catch respectively. *Pachygnatha degeeri* was the most frequently caught tetragnathid and accounted for 5% of all spiders. Numbers of all other families were low.

In 1991, a species of linyphiid spider new to science was discovered. This has now been named *Centromerus minutissimus* (Merrett *et al.*, 1993). This spider is believed to feed on springtails and immature aphids. Only small numbers of males were recovered.

At Drayton, the linyphiids comprised 50% of the total numbers of spiders trapped and *O. apicatus* and *E. atra* were the most abundant species in this family (**Table 2.7.2**). Lycosidae were particularly numerous in 1994/1995 and 1995/1996, contributing 47% and 48% respectively, of all spiders for these years.

The linyphiids were the most common group at High Mowthorpe and provided 78% of the total spider catch (**Table 2.7.2**). *E. atra* and *E. dentipalpis* were by far the most numerous linyphiids (and spider species) recorded both within individual years and over the whole experimental period. Together, they comprised almost 50% of all spiders caught. Only two other linyphiid species contributed more than 5% of the total spider catch. These were *L. tenuis* at 7% and *Oedothorax fuscus* at 6% of the total spider catch. The Lycosidae was the second most common spider family and *P. palustris* was the most common species, accounting for 8% of the total spider catch at High Mowthorpe.

Insecticide and molluscicide effects

In general, pitfall trap catches were very variable within and between cropping years, even in the absence of pesticide application. Therefore, detecting the effect of pesticides on arthropods was difficult when viewed against this inherent background variability. It is possible that natural variation in trap catches could mask any short-lived effect of pesticide treatment. Alternatively, natural variation in the numbers of arthropods trapped could be mistakenly attributed to an effect of pesticide. Therefore, pitfall trap data were interpreted with care, and trends sought between sites and between years to substantiate any potential effect of pesticide.

Pesticide applications were divided into four groups: molluscicides, autumn aphicides in cereals, summer aphicides in cereals, and other insecticides. In total, this accounted for 66 applications but only on seven occasions was there evidence of a possible effect of pesticide on pitfall trap catches.

Molluscicides

Methiocarb was the only molluscicide applied in TALISMAN. Methiocarb, as a pelleted bait formulation, was normally applied by broadcasting the pellets on the soil surface before, during or after crop emergence. Methiocarb was used in winter triticale, winter wheat, winter oilseed rape and spring barley (Chapter 2.6). On one occasion, in spring barley following winter triticale (abandoned owing to slug damage), methiocarb pellets were mixed with the crop seed (admixed) as a precautionary measure prior to sowing. Drayton and Boxworth were the major users of methiocarb because of the slug problems encountered on the heavy clay soils of these sites. Twenty full label-rate applications of methiocarb were made to the CCP regime of cereals and six were made to the CCP break crops. Methiocarb accounted for 39% of applications of the combined insecticide and molluscicide usage in TALISMAN. Drayton was the heaviest user, accounting for 88% of the methiocarb applied in TALISMAN, because of the slug attacks to winter triticale and oilseed rape at this site (Chapter 2.6).

There was some evidence of adverse effects of methiocarb on the monitored arthropod taxa on only three out of the 26 occasions on which it was applied.

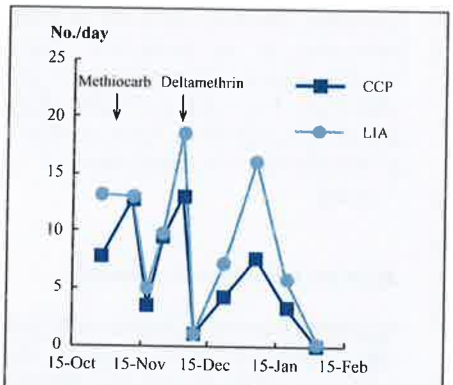

Figure 2.7.1. Pitfall trap catches of carabid beetles in winter triticale at Drayton in 1991–92 following application of methiocarb and deltamethrin to CCP only.

In the autumn of 1991, the CCP plots of winter triticale at Drayton were treated with full-rate methiocarb on 14 November to reduce the effects of a severe but localised slug attack. Carabid catches were declining on all plots at the time of methiocarb application and although they recovered over the next three weeks, the number of beetles caught was about 40% higher on the LIA in comparison with the CCP treatment (**Fig. 2.7.1**). Catches again declined between 4 and 9 December but between 23 December and 20 January consistently more beetles were trapped in the LIA than in the CCP treatment. It is possible that this represents a persistent deleterious effect of methiocarb application on 14 November but catches may also have been influenced by a spray of deltamethrin on 4 December, to the CCP plot only, to control the aphid vectors of barley yellow dwarf virus (BYDV).

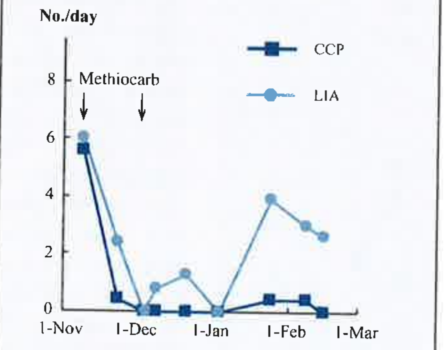

Figure 2.7.2. Pitfall trap catches of *Trechus quadristriatus* in winter triticale at Drayton in 1992–93 following application of methiocarb to CCP only.

In the following crop of winter triticale at Drayton in autumn 1992, two full-rate applications of methiocarb were made on 10 November and 4 December. The most numerous carabid at this time was *T. quadristriatus* and catches of this beetle were consistently higher in LIA than CCP plots from 23 November until 15 February (**Fig. 2.7.2**).

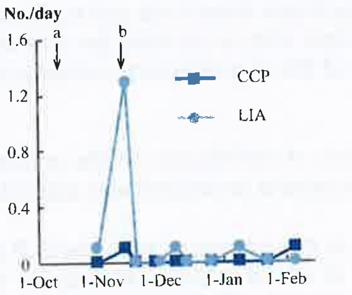

Figure 2.7.3. Pitfall trap catches of *Bembidion obtusum* in winter triticale at Drayton in 1994–95 following two applications of full-rate methiocarb to the CCP plot (a & b) and a half-rate application to the LIA plot (b only).

Slug damage once again necessitated the use of methiocarb in winter triticale at Drayton in autumn 1994. CCP plots received a full-rate application on 13 October and 14 November and the LIA plots a half-rate treatment on 14 November. Although catches of the most numerous carabid, *B. obtusum*, were generally low from October to early February, on 14 November more beetles were recovered from the LIA plot than from the CCP plot (**Fig. 2.7.3**). This may have been an effect of the methiocarb application on 13 October.

Autumn aphicides in cereals

Synthetic pyrethroid insecticides are widely used in cereals during the autumn months to control the aphid vectors of barley yellow dwarf virus (BYDV). This particular use accounted for 23% (15 sprays) of the insecticide and molluscicide applications in TALISMAN. Cypermethrin was the most frequently applied pyrethroid insecticide for control of aphid vectors of BYDV in TALISMAN as Pesticide Usage Survey data indicated that it was the most widely used product for this purpose nationally (Davis *et al.*, 1992). Another type of pyrethroid, deltamethrin, was also applied on four occasions in TALISMAN to control aphid vectors of BYDV. On only one occasion was there any evidence of a deleterious effect of pyrethroids on arthropods.

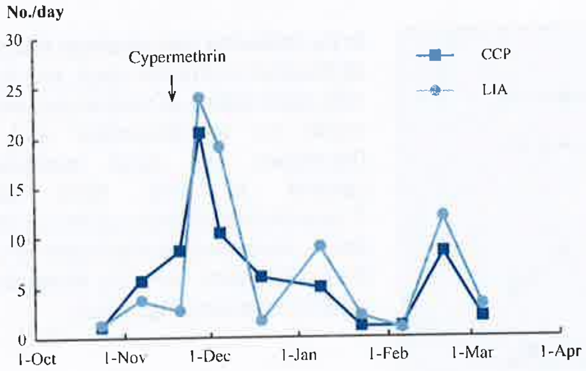

Figure 2.7.4. Pitfall trap catches of carabid beetles in winter wheat at Boxworth in 1995–96 following application of cypermethrin to CCP only.

At Boxworth in 1995/96, full-rate cypermethrin was applied to CCP plots of winter wheat (Standard Rotation) on 20 November. For approximately four weeks after this date, there was a tendency for more carabids to be trapped in the unsprayed LIA plots than in the corresponding CCP plots (**Fig. 2.7.4**). There was also a consistent difference between the two phases of the Standard Rotation over the same period, with larger catches in plots of Phase II than Phase I. This difference was larger than that between LIA and CCP plots, suggesting that the effect of insecticide was less than that of rotation.

Summer aphicides in cereals

Sixteen dimethoate sprays were applied to control aphid attacks in cereals during the summer, this being the most numerous single usage of insecticide in TALISMAN. No other active ingredients were employed for this purpose, which accounted for 24% of the insecticides and molluscicides applied in TALISMAN.

Despite the approval of other non-organophosphorus products for summer aphid control, such as the carbamate pirimicarb and certain synthetic pyrethroids, dimethoate was chosen as it remains the most widely used product for this problem (Davis *et al.*, 1992). High Mowthorpe had cause to apply the most dimethoate; 56% of the dimethoate sprays were applied there, reflecting the problems experienced with cereal aphid attacks at that site (Chapter 2.6). Boxworth accounted for 19% of dimethoate use and Drayton for 25%.

In only one case out of 16 was there any evidence to suggest a harmful effect of dimethoate on the non-target groups monitored.

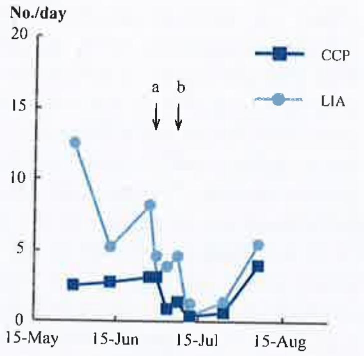

Figure 2.7.5. Pitfall trap catches of carabid beetles in spring oats at Drayton in 1994 following two full-rate applications of dimethoate to CCP (a & b) and a half-rate application to LIA (b only).

In 1994 at Drayton on spring oats, a rapid build up of grain aphid (*Sitobion avenae*) and rose-grain aphid (*Metopolophium dirhodum*) required two treatments with full-rate dimethoate to the CCP plot on 30 June and 8 July, with a single half-rate application to the LIA plot on 8 July. On 30 June, at the time of the first dimethoate treatment, carabid catches were approximately equal in both CCP and LIA plots (**Fig. 2.7.5**). On the two subsequent trapping occasions, catches declined in the CCP treatment where the full rate of the insecticide had been used but increased in the unsprayed LIA plot. Following dimethoate application on 8 July, at the full- and half-rate in CCP and LIA treatments respectively, numbers of carabids caught declined in both plots. This suggested that the reduced-rate of the insecticide was equally as damaging as the full-rate. However, the effects appeared to be short-lived and catches had recovered by early August, probably owing to the small plot size which allowed re-invasion.

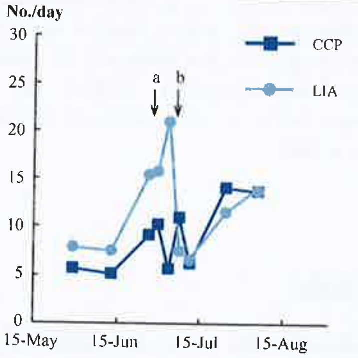

Figure 2.7.6. Pitfall trap catches of linyphiid spiders in spring oats at Drayton in 1994 following two full-rate applications of dimethoate to CCP (a & b) and a half-rate application to LIA (b only).

The dimethoate applied to spring oats at Drayton in 1994 also appeared to have a deleterious effect on linyphiid spiders (**Fig. 2.7.6**). Following its application on 30 June to the CCP plot, CCP catches declined in comparison with an increase in catches in the untreated LIA plot. Approximately 15 more spiders per day were caught in the LIA plot than in the CCP plot. Catches declined in both treatments in July, but had recovered by August.

Other insecticides

A relatively small number of insecticides was applied to control attacks by black bean aphid (*Aphis fabae*) in field beans (three sprays), pollen beetle (*Meligethes aeneus*) or cabbage seed weevil (*Ceutoryhynchus assimilis*) in oilseed rape (five sprays) and flea beetle (*Longitarus parvulus*) in linseed (one spray). Overall, these products accounted for 14% of the insecticide and molluscicide use in TALISMAN.

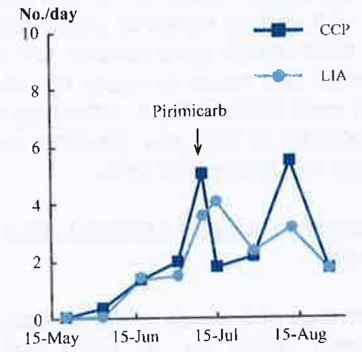

Figure 2.7.7. Pitfall trap catches of *Pterostichus melanarius* in spring beans at Drayton in 1991 following application of pirimicarb to CCP only.

There were two instances when there was an apparent effect of insecticide application on non-target arthropods. Pirimicarb was applied to the CCP plot of spring beans at Drayton to control black bean aphid on 10 July 1991. In the five days after treatment, total catches of *P. melanarius* declined in CCP plots but gradually increased in the LIA plots (**Fig. 2.7.7**). Pirimicarb is known to have little effect on arthropods other than aphids. Therefore, it is possible that the differences between LIA and CCP treatments were due to a reduction in the population of black bean aphids which provided food for the beetles. If their food source was removed the beetles may have migrated elsewhere in search of prey. By the time of the next assessment at the end of July, beetle catches in the LIA plots were decreasing but they were increasing in the CCP plots. This change in the pattern of catches from mid-July is difficult to explain but may be due simply to natural variation. If this is the case, then the apparent deleterious effect of pirimicarb around 10 July should be treated with caution.

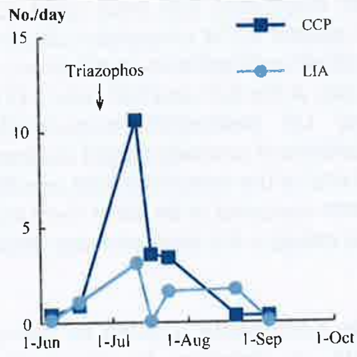

Figure 2.7.8. Pitfall trap catches of *Agonum dorsale* in winter oilseed rape at High Mowthorpe in 1991 following application of triazophos to CCP only.

Evidence of another potential effect of insecticide use was recorded at High Mowthorpe in 1991 following the application of triazophos to oilseed rape on 28 June to control cabbage seed weevil and pod midge. Catches of the most numerous carabid, *A. dorsale*, increased markedly in the CCP plot in comparison with the unsprayed LIA treatment approximately two weeks after insecticide application (**Fig. 2.7.8**). It is possible that this was due to an increase in beetle activity brought about by a reduction in the numbers of prey species.

Multivariate analysis of arthropod data

All of the results discussed so far have adopted the same approach to the measurement of the ecological effects of the CCP and LIA treatments. The arthropods were identified and then their abundance compared in relation to treatment. Such an analysis is useful in that it provides readily interpretable conclusions in terms of which species are favoured by particular treatments. However, it is inefficient in that only a small part of the total data is considered.

An alternative approach to the analysis of these data was undertaken by Dr M L Luff of the University of Newcastle upon Tyne and is summarised here to compare with and complement the results already discussed. The technique involved analysis of whole datasets of the abundance of many taxa using ordination techniques. Ordination is a method of summarising ecological community data by producing a two- or three-dimensional framework (ordination space) within which similar species or samples are close together and dissimilar ones are far apart. The axes of the two- or three-dimensional ordination space represent the major trends of any variation in the data, in decreasing order of importance from the first to the second or third axes. The positions of any particular samples along the axes are then a measure of how much these are affected by the environmental factors that contribute to the variation along the axes.

The main objectives of the analysis were:

- to compare the effects of nitrogen/pesticide regimes (LIA vs CCP), crop rotations and years on the overall composition of the arthropod fauna, as measured by the axis scores of each sample plot;
- to detect any significant treatment effects and to indicate the species or taxa involved so that these might be subjected to further individual species analysis.

Method of data analysis

Data were analysed from three TALISMAN sites (**Table 2.7.3**). These included the whole season totals of pitfall catches of each arthropod species in each combination of treatment, rotation and year, with separate files for each TALISMAN site. The numbers of species included in the analysis are shown in **Table 2.7.4**. For each of the sites, a detrended correspondence analysis (DECORANA) was done using the CANOCO statistical package (Ter Braak, 1998). This analysis ordinates the species and sample plots in up to four dimensions of ordination space, without allowing for the effects of any known environmental variables or treatments. The axis 1 and axis 2 ordination scores were then tested for any significant effects of year, rotation or treatment using conventional analysis of variance. Possible interactions between these three sources of variation were also tested. Where any significant treatment effects were detected, a more detailed comparison was made using paired t-tests between LIA or CCP axis scores for each plot, to allow for inter-plot variations more effectively.

Results and discussion of analysis

Examples of ordination diagrams for all three sites are shown (**Figs 2.7.9 – 2.7.11**). In each diagram, the number of points shown represents combinations of years, rotation and LIA and CCP treatment. At Boxworth, the dataset comprised four years with three rotations each with LIA and CCP treatment. This resulted in 24 plot/year combinations in the analysis. At Drayton and High Mowthorpe, there were two years and four rotations each with CCP and LIA treatments providing 16 plot/year combinations.

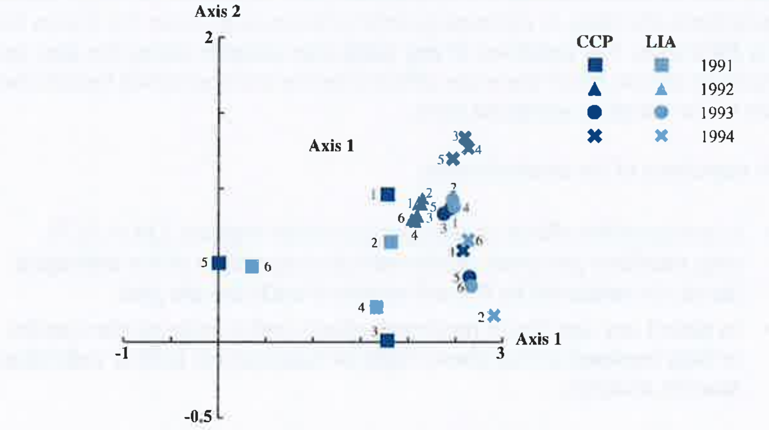

Figure 2.7.9. DECORANA ordination of invertebrate assemblages between 24 plot/year combinations over four years (1991–1994), three rotations (Standard Phases I and II, Alternative Phase I) and two treatment regimes (CCP & LIA) at Boxworth. The numbers against data points identify rotations as listed in Table 2.1.2, Chapter 2.1

At Boxworth (**Fig. 2.7.9**), it was evident that the 1991 plots were to the left of axis one with both the Alternative Rotation plots being very distinct from the remaining plot/year combinations. Analyses of variance of axis one and axis two scores showed that year of sampling had a significant effect ($P < 0.001$) on axis one scores and there was a significant interaction ($P < 0.001$) between year and rotation with both axes. There was no significant difference between treatments on either axis.

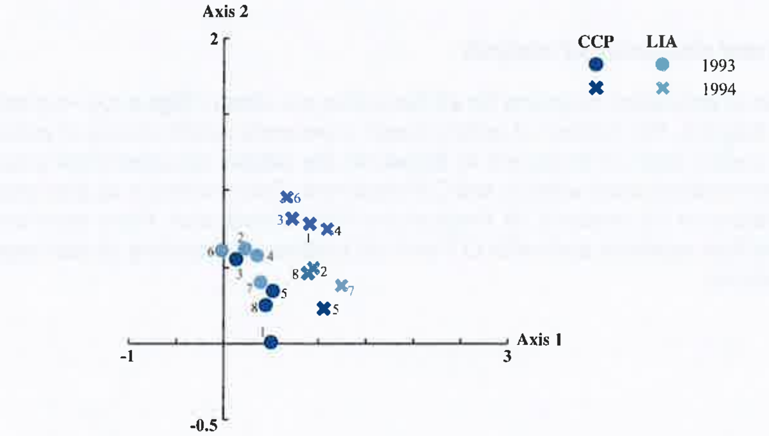

Figure 2.7.10. DECORANA ordination of invertebrate assemblages between 16 plot/year combinations over two years (1993 & 1994), four rotations (Standard Phases I and II, Alternative Phases I and II) and two treatment regimes (CCP & LIA) at Drayton. The numbers against data points identify rotations as listed in Table 2.1.2, Chapter 2.1

The ordination diagram for Drayton (**Fig. 2.7.10**) shows the plots to be more closely bunched than at Boxworth. Despite this, the 1993 plots lie to the left, and to some extent below, those from 1994. Analyses of variance showed a significant difference in the arthropod fauna between years and rotations on both axes ($P < 0.001$ for axis one, $P < 0.05$ for axis two). There was also a significant interaction ($P < 0.001$) between year and rotation for axis one. There was no significant difference between CCP and LIA treatments.

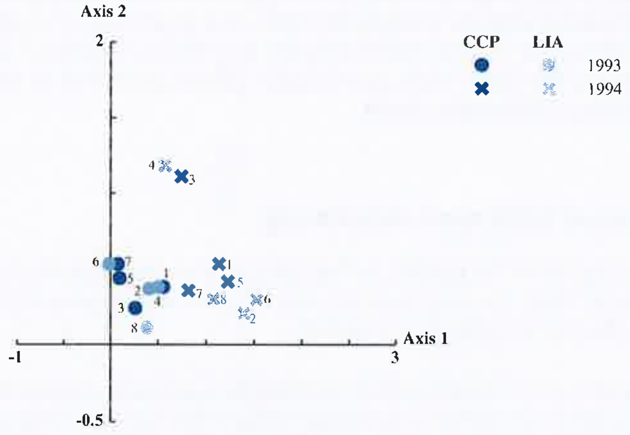

Figure 2.7.11. DECORANA ordination of invertebrate assemblages between 16 plot/year combinations over two years (1993 & 1994), four rotations (Standard Phases I and II, Alternative Phases I and II) and two treatment regimes (CCP & LIA) at High Mowthorpe. The numbers against data points identify rotations as listed in Table 2.1.2, Chapter 2.1

The results of the ordination of the High Mowthorpe dataset (**Fig. 2.7.11**) are similar to those for Drayton, with the 1993 plots lying partially to the left of and below those from 1994. There was a significant difference ($P < 0.001$) between years for axis one scores and a significant interaction with rotation ($P < 0.05$). On axis two, there was also a significant interaction between year and rotation ($P < 0.05$). There was no evidence of any significant difference between CCP and LIA treatments.

The one factor in common to all three TALISMAN sites was that the main source of variation in the arthropod analyses was in year-to-year differences. The same conclusions were reached by Sanderson (1994) from analyses of the Boxworth Project data (Greig-Smith *et al.*, 1992) and by Luff (1996) from a large-scale analysis of cereal invertebrates and from Welsh upland grassland beetles. In TALISMAN, the between-year variation was additional to any (usually significant) variation between rotation used. Thus, any changes from year-to-year in the arthropod assemblage were not just due to the annual changes in crops as part of the rotations. However, the rotations used also affected the arthropod assemblages found, and the significant year by rotation interactions in many of the analyses of variance indicated that the differences between rotations themselves varied from year-to-year. This is to be expected, as each rotation has different management and crops each year. Both of these factors are known to influence the overall assemblages of invertebrates such as ground beetles (Booij, 1994).

Where there was any significant effect of LIA treatments on the arthropod assemblages, this was always dependent on the data of the individual year in question. There were no consistent treatment effects across all years at any one TALISMAN site, or across more than one site. Thus, at Drayton, LIA treatments had significantly different assemblages from CCP treatments in both 1993 and 1994 but the differences were reversed between the two years.

Overall, these analyses suggest that, while the adoption of the low-input regime may have an impact on surface-active arthropods, any such effect is transitory and inconsistent from season to season. One reason for this result could be the small plot size used in the TALISMAN experiments. Many of the more active arthropods, such as the larger ground beetles and the spiders, will readily forage across more than one plot in a single night and will occur in some plots even though they might not breed there. This will blur any possible inter-treatment effects. If correct, the fact that some treatment effects did occur implies that the larger-scale adoption of the LIA regime might have an impact on the composition of the surface-active assemblages. At this stage, however, it is not possible to surmise just what such an effect might be nor whether it would be consistent or whether it would vary from season to season, as in the present results. Any effect, however, is likely to be outweighed by the large scale year-to-year effects apparent in this and the previous analyses referred to above.

Discussion of arthropod monitoring

Throughout the life of TALISMAN, 66 insecticide or molluscicide treatments were applied over all sites. On only seven occasions (11%) was there some evidence of a possible effect on non-target arthropods.

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.

Other workers have also recorded similar effects of these pesticides. Purvis (1992) noted a substantial reduction in catches of *B. obtusum, N. brevicollis* and *T. quadristriatus* following methiocarb use but recovery for most species occurred within one year. The effects of synthetic pyrethroids on predatory arthropods were studied by Matcham & Hawkes (1985). Catches were reduced by about 30% after a spray of deltamethrin to control the aphid vectors of BYDV. Powell *et al.* (1985) demonstrated that the use of dimethoate to control aphids in winter wheat at early to mid-flowering (GS 61-65) reduced the numbers of carabid beetles, staphylinid beetles and spiders. In contrast, in the Boxworth Project (Greig-Smith *et al.*, 1992), numbers of *T. quadristriatus* increased under the full insurance regime, possibly owing to a reduction in competition or predation.

The use of pirimicarb and triazophos also appeared to influence pitfall trap catches of predatory arthropods, possibly owing to the effect on prey species. Pirimicarb is considered to be a selective aphicide (Anon., 1993) which has limited effect on predators and parasitoids within the crop. Despite this, some possible effects on predatory beetles (*P. melanarius*) were observed where pirimicarb was applied to a crop of spring beans at Drayton. It is possible, in this instance, that as aphid numbers were reduced by insecticide application, the predatory beetles migrated elsewhere in search of food. Triazophos has a broader insecticidal spectrum than pirimicarb but after its application to oilseed rape at High Mowthorpe in 1991, catches of *A. dorsale* surprisingly increased. In this case, it was probable that the prey-searching activity of this species intensified following treatment, thus increasing their rate of capture in pitfall traps. Chiverton (1984) offered the same explanation to account for increases in catches of *P. melanarius* following application of fenitrothion and fenvalerate to spring barley.

Broadly speaking, the results of arthropod monitoring in TALISMAN were in agreement with the more intensive studies undertaken in SCARAB. Both experiments detected apparent short-term deleterious effects of insecticides on arthropods. Not surprisingly, these effects were detected most frequently in SCARAB which was designed specifically to investigate the effect of pesticides on invertebrate species. SCARAB also detected certain long-term negative effects of chlorpyrifos on springtails but this product was not used in TALISMAN.

In both TALISMAN and SCARAB, dimethoate and triazophos appeared to be damaging to arthropods in the short term. There was also a possible effect of pyrethroids and pirimicarb in TALISMAN although this was not repeated in SCARAB. This result suggests that the apparent effect in TALISMAN should be treated with caution and could also be explained by natural variation in trap catches. Slug pellets were the most frequently applied pesticide in TALISMAN but no comparative data are available from SCARAB as these pesticides were not used in that study.

Throughout the life of TALISMAN, only limited effects of pesticide on non-target species were detected. This could be due to a number of factors. Where products are applied early in the life of the crop, a significant proportion of the spray will make contact with the soil surface. Consequently, autumn treatments such as sprays for BYDV may be expected to be potentially damaging to non-target species. However, arthropods are generally least active during the autumn and winter so few species will come into contact with the treated soil or crop. During the spring and summer, arthropod activity increases but crop canopies are larger at that stage and a larger proportion of a spray is intercepted by the foliage before reaching the soil surface. Consequently, non-target species may escape the effects of pesticide application, either by being inactive at the time of treatment, or through physical protection afforded by the crop canopy.

Pitfall trap catches also showed considerable variability, both between and within CCP and LIA treatments, even in the absence of pesticide application. This suggests that other factors such as weather and crop may have a greater effect on arthropod numbers than pesticide application. Detailed multivariate analyses undertaken by Dr Luff support this theory. Although differences between CCP and LIA treatments were demonstrated at Drayton and High Mowthorpe, variation within year and rotation had a greater influence on species assemblages at all sites.

On the whole, results from arthropod monitoring in TALISMAN suggest that the adoption of the Low Input Approach was less damaging to some arthropod species on some occasions. However, the effects appear to be largely transitory and populations recover. In general, variations between years and between rotations appear to have a greater effect on the arthropod fauna than pesticide applications.

Nematode monitoring

Nematode populations were monitored by Dr Brian Boag and his colleagues at the Scottish Crops Research Institute (SCRI). There were two main objectives for monitoring nematode populations during the TALISMAN experiment. The first was to see if the effect of altering the rotation or reducing fertiliser and herbicide applications increased plant-parasitic nematode populations and the second was to monitor the effect the treatment regimes had on other (non plant-parasitic) trophic groups of nematodes found in the soil.

Nematology methods

The range of samples examined was the same as those taken for examination of weed seedbanks (Chapter 2.4). These samples were restricted at all three sites to the following four main treatments:

1. Standard Rotation Phase I (Phase II at Boxworth), CCP nitrogen;
2. Standard Rotation Phase I (Phase II at Boxworth), LIA nitrogen;
3. Alternative Rotation Phase I, CCP nitrogen;
4. Alternative Rotation Phase I, LIA nitrogen.

Within each of the above main treatments, the All High and the Low Herbicide sub-treatments were subsequently sampled.

The samples, each *c.* 500 g of soil, were collected at the different sites from fixed quadrat points within each plot and sent to SCRI. The first set of samples was collected in the spring of 1991 after the oilseed rape had been sown in the autumn of 1990. Autumn sampling was adopted in 1993 and 1996. On receipt of samples, a 200 g sub-sample was removed and stored at 4°C until nematodes were extracted using a modified sieving and decanting technique (Boag, 1974). Extracted nematodes were heat killed at 60°C for two minutes and fixed in triethanolamine formalin (TAF). A low-powered microscope was used to count the nematodes. A sub-sample of at least 25 plant-parasitic specimens was examined and identified using a high-powered microscope. Another 25 nematodes, other than plant-parasitic species, were also identified from the samples from the 1991 and 1996 samples from Boxworth. The nematode counts were transformed to log (x+1) values (Boag & Topham, 1984) before being analysed statistically. The designation of the nematodes to different trophic groups followed Yeates *et al.* (1993). The analysis of species richness, evenness and diversity indices was completed using 'Primer' (Carr, 1991).

Plant-parasitic nematodes

Initial populations at the three sites varied considerably (**Table 2.7.5**). At Boxworth, the mean number of plant-parasitic nematodes per 200 g was 1,605 compared with 589 at Drayton and 651 at High Mowthorpe. At all three sites, the most numerous nematode species was *Helicotylenchus vulgaris*, followed by *Tylenchus* spp. Differences were also observed in the numbers between sampling dates and these differences varied between sites. At Boxworth, plant-parasitic nematode populations decreased significantly from 1,605 nematodes per 200 g soil in 1991 to only 254 in 1993 but increased again to 506 in 1996. A similar initial drop was seen at Drayton from 1991 to 1993, but these numbers continued to drop to 104 nematodes per 200 g soil in 1996. At High Mowthorpe, the trend in plant-parasitic nematode populations was an increase from 651 nematodes per 200 g soil in 1991 to 929 in 1993, this level being maintained in the final year (1996) which indicated 915 nematodes/200 g soil. Although some plant-parasitic nematode genera/species followed the overall trend observed in the total numbers, there were exceptions. For example, at High Mowthorpe, *Pratylenchus* species decreased after the second sampling date in 1993 whereas *Tylenchorhynchus* spp. showed an increase.

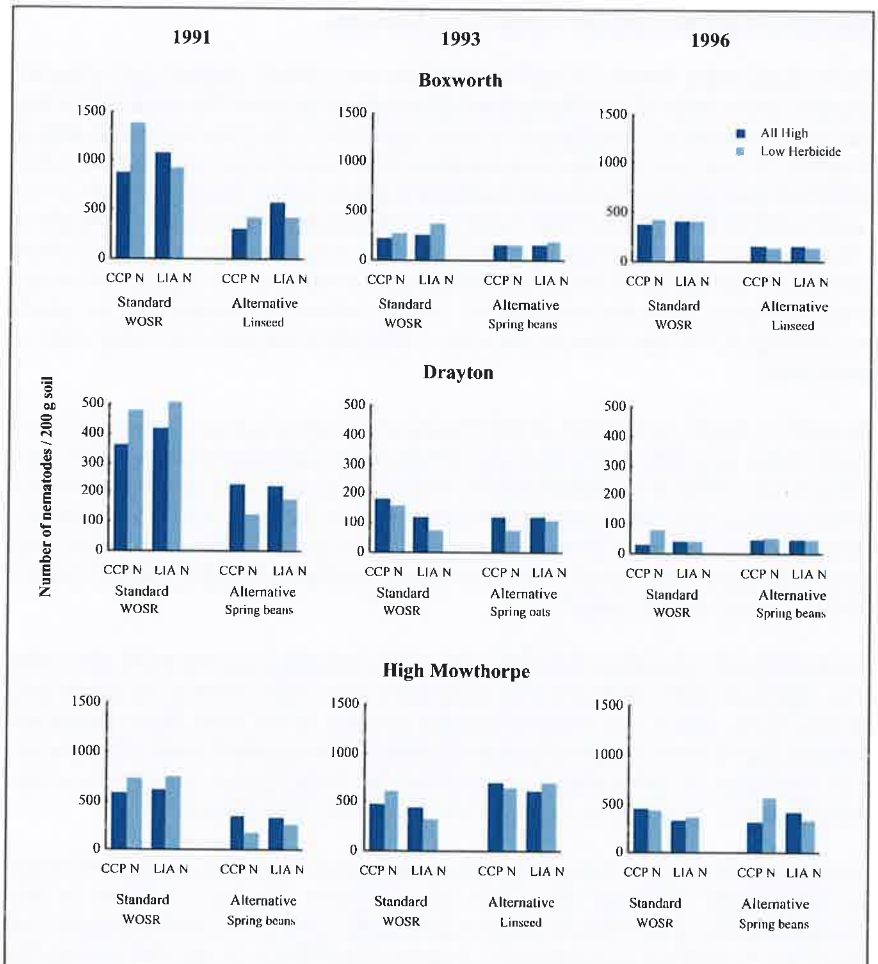

Figure 2.7.12. The effect of TALISMAN rotations, nitrogen and pesticide regimes on populations of the soil-dwelling nematode, *Helicotylenchus vulgaris*.

To illustrate the effect of the different rotations, fertiliser and herbicide treatments, data for *H. vulgaris* are shown (**Fig 2.7.12**). These data indicate, that apart from the results following the site-to-site and year-to-year variation in total nematode populations, there was an effect of rotation at Boxworth and Drayton. At Boxworth, the difference between Standard and Alternative Rotations persisted into 1993 and 1996, whereas at Drayton it did not continue beyond 1993 ($P < 0.05$). There was no effect of reduced herbicide or reduced fertiliser use on *H. vulgaris* populations at any of the sites.

Nematode community structure at Boxworth

The composition of the total nematode fauna for 1991 and 1996, including plant-parasitic, predatory, omnivorous, fungal- and bacterial-feeding nematodes, is shown in **Table 2.7.6**. The data are expressed as percentages to allow the results from 1991 and 1996 to be compared more easily, since the overall population in these two years differed so much.

With the exception of the two dominant species *H. vulgaris* and *Acrobeloides* sp., which together accounted for over 40% of the total population in 1991, all of the rest were present in low numbers. Relatively large differences were observed between the nematode counts from treatment to treatment within both 1991 and 1996 data sets, which meant that it was difficult to detect any meaningful trend attributable to any of the treatments.

Nematology discussion and conclusions

In the past, most interest in soil nematodes has centred on the plant-parasitic species since some of them have been shown to be of economic importance and can, under certain circumstances, reduce significantly the yield and/or quality of horticultural and agricultural crops. However, there is an increasing awareness that other nematodes (e.g. fungal and bacterial feeders) might act as indicators of the 'well being' of the soil since their community structure could act as an indicator of other soil processes involving fungi and bacteria. Nematode species such as these could be indirectly affected by agrochemicals. A reduction in agrochemical use might enhance microbial activity and, hence, indirectly change the nematode assemblages. The nematode monitoring in TALISMAN set out to investigate these questions.

Apart from work undertaken on plant-parasitic nematodes and studies on non-arable land, very little is known about other soil-inhabiting nematodes within the British Isles. Recent investigations by Yeates *et al.* (1997) at grassland sites in Wales found overall mean nematode counts (7,400 per 200 g soil) approximately twice that recovered at Boxworth in 1991 (4,104 per 200 g soil). However, the Boxworth counts were greater than those recorded from an arable field in Scotland (Boag & Lopez-Llorca, 1989).

In general, the initial plant-parasitic nematode populations at the three sites were also relatively high compared with those from some other surveys of arable land (Boag, 1979, 1980). The most numerous species at all sites, *Helicotylenchus vulgaris*, has a relatively cosmopolitan distribution throughout most of Britain and was recorded in the surveys undertaken by Boag (1979, 1980) with mean populations of 15 and 35 nematodes per 200 g soil, respectively.

Populations of a similar spiral nematode, *Rotylenchus uniformis*, have been shown to significantly decrease the yields of a number of crops at levels of 200 nematodes/200 g soil (Oostenbrink, 1972; Boag, 1979). This would suggest that the initial *H. vulgaris* populations at Boxworth and Drayton and throughout the experiment at High Mowthorpe may have been at a level which would have chronically depressed crop yields. This may have been compounded by the effect of other plant-parasitic species but it is difficult to predict by how much because knowledge is lacking about interactions between the different plant-parasitic species and other abiotic stress factors, for example, drought (McSorley, 1997).

Although there were differences in *H. vulgaris* populations between sites in 1991, these were not repeated in subsequent years. The effect of rotation was not detected at High Mowthorpe or Drayton in 1996, which would suggest that factors associated with site or local climate may be important in determining nematode populations. Bouwman & Zwart (1993) found that nematode biomass under conventional management followed a different seasonal pattern to that under an integrated management system. Therefore, in TALISMAN, the sampling dates may also have been important in determining whether differences between treatments were detected.

The effect on nematode community structure of changes in agricultural practices and management regimes has recently received considerable interest. Yeates *et al.* (1997), when comparing the effect of conventional and organic management regimes at three different sites in Wales, found greater nematode populations under organic than under conventional management. Detailed analysis showed positive correlations between total nematode population counts and bacterial PLFA (phospholipid fatty acid) and biomass carbon. However, there were no correlations between fungal feeding nematodes with fungal PLFA.

In TALISMAN, the differences between plots were great, probably due to the taking of single point samples which could be strongly influenced by nematode aggregation. The taking of multiple sub-samples to make up a sample which would then be processed could have reduced the variability between samples (Boag *et* *al.*,1987) and increased the sensitivity of any statistical test to differentiate the effect of different treatments. However, the data from Boxworth suggested that, although rotation did affect total nematode numbers, the nematode community structure was not influenced by rotation, or by reduced fertiliser or herbicide applications (**Table 2.7.6**). These results might seem to be at variance with those of Yeates *et al.* (1976) who found that a significant reduction in plant-parasitic nematodes occurred after the application of a herbicide. However, in that experiment, the effect was observed only after prolonged use of paraquat which totally eliminated all potential host plants, an artificial agricultural situation that was not found in TALISMAN.

Three main nematological conclusions were drawn from the TALISMAN experiment:

a) Neither a reduction in fertiliser use nor a reduction in herbicide use had any effect on the plant-parasitic nematode population or the structure of the nematode community. 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 unaffected by these treatments.

b) Large differences were observed in nematode counts between sites and years. The reasons for these changes were unclear, but the proportions of nematodes in the different trophic groups at Boxworth in 1991 and 1996 were very similar, suggesting that, whatever the factor, it affected all nematodes in a similar manner. Furthermore, this effect was not density dependent since numerous species were influenced to the same extent as less numerous species.

c) The choice of site could affect the influence rotation had on nematode populations. Again, the reason for this was unclear but elevated plant-parasitic nematode populations occurred on plots sown with winter crops at Boxworth in 1991, 1993 and 1996 and at Drayton in 1991. This suggests that the roots of these crops at these sites may have helped maintain or increase the nematode populations.

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Table 2.7.1. Numbers and percentage of total catch of arthropods recovered from TALISMAN pitfall traps, 1990–1996.

Arthropod group	Boxworth		Drayton		High Mowthorpe	
	Total	% of total catch	Total	% of total catch	Total	% of total catch
Acari	1,364,695	62	93,643	6	26,212	5
Araneae	24,893	1	41,513	3	24,453	4
Coleoptera	52,107	2	69,856	4	44,970	8
Collembola	689,122	31	1,310,330	81	229,529	42
Dermaptera	0	0	0	0	29	<1
Diptera	40,420	2	55,680	3	78,988	14
Hemiptera	15,615	1	16,239	1	30,498	6
Hymenoptera	20,092	1	25,310	2	27,545	5
Myriapoda	5,690	<1	0	0	0	0
Thysanoptera	121	<1	13,595	1	86,240	16
Total	2,212,755		1,626,166		548,464	

Table 2.7.2. Numbers and percentage of total family catch of the most common species of carabid and staphylinid beetles and linyphiid and lycosid spiders caught in TALISMAN pitfall traps, 1990–1996.

Arthropod group	Boxworth		Drayton		High Mowthorpe	
	Total	% of total catch of family	Total	% of total catch of family	Total catch	% of total catch of family
Carabidae						
Agonum dorsale	1,943	6	193	1	9,195	24
Bembidion obtusum	12,665	39	2,417	7	1,181	3
Nebria brevicollis	501	2	1,481	5	6,361	17
Notiophilus bigutattus	1,376	4	0	0	1,254	3
Pterostichus melanarius	3,362	10	6,979	22	6,368	17
Trechus quadristriatus	7,826	24	10,414	32	686	2
Other species	4,682	15	11,006	34	12,734	34
Staphylinidae						
Anotylus sculpturatus	685	7	0	0	61	2
Lathrobium fulvipenne	745	8	0	0	0	0
Philonthus cognatus	194	2	0	0	706	18
Tachyporus hypnorum	2,401	24	2,158	14	1,284	33
Xantholinus linearis	1,136	11	0	0	49	1
Other species	4,764	48	13,034	86	1,835	47
Linyphiidae						
Bathyphantes gracilis	813	6	1,220	6	430	2
Erigone atra	2,603	18	4,238	20	6,021	32
Erigone dentipalpis	154	1	109	1	5,979	32
Lepthyphantes tenuis	1,634	12	1,341	6	1,647	9
Oedothorax apicatus	5,199	37	5,405	26	77	<1
Other species	3,745	26	8,586	41	4,560	24
Lycosidae						
Pardosa amentata	22	<1	-	-	896	24
Pardosa monticola	0	0	-	-	548	15
Pardosa palustris	6,402	72	-	-	1,885	51
Pardosa pullata	11	<1	-	-	125	3
Trochosa ruricola	320	4	-	-	0	0
Other species	2,196	25	-	-	236	6

Table 2.7.3. TALISMAN arthropod monitoring datasets subjected to ordination analysis.

Site	Years	Rotations	Treatments
Boxworth	1991, 1992, 1993, 1994	Standard, Phases I & II Alternative, Phase I	CCP, LIA
Drayton	1993, 1994	Standard, Phases I & II Alternative, Phases I & II	CCP, LIA
High Mowthorpe	1993, 1994	Standard, Phases I & II Alternative, Phases I & II	CCP, LIA

Table 2.7.4. Numbers of species included in data ordination analyses of TALISMAN arthropod data.

Site	Carabidae (ground beetles)	Staphylinidae (rove beetles)	Other Coleoptera (beetles)	Araneae (spiders)
Boxworth	30	25	10	37
Drayton	6	11	0	5
High Mowthorpe	21	11	0	9

Table 2.7.5. Plant-parasitic nematode genera recovered from ADAS Boxworth, Drayton and High Mowthorpe 1991, 1993 and 1996 (mean number of nematodes/200 g soil).

	Boxworth			Drayton			High Mowthorpe		
	1991	1993	1996	1991	1993	1996	1991	1993	1996
Amplimerlinius	106	5	0	11	12	0	0	1	0
Criconemoides	0	0	0	0	0	0	0	1	0
Helicotylenchus	724	194*	241*	318	119*	65*	328	541*	376*
Heterodera	0	0	0	0	0	0	1	0	0
Longidorus	0	0	0	0	0	0	1	2	0
Merlinius	60	6*	8*	20	1*	3*	6	33*	54*
Neopsilenchus	0	1	0	0	1	1	0	1	0
Paratylenchus	0	0	0	0	0	0	1	1	0
Pratylenchus	8	4	7	19	2	8	233	247	62
Psilenchus	0	0	0	0	1	1	0	1	0
Trophurus	6	6	6	13	20	6	0	0	0
Tylenchorhynchus	69	6*	7*	12	2*	3*	8	4*	100*
Tylenchus	632	32*	238*	196	41*	17*	74	98*	323*
Total	1,605	254*	507*	589	199*	104*	652	930*	915*

* Statistically significantly different from the 1991 data.

Table 2.7.6. Percentage composition of TALISMAN nematode communities at Boxworth, classified by trophic group, 1991–1996.

Nematode trophic groups	Year	Main treatments (rotation & nitrogen) and pesticide sub-treatments							
		Standard Rotation, CCP nitrogen		Standard Rotation, LIA nitrogen		Alternative Rotation, CCP nitrogen		Alternative Rotation, LIA nitrogen	
		All High	Low Herbicide	All High	Low Herbicide	All High	Low Herbicide	All High	Low Herbicide
Plant feeders	1991	32.3	43.9	40.8	32.3	38.4	35.7	41.3	47.6
	1996	35.1	39.1	40.2	37.9	38.1	33.8	44.5	38.7
Bacterial feeders	1991	49.2	39.4	44.7	54.0	47.6	58.5	42.2	38.1
	1996	44.6	46.0	38.2	46.5	43.6	45.1	34.2	42.0
Fungal feeders	1991	4.7	4.5	1.4	6.3	0.7	0.5	1.7	0.6
	1996	4.9	4.5	5.9	7.8	7.7	12.3	6.5	11.3
Predators	1991	1.9	2.5	2.4	1.3	0.8	1.0	4.0	1.8
	1996	5.0	2.1	1.2	2.8	1.8	1.7	2.3	1.0
Omnivores	1991	11.9	9.5	10.7	6.1	12.5	4.4	11.7	11.9
	1996	10.4	7.2	14.5	5.0	8.8	7.9	12.5	7.1
Total nematodes/200g soil	1991	5,938	5,804	4,832	5,580	2,471	3,044	2,784	2,370
	1996	1,869	2,030	1,532	1,725	935	1,059	842	631

THE IMPACT OF LOW-INPUT PESTICIDE USE ON CROP YIELDS AND ECONOMICS

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Introduction

Over the past three decades, arable crop yields have increased dramatically and arable farmers have been quick to adopt the latest agronomic tools to improve crop yields (Scott & Sylvester-Bradley, 1998). Furthermore, the agrochemical and plant breeding industries have made a major contribution to productivity by developing efficient pesticides and fertilisers, together with high-yielding and disease-resistant varieties of crops. Against a background of overproduction and increasing government and public pressure for farming to become more environmentally friendly, TALISMAN set out to investigate the overall impact on crop yield and financial returns of reducing pesticide use by at least 50%. This chapter examines the overall economic consequences of reducing pesticide use on the major combinable crops grown in the UK, as investigated in the TALISMAN study.

Once harvested, the overall yield of the saleable portion of a crop determines the basic financial output per unit area and is a crucial factor in determining the profitability of a crop. However, whilst yield is the major driver of crop profitability, crop gross margin is the standard measure adopted to assess economic performance. Gross margins are a measure of crop profitability and can be defined as the financial income (£/ha) generated by the sale of crop yield, following deduction of variable costs such as seed, fertiliser and pesticides. Fixed costs such as machinery and labour are not included in the calculation. Gross margins were, therefore, used as a standard measure of the relative financial performance of the crops grown in the TALISMAN study.

Standardised variable costs were used in the annual calculation of the TALISMAN gross margins. In the case of pesticides and nitrogen, prices based on competitive quotes obtained from merchants and distributors were applied each year. However, seed costs, including the cost of any seed treatments applied, were based on local merchant prices. In calculating the sale value of each crop, actual prices given by local merchants were used. If, owing to the complexities of storage and handling charges, the actual prices were not known, the published market price for a given crop at the time of sale was applied.

All gross margins quoted here include the relevant Arable Area Payment in force during the year of harvest. These payments, which were intended to compensate growers for reductions in the European Union support price for cereals, were made under the UK government's Arable Area Aid Payments Scheme (AAPS) from 1993. Payments are made at different rates for different crops. To qualify for payments, growers must each year set aside (i.e. take out of production) a certain proportion of their arable area normally used for growing various cereals, oilseeds and pulses. The required percentage of set-aside land and the Area Aid Payments are revised on an annual basis.

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 order to simplify the presentation of the TALISMAN results, the consequences of reducing nitrogen use have been dealt with separately in Chapter 2.2. The specific effects of reducing herbicide, fungicide and insecticide use, for the control of weeds, diseases and invertebrate pests respectively, are covered in-depth in Chapters 2.3, 2.5 and 2.6. TALISMAN aimed to reduce overall pesticide use by at least 50%, as defined according to the number of pesticide units applied, where one unit equals one full label-rate application of a single active ingredient. Further details on the scope and extent of the reductions achieved in TALISMAN pesticide use are documented in Chapters 2.1, 2.3, 2.5 and 2.6. This chapter focuses on the overall combined effects of reducing the use of all three categories (i.e. herbicides, fungicides and insecticides) of pesticides. Therefore, the results discussed in this chapter are restricted to the cross-nitrogen means of the All High and All Low pesticide sub-treatments (see Chapter 2.1 for design details). For ease of interpretation, the majority of data presented in this chapter are in the form of charts comparing yields and gross margins. A full set of numerical yield and gross margin data, complete with standard errors and degrees of freedom, is available in Appendix 1.

Comparison with national averages

With the exception of winter and spring barley, the average yield of TALISMAN cereal crops was below the national average (**Table 2.8.1**). However, it should be borne in mind that the TALISMAN yields used in this comparison are cross-nitrogen averages. Therefore, the TALISMAN average yields will be distorted unfavourably by the yield losses experienced from cutting nitrogen use by 50% in the Low Input Approach (see Chapter 2.1). None of the TALISMAN break-crop yields was below the national averages, except those of winter and spring oilseed rape. Overall, TALISMAN yields were 2% and 6% below national averages for the equivalent set of cereal and break crops respectively. However, the average yield of the TALISMAN break crops was distorted by the poor yield of the two crops of spring oilseed rape grown following failure of winter oilseed rape at Boxworth and Drayton (see spring oilseed rape section below). If the spring oilseed rape yields are withheld from the calculation, the average yield of the TALISMAN break crops compares more favourably and has an average which is 11% greater than the national average yield for the equivalent set of crops.

The average gross margins from the TALISMAN crops generally fared better in comparison with the national averages than the TALISMAN yields (**Table 2.8.2**). With the exception of winter triticale and spring oats, all of the TALISMAN cereal crop gross margins exceeded their national averages. The overall TALISMAN cereal crop gross margin was 32% above the national average for the equivalent set of cereal crops. Turning to the break crops, once again their overall gross margin performance was disadvantaged by the poor crops of spring oilseed rape. Average gross margins of winter oilseed rape and spring beans in TALISMAN also fell below the national averages. Taken as a group, the average gross margin from TALISMAN break crops was 8% less than the national average for the equivalent set of crops. Excluding spring oilseed rape from the calculation reduced the deficit and indicated that the average gross margin from TALISMAN break crops was 1% below the equivalent national average. Taking TALISMAN crops altogether, their average gross margin was 16% greater than the equivalent national average, owing to the relatively better financial performance of cereals compared with that of the break crops.

The impact of reducing pesticide use by at least 50%

The combined low-input use of all categories of pesticides in the All Low pesticide regime generally resulted in a loss in yield in comparison with the All High regime (**Fig. 2.8.1 & 2.8.2**). In the cereals, the average cross-site yield losses ranged from 1 to 11% and averaged 5%. There was much greater variation in the yield of the break crops, owing to the highly variable performance of the oilseed rape. Excluding oilseed rape, the average cross-site yield losses of the break crops ranged from 0 to 8% and averaged 4%. Oilseed rape proved to be a problematical crop to grow successfully in TALISMAN at all sites except High Mowthorpe. Information relating to oilseed rape is discussed in the relevant individual crop sections later in this chapter.

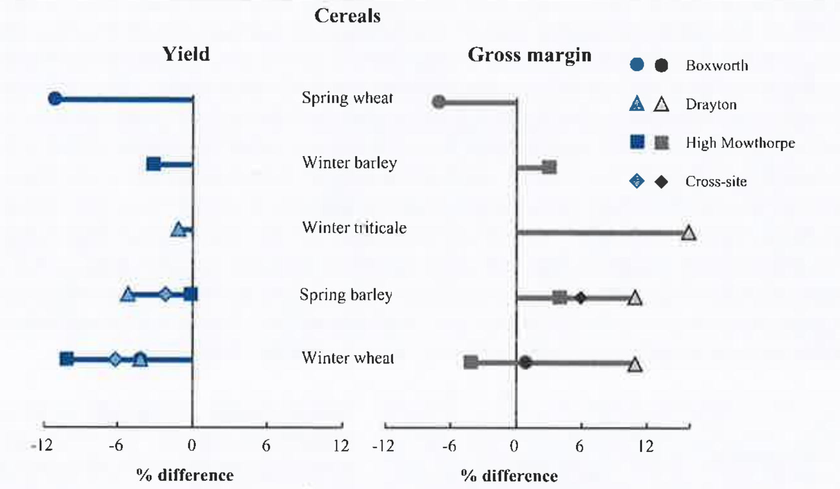

Figure 2.8.1. The effect of the All Low pesticide regime on mean yields and gross margins from the TALISMAN cereal crops, shown as percentage difference of the All Low from the All High pesticide regimes.

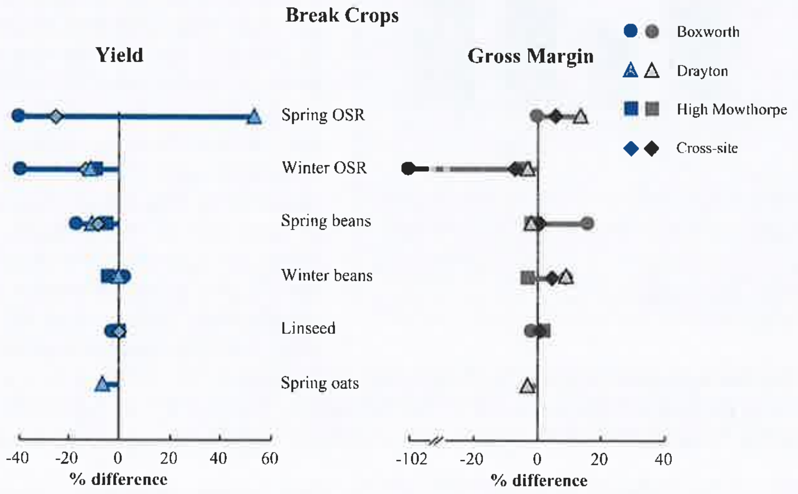

Figure 2.8.2. The effect of the All Low pesticide regime on mean yields and gross margins from the TALISMAN break crops, shown as percentage differences of the All Low from the All High pesticide regimes.

The savings made in variable costs through the reduction of pesticide use in the All Low pesticide regime often compensated for losses in yield. Consequently, the All Low pesticide regime gross margins often exceeded those of the All High (**Fig. 2.8.1 & 2.8.2**). Looking at the overall effect of the All Low pesticide treatment across all crops grown in TALISMAN revealed that the cross-site average gross margin from the All Low regime exceeded that from the All High by 2% or £12/ha ($P < 0.05$). However, this statistic tends to mask the relative differences between the three TALISMAN sites (**Fig. 2.8.3**). As will become plain in the sections below which detail the performance of each type of crop, there was a strong tendency for the absolute yields and gross margins to be greatest at High Mowthorpe, followed by Boxworth and Drayton. In terms of the relative responses of yield and gross margins to the All Low pesticide regime, it was Drayton that tended to respond most favourably and High Mowthorpe the least favourably in comparison with the All High pesticide regime.

At High Mowthorpe, the average gross margin for all TALISMAN crops was 2% less in the All Low pesticide regime than in the All High. In comparison, at Drayton, the All Low gross margin exceeded the All High by 9%, whereas at Boxworth there was no difference between the All Low and All High pesticide treatments. Although High Mowthorpe tended to be the highest yielding and most financially profitable site, no overall financial benefits were gained from the All Low pesticide regime at this site. In contrast, although the overall yield and financial output at Drayton was lower than at Boxworth or High Mowthorpe, the average gross margin from the All Low pesticide regime at Drayton was 9% greater than the All High regime (**Fig. 2.8.3**). This observation suggests that the crops grown at Drayton had a tendency not to respond positively to the relatively high use of pesticides at this site, as reductions in pesticide use did not result in overall financial penalties. Further observations on differences in pesticide use between sites are detailed in Chapter 2.1.

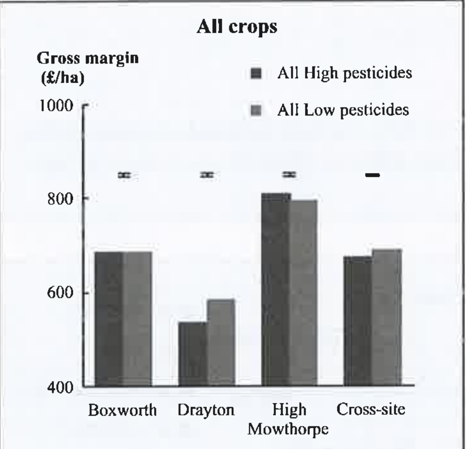

Figure 2.8.3. The effect of the All Low pesticide regime on the mean gross margins from all crops grown in TALISMAN. Error bars show SEDs for within-site comparisons.

Taking cereal and break crops as individual groups, the cross-site gross margin from the All Low was 2% greater than the All High pesticide regime in cereals ($P < 0.05$) and 1% greater in the break crops (**Figs. 2.8.4 & 5**). The cross-site averages again masked the trends at individual sites. The gross margins for cereal crops at the individual sites revealed that, at Drayton, the All Low was 12% more profitable than the All High pesticide sub-treatment ($P < 0.05$) but 1% and 2% less profitable at Boxworth and High Mowthorpe respectively (**Fig. 2.8.4**). Therefore, at one out of three sites, the financial return from the cereals in the All Low pesticide regime was significantly better than the All High. A similar trend was observed in the average gross margins from the break crops except that, in this instance, the All Low pesticide regime exceeded the All High by 3% and 2% at Boxworth and Drayton respectively, whilst there was a 2% loss at High Mowthorpe (**Fig. 2.8.5**).

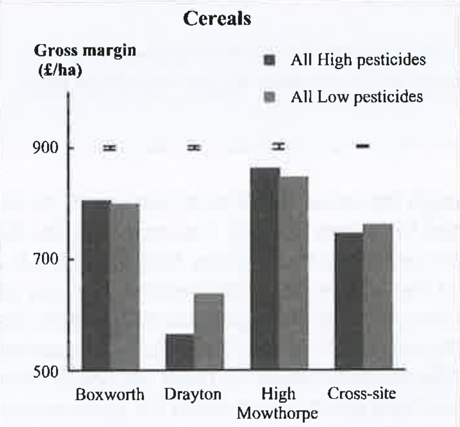

Figure 2.8.4. The effect of the All Low pesticide regime on the mean gross margins from TALISMAN cereal crops. Error bars show SEDs for within-site comparisons.

The above discussion gave a general overview of how the crops grown in TALISMAN, consolidated as cereals, breaks and 'all crops', performed in terms of average yields and gross margins. The following sections will consider the performance of the individual types of crop grown in TALISMAN and will discuss how pesticide use and its associated control of weeds, diseases and invertebrate pests influenced the relative yields and gross margins of each type of crop.

Winter wheat

In the TALISMAN Standard Rotations, winter wheat was grown as first or second wheats, after break and wheat crops respectively. However, owing to the fact that winter wheat never appeared in two successive years in the Alternative Rotations, this rotation featured only first winter wheats. Winter wheat is considered here as a single group of crops, as first and second wheats both followed the same general trends in yield and gross margin responses.

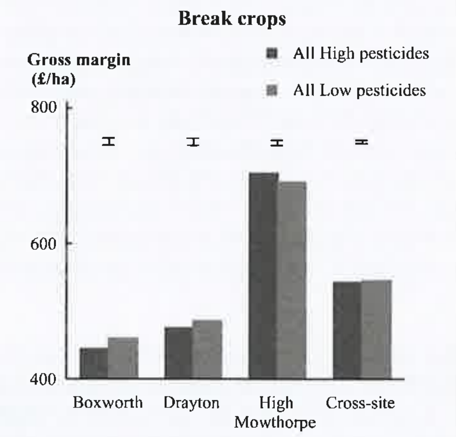

Figure 2.8.5. The effect of the All Low pesticide regime on the mean gross margins from TALISMAN break crops. Error bars show SEDs for within-site comparisons.

Overall, winter wheat yields in the All Low pesticide regime were consistently lower than the All High regime at all sites (**Fig. 2.8.6**). The greatest yield reduction (10%) occurred at High Mowthorpe and the cross-site yield reduction averaged 6% ($P < 0.05$). At Boxworth, four out of ten crops of winter wheat suffered a significant reduction in yield in the All Low pesticide regime in comparison with the All High ($P < 0.05$). In these instances, cereal aphids were implicated in one crop (1995) and weeds in another (1992), whereas in the remaining two cases no specific causes were identified. At Drayton, four out of eight winter wheat crops in the All Low pesticide regime suffered significant reductions in yield compared with those in the All High treatment. In two of these cases, foliar or ear diseases were implicated, whereas in the remaining instances the yield reductions could not be attributed to specific causes. At High Mowthorpe, statistically significant reductions in the yield in the All Low pesticide regime compared with the All High occurred in nine out of ten crops of winter wheat. In these instances, the yield losses were attributed to cereal aphids (four crops) and broad-leaved weeds (four crops), whilst, in one crop, no causes could be identified. In summary, out of a total of 28 winter wheat crops in TALISMAN, significant ($P < 0.05$) reductions in yield in the All Low pesticide regime occurred in 17 (61%) of these crops in comparison with the All High pesticide regime.

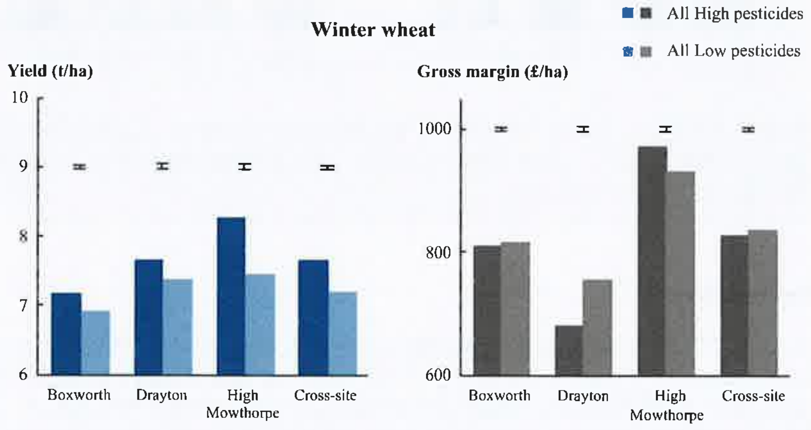

Figure 2.8.6. The effect of the All Low pesticide regime on the mean yield and gross margins from TALISMAN winter wheat (first and second year) crops. Error bars show SEDs for within-site comparisons.

The impact of the All Low pesticide regime on the gross margins of winter wheat was not as pronounced as it was on yield. The negative impact of yield reductions on the financial output from the All Low regime was generally counteracted by overall savings in the variable costs of pesticides. Gross margins from the All Low regime exceeded those from the All High in 16 out of 28 crops of winter wheat. At Boxworth, the gross margins from the All Low pesticide regime exceeded those from the All High in seven out of nine crops. At Drayton, the gross margins from the All Low were greater than those from the All High in all eight crops of winter wheat grown. However, a proportionally larger number of gross margin reductions were experienced at High Mowthorpe, where the All Low gross margins exceeded the All High in only one out of ten winter wheat crops. Therefore, the majority of gross margin reductions (9 out of 12) occurred at High Mowthorpe. However, in only two cases did a significant ($P < 0.05$) reduction in gross margin correspond to a significant loss in yield in the same individual crop. These instances both occurred at High Mowthorpe and were noted in one crop of winter wheat in 1992 which suffered from aphid attack and one crop in 1995 where poor weed control was to blame (see Chapters 2.3 & 2.6).

At two of the three TALISMAN sites, the average gross margins from the winter wheat All Low pesticide regime exceeded those from the All High, by 1% (£6/ha) at Boxworth and by 11% (£76/ha) at Drayton (**Fig. 2.8.6**). In contrast, High Mowthorpe was the loss-making site; here, the average All Low gross margins were 4% (£9/ha) below the All High. Cross-year analysis indicated that these findings were statistically significant ($P < 0.05$) at Drayton and High Mowthorpe but not at Boxworth. Cross-site analysis of winter wheat gross margins indicated that the All Low pesticide regime exceeded the All High by 1% or £9/ha ($P < 0.05$).

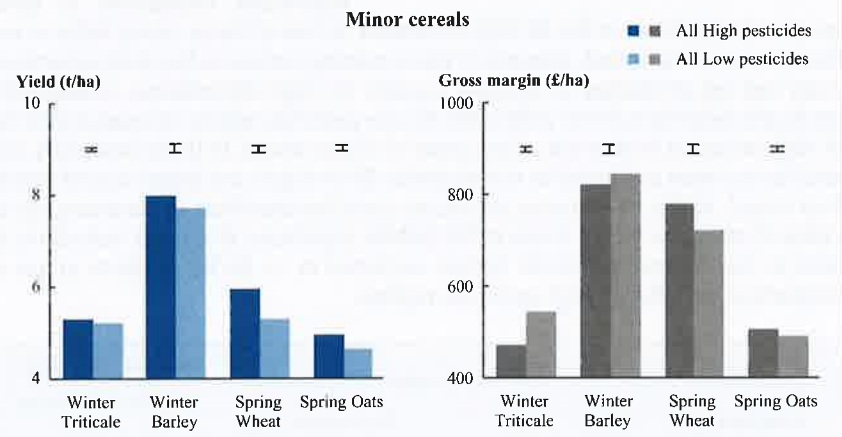

Figure 2.8.7. The effect of the All Low pesticide regime on the mean yields and gross margins from TALISMAN winter triticale, spring oats, spring wheat, and winter barley. Error bars show SEDs for within-site comparisons.

Winter triticale

Six crops of winter triticale were grown at Drayton only. Winter triticale was less susceptible than winter wheat to yield losses arising from reduced pesticide use. There were no statistically significant yield losses associated with the All Low pesticide regime. Across all crops of triticale, the yield in the All Low regime was 1% less than that in the All High (**Fig. 2.8.7**). Savings in the variable costs of pesticides were such that the average gross margin for the All Low pesticide regime exceeded the All High by 15% or £71/ha ($P < 0.05$), demonstrating the financial advantage of low-input pesticide use in triticale (**Fig. 2.8.7**). However, two crops of winter triticale failed to establish owing to slug attack, details of which are discussed in Chapter 2.6. The slug-damaged crops of winter triticale were subsequently replaced with spring barley.

Winter barley

Two crops of winter barley were grown at High Mowthorpe. The yield for the All Low pesticide regime was 3% less than that for the All High (**Fig. 2.8.7**). A significant ($P < 0.05$) yield loss was experienced in one crop in 1993, in which poor control of broad-leaved weeds was implicated. The gross margin from the All Low pesticide regime exceeded the All High in one out of the two crops grown. The All Low pesticide regime gross margin from the crop which suffered from a weed-induced yield loss was subsequently £24/ha less than the All High. However, the overall average gross margin of winter barley indicated that the All Low regime exceeded the All High by 3% or £24/ha (**Fig. 2.8.7**).

Spring barley

A total of six crops of spring barley was grown, two at Drayton and four at High Mowthorpe. Spring barley was not originally intended to be grown at Drayton but was used to replace the two crops of winter triticale which failed to establish owing to slug damage (see Chapter 2.6).

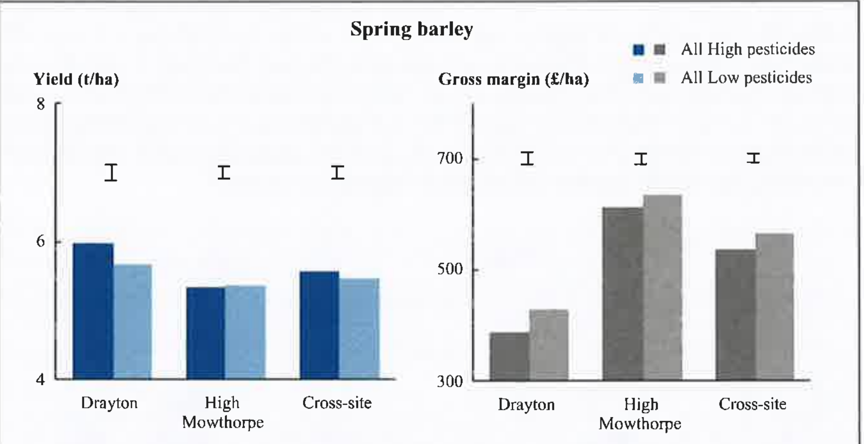

Figure 2.8.8. The effect of the All Low pesticide regime on the mean yields and gross margins from TALISMAN spring barley. Error bars show SEDs for within-site comparisons.

The yield in the All Low pesticide regime at Drayton was 5% less than that in the All High, whilst at High Mowthorpe there was no difference between the yield of the All Low and All High pesticide regimes (**Fig. 2.8.8**). No specific causes could be identified in connection with the yield loss at Drayton. Across both sites, there was a yield reduction of 2% in the All Low compared with the All High pesticide regime.

Despite the yield losses, the gross margins from the spring barley All Low pesticide regime were consistently better than those from the All High owing to savings in pesticide costs (**Fig. 2.8.8**). The cross-site average gross margin from the All Low pesticide regime exceeded the All High treatment by 6% or £30/ha. Furthermore, in two single crops at Drayton and High Mowthorpe in 1993, the All Low gross margins were greater than those from the All High by £41/ha and £25/ha respectively.

Spring wheat

Two crops of spring wheat were grown at Boxworth. The average yield for the All Low pesticide regime was reduced by 11% compared with the All High (**Fig. 2.8.7**). In the 1996 crop, a significant yield loss was associated with poor control of broad-leaved weeds in the All Low pesticide regime compared with the All High ($P < 0.05$). Savings in pesticide costs did not compensate for the yield reductions. In the 1996 crop, which was adversely affected by weeds, the All Low gross margin was reduced by £24/ha compared with the All High. Overall, the average gross margin from the All Low pesticide regime was 7% or £57/ha less than the All High ($P < 0.05$) (**Fig. 2.8.7**).

Spring oats

Two crops of spring oats were grown at Drayton. The average yield from the All Low pesticide regime was depressed by 6% in comparison with the All High (**Fig. 2.8.7**). A relatively large yield reduction of 0.58t/ha occurred in the All Low regime of the 1994 crop. The equivalent gross margin of the 1994 All Low regime was reduced by £36/ha in comparison with the All High, whilst in the 1991 crop there was a small increase of £10/ha. Overall savings in pesticide costs failed to compensate for the lower yields and the average gross margin from the All Low regime was 3% or £13/ha less than that from the All High (**Fig. 2.8.7**). No specific causes could be attributed to these losses.

Winter beans

Six crops were grown, two at each of the sites. At Boxworth and Drayton, the yield in the All Low pesticide regime exceeded that in the All High by 3% and 1% respectively (**Fig. 2.8.9**). However, at High Mowthorpe, the yield in the All Low pesticide regime was depressed by 4% in comparison with the All High ($P < 0.05$). Although, in 1991, the All Low regime for the winter beans at High Mowthorpe suffered a significant ($P < 0.05$) yield reduction in comparison with the All High treatment, no specific causes could be attributed to this loss.

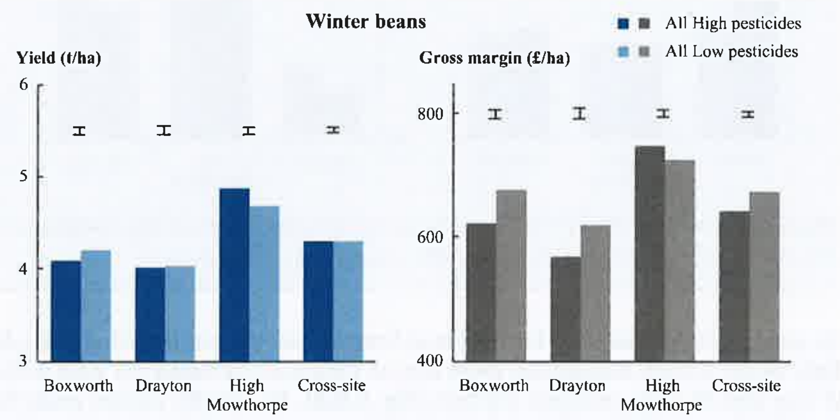

Figure 2.8.9. The effect of the All Low pesticide regime on the mean yield and gross margins from TALISMAN winter beans. Error bars show SEDs for within-site comparisons.

Gross margins followed a similar pattern to yields (**Fig. 2.8.9**). At both Boxworth and Drayton, the average gross margin from the All Low pesticide regime exceeded that from the All High by 9% ($P < 0.05$). Once again, High Mowthorpe proved to be more responsive to pesticides than the other sites, the average gross margin from the All Low being 3% less than the All High pesticide regime. Taken across all sites, the average All Low gross margin for the winter beans exceeded the All High by 5% or £30/ha ($P < 0.05$).

Spring beans

Five crops were grown, one at Boxworth and two each at Drayton and High Mowthorpe. Spring bean yields were consistently lower in the All Low pesticide regime. Yield reductions, averaging 8%, occurred in the All Low compared with the All High regime across all sites (**Fig. 2.8.10**). The only significant yield-reducing event connected with the poor control of a weed, pest or disease problem occurred at Drayton, where an outbreak of black bean aphid was experienced in 1991 (see Chapter 2.6). This outbreak made a major contribution to a yield loss of 0.56 t/ha in the All Low regime, in comparison with the All High pesticide regime ($P < 0.05$).

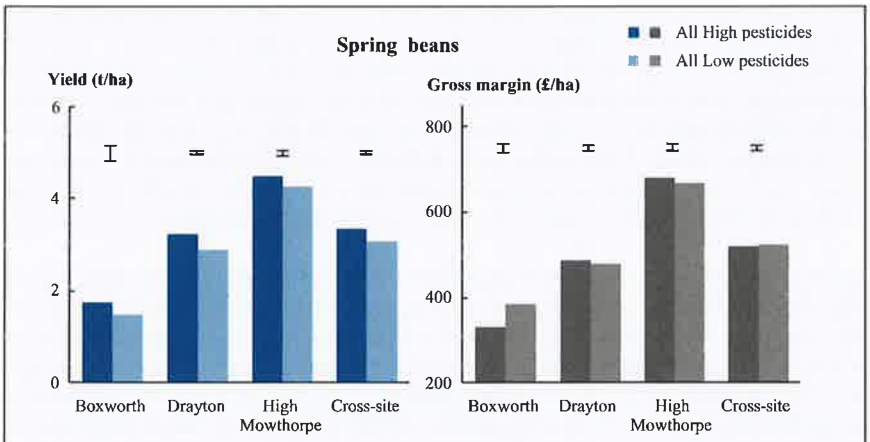

Figure 2.8.10. The effect of the All Low pesticide regime on the mean yield and gross margins from TALISMAN spring beans. Error bars show SEDs for within-site comparisons.

The All Low gross margins did not suffer so badly as the yields, owing to savings made in pesticide costs (**Fig. 2.8.10**). Taken overall, across all three sites, the All Low regime resulted in a minor 1% (£3/ha) increase compared with the All High. The All Low pesticide regime for the spring beans at Boxworth successfully produced an average gross margin which was 16% better than that for the All High. However, the cross-site average masks the fact that the gross margins from the All Low regime were 2% less than those from the All High regimes at both Drayton and High Mowthorpe. Despite the disadvantage of the large yield loss caused by the black bean aphid outbreak at Drayton in 1991, savings in pesticide costs were such that the overall loss in gross margin from the All Low compared with the All High pesticide regime at Drayton (two crops), was only £11/ha.

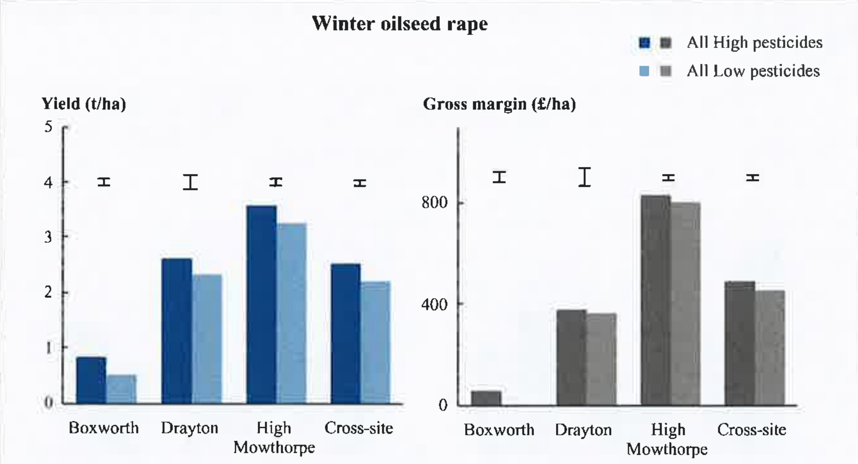

Figure 2.8.11. The effect of the All Low pesticide regime on the mean yields and gross margins from TALISMAN winter oilseed rape. Error bars show SEDs for within-site comparisons.

Winter oilseed rape

Four crops of winter rape were harvested. Six crops were planned originally but, in autumn 1993, single crops at Boxworth and Drayton failed to establish, owing to slug damage (see Chapter 2.6). The failed crops were subsequently replaced with spring oilseed rape (see below). The yield in the All Low pesticide regime in the winter rape was consistently lower at all sites and in all years (**Fig. 2.8.11**). There was a drastic reduction in yield of the single crop of winter rape grown at Boxworth in 1990–91 caused by a failure to control volunteer wheat, which was exacerbated by the low-rate use of herbicide (see Chapter 2.3). The yield in the All Low pesticide regime in the Boxworth crop was subsequently 39% less than in the All High treatment ($P < 0.05$). A significant reduction in yield also occurred at High Mowthorpe, where the yield in the All Low pesticide regime was 9% below that in the All High treatment ($P < 0.05$). However, no specific reasons could be attributed to the reduced yield of the winter rape at Drayton or High Mowthorpe. Across all sites, the All Low pesticide regime resulted in a 13% yield loss in the All Low compared with the All High pesticide regime of the winter oilseed rape ($P < 0.05$).

Savings in pesticide costs were insufficient to compensate for the yield losses experienced in the All Low pesticide regime, indicating a degree of vulnerability of this crop to cuts in certain pesticide inputs (**Fig. 2.8.11**). Gross margins were lower in the All Low pesticide regime at all sites. The largest reduction in gross margin occurred at Boxworth, reflecting the yield loss caused by the volunteer wheat problem that occurred in one crop. Across all sites, the gross margin from the All Low pesticide regime on winter oilseed rape was 7% or £34/ha less than that from the All High pesticide regime.

Spring oilseed rape

Two crops of spring oilseed rape were grown, one at Boxworth and the other at Drayton. In both cases, the spring rape was sown as a replacement crop for winter oilseed rape that failed to establish in autumn 1993, owing to attack by slugs (see Chapter 2.6). The yield of both spring crops was disappointingly low and well below the national average yield (**Table 2.8.1**), owing to pigeon damage experienced during crop establishment. Despite the use of various bird-scaring methods, including gas bangers, pigeons badly depleted the plant population of both crops to such an extent that crop yield was seriously reduced. Reduced-rate herbicide use in the spring rape at Boxworth failed to provide adequate weed control, such that the yield from the All Low pesticide regime was 0.36 t/ha less than that from the All High ($P < 0.05$). The cross-site yield from the spring rape All Low pesticide regime was subsequently 25% less than the All High regime (**Fig. 2.8.12**).

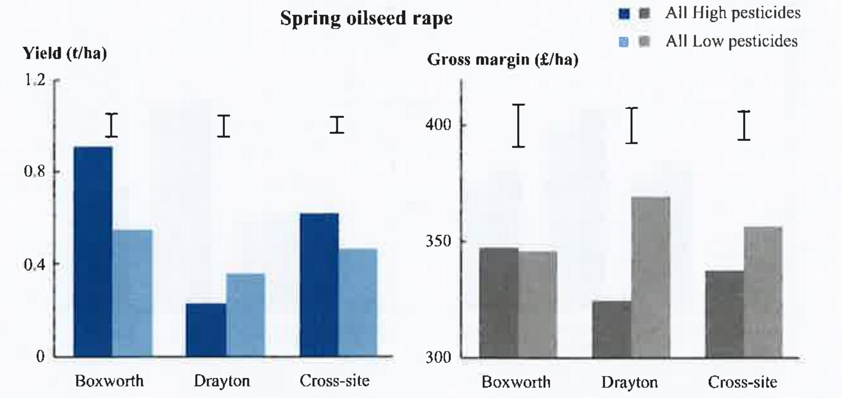

Figure 2.8.12. The effect of the All Low pesticide regime on the mean yield and gross margins from TALISMAN spring oilseed rape. Error bars show SEDs for within-site comparisons.

Despite the poor overall yields, plus the yield losses experienced in the All Low pesticide regime at Boxworth, savings in pesticide costs were such that the gross margins from the All Low regime did not fall greatly below those from the All High regime at either site. At Boxworth, the All Low and All High gross margins were virtually identical, whereas at Drayton the All Low gross margin was 14% greater than the All High. Across both sites, the gross margin from the spring oilseed rape All Low pesticide regime was 6% or £19/ha better than the All High (**Fig. 2.8.12**).

Spring linseed

Three crops of linseed were grown, two at High Mowthorpe and one at Boxworth. At Boxworth, the yield from the All Low pesticide regime was reduced by 2% in comparison with the All High, whereas at High Mowthorpe there was a 1% increase. Across both sites, there was no difference in yield between the All Low and All High pesticide regimes (**Fig. 2.8.13**). There were no confirmed instances of statistically significant reductions in yield associated with poor control of weeds, pests or diseases arising from low-input pesticide use in linseed.

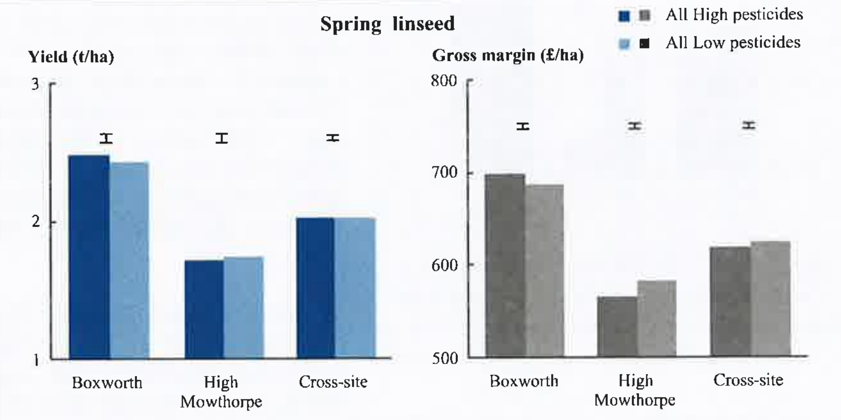

Figure 2.8.13. The effect of the All Low pesticide regime on the mean yield and gross margins from TALISMAN spring linseed. Error bars show SEDs for within-site comparisons.

Savings in pesticide costs did not compensate for the lower yield of linseed at Boxworth. The gross margin from the All Low pesticide regime at Boxworth was 2% (£11/ha) less than that from the All High. In contrast, the linseed gross margins responded more favourably to the All Low pesticide regime at High Mowthorpe where the gross margin from the All Low was 3% (£17/ha) greater than the All High regime. Taken across both sites, the effect of the All Low regime was fairly neutral. The average gross margin from the All Low was 1% (£6/ha) better than the All High pesticide regime in linseed (**Fig. 2.8.13**).

Crop rotations

The Standard Rotations in TALISMAN were based on winter cropping whereas the Alternative Rotations were based on winter and spring cereals and spring break crops (see Chapter 2.1). Conventionally, winter cropping is considered to be more profitable than spring cropping in most arable areas of the UK owing to its higher output value (Nix, 1999). This is mainly due to the higher yields and greater reliability of winter crops compared with spring crops.

In terms of the acceptability of the TALISMAN rotations to farmers, spring break crops are a less attractive financial option than winter crops in most instances, although the former can provide a useful alternative where opportunities for winter crops are missed, e.g. through adverse weather conditions in the autumn. The potential of rotations based on spring crops lies in the opportunity to dramatically reduce variable inputs. However, most farmers would accept that gross outputs in terms of crop yield and monetary value are the main economic factors in the profitability of any crop rotation. The Alternative Rotation was, therefore, designed with an element of spring cropping with the intention of creating a system with an inherently lower demand for nitrogen and pesticides. Whilst the Alternative Rotations succeeded in their objective of having a lower demand for nitrogen fertiliser (Chapter 2.2), the outcome was not as favourable in the case of pesticide use. The Alternative Rotations did not ultimately reduce the overall demand for pesticides compared with the Standard Rotations (Chapter 2.1). Furthermore, the overall financial impact of low-input pesticide use was not always as beneficial in the Alternative compared with the Standard Rotation.

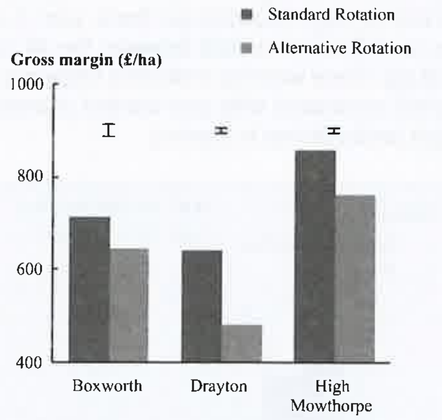

Figure 2.8.14. The effect of crop rotation on the mean gross margins from the TALISMAN sites. Error bars show SEDs for within-site comparisons.

The Standard Rotations were, as expected, more profitable than the Alternative Rotations (**Fig. 2.8.14**). High Mowthorpe was the most profitable of the three sites, followed by Boxworth and Drayton, reflecting the general pattern of profitability observed in the individual crops (see above). The average gross margin from the Alternative Rotation (£626/ha) was 15% or £109/ha less than that from the Standard Rotation (£735/ha) across all sites.

At Boxworth and Drayton, the combination of crops in the Alternative Rotation did not confer any advantage over the Standard Rotation in terms of improving the relative financial performance of the low-input pesticide regime (**Fig. 2.8.15**). The changes in average gross margins brought about by the All Low pesticide regime were marginally more favourable in the Standard Rotations than in the Alternative Rotations at Boxworth and Drayton. However, at High Mowthorpe, the relative change in average gross margin resulting from the All Low pesticide regime in the Alternative Rotation compared more favourably with that from the Standard Rotation (**Fig. 2.8.15**).

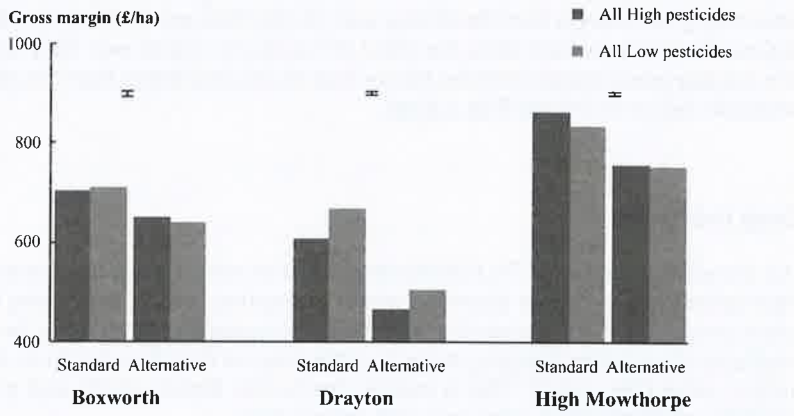

Figure 2.8.15. The interaction of crop rotation and pesticide regime on mean gross margins from the TALISMAN sites. Error bars show SEDs for within-site comparisons.

There was virtually no difference between the average gross margins from the All High and All Low pesticide regimes in the Alternative Rotation at High Mowthorpe. However, in the Standard Rotation at High Mowthorpe, the gross margin from the All Low pesticide regime was 3% (£28/ha) less than that from the All High. The low-input crops grown in the Alternative Rotation at High Mowthorpe included spring beans, spring barley and spring linseed. Judging from the financial performance of these crops at High Mowthorpe, it is clear that the neutral financial impact of the All Low pesticide regime in the Alternative Rotation at High Mowthorpe was due to the favourable gross margins from the All Low pesticide regime in the spring barley and spring linseed crops.

These results demonstrate that, at sites such as High Mowthorpe, rotations containing spring-sown crops may be more compatible with low-input pesticide use. With the right combination of crops, the financial benefits from adopting a low-input pesticide use strategy may be maximised. However, before adopting Alternative Rotations similar to those used in TALISMAN, the suitability of the site should be carefully assessed together with the prospect of lower overall financial outputs from spring compared with winter crops.

Pesticide sub-treatments

The pesticide sub-treatments adopted in TALISMAN permitted the relative economic contribution of each category of pesticide use, i.e. herbicides, fungicides or insecticides (including molluscicides), to be assessed in relation to the overall performance of the low-input pesticide regime.

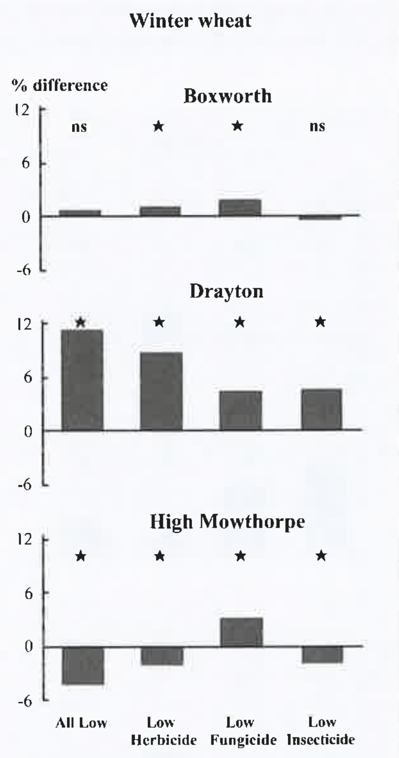

Figure 2.8.16. The effect of the pesticide sub-treatments on mean gross margins (£/ha) from TALISMAN winter wheat, shown as percentage differences from the All High sub-treatment. ★ = $P < 0.05$; ns = not significant.

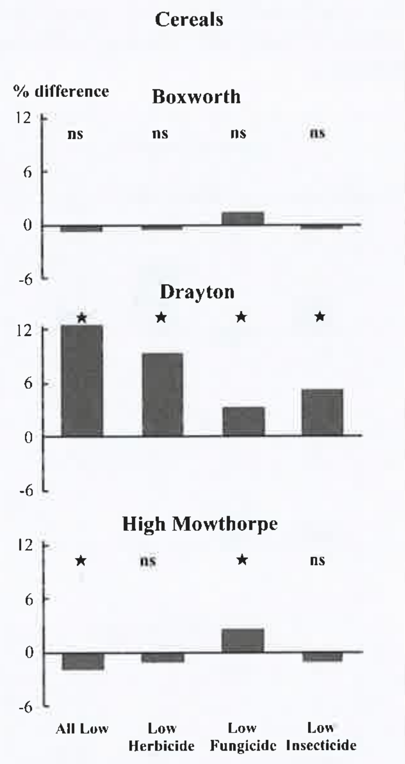

Figure 2.8.17. The effect of the pesticide sub-treatments on mean gross margins (£/ha) from TALISMAN cereal crops, shown as percentage differences from the All High sub-treatment. ★ = $P < 0.05$; ns = not significant.

In other words, when adopting a low-input pesticide regime, from which group of pesticides do the greatest potential savings from reductions in pesticide use arise? The charts used in support of this section show the percentage difference in the mean gross margins of the respective pesticide sub-treatments (All Low, Low

Fungicide, Low Herbicide and Low Insecticide) from the reference All High sub-treatment, in which all pesticides were applied at full rate according to the conventional CCP regime.

In winter wheat, the Low Fungicide sub-treatment produced consistent gains across all sites. However, the greatest benefit was noted at Drayton where the Low Herbicide regime made the highest contribution (**Fig. 2.8.16**). Taking cereals as a group, a similar pattern emerged. The Low Fungicide sub-treatment once again exhibited an advantage at all sites (**Fig. 2.8.17**). In the break crops, a slightly different picture was found (**Fig. 2.8.18**). The Low Fungicide sub-treatment gross margins were favourable at Boxworth and High Mowthorpe but not at Drayton. Additionally, the mean gross margin from the All Low sub-treatment exceeded that from the All High at all sites except High Mowthorpe.

By taking an overview of all crops grown in TALISMAN, the Low Fungicide sub-treatment compares favourably with the other sub-treatments (**Fig. 2.8.19**). However, the largest single gain over the All High sub-treatment was achieved by the Low Herbicide regime at Drayton. The greatest overall gain from the All Low regime (compared with the All High) was subsequently evident at Drayton, whilst the equivalent sub-treatment at Boxworth was neutral and at High Mowthorpe slightly negative. Apparently, the crops at Drayton were not as responsive to pesticide inputs as they were at the other sites. The variation displayed between pesticide groups and between sites indicates that the identification of when and where crops will, or will not, respond economically to pesticide inputs is central to decision making and the key to the successful adoption of low-input pesticide strategies.

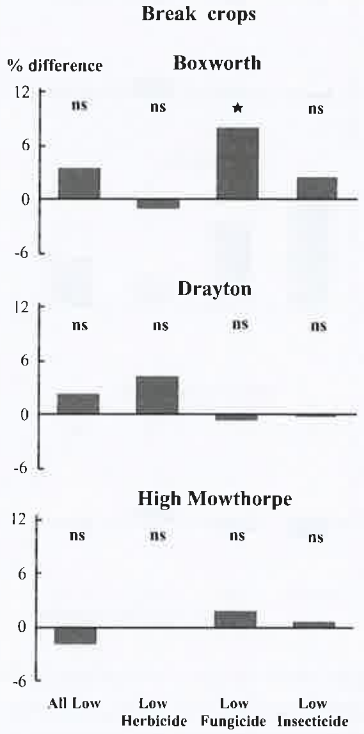

Figure 2.8.18. The effect of the pesticide sub-treatments on mean gross margins (£/ha) from TALISMAN break crops, shown as percentage differences from the All High sub-treatment. ★ = $P < 0.05$; ns = not significant.

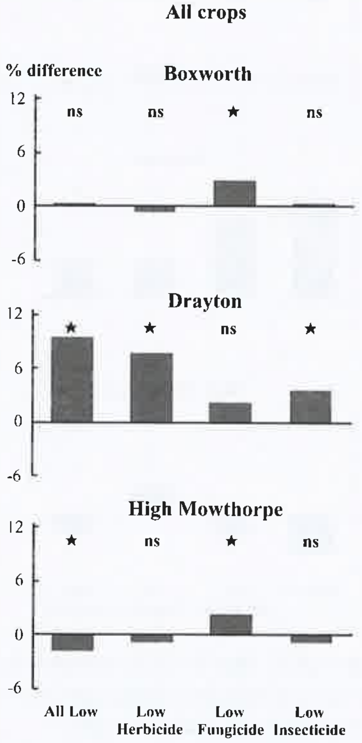

Figure 2.8.19. The effect of the pesticide sub-treatments on mean gross margins (£/ha) from all TALISMAN crops, shown as percentage differences from the All High sub-treatment. ★ = $P < 0.05$; ns = not significant.

Amalgamating TALISMAN crops into their various categories (winter wheat, cereals, break crops and 'all crops') and by analysing the pesticide sub-treatment gross margins across all sites, confirmed that the greatest gains were produced from reducing fungicide use (**Fig. 2.8.20**). Substantial benefits were also realised from reducing herbicide use but the gains from reducing insecticide and molluscicide use were smaller, as the comparatively low cost of insecticides translated into only relatively minor savings.

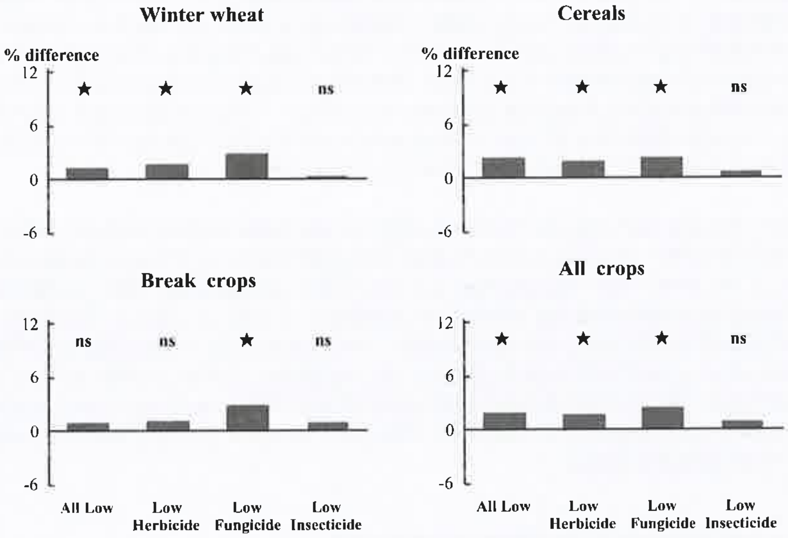

Figure 2.8.20. The effect of the pesticide sub-treatments on cross-site mean gross margins (£/ha) from winter wheat, cereals, breaks and all crops grown in TALISMAN, shown as percentage differences from the All High sub-treatment. ★ = $P < 0.05$; ns = not significant.

Financial scenarios

The basic data relating to the financial performance of the various crops studied in TALISMAN were re-analysed using two key 'what if' scenarios. The aim of this exercise was to look ahead and assess the consequences of low-input pesticide use under economic conditions which may prevail in the near future. The following scenarios were thus adopted:

Financial scenario 1: generalised sale prices

In this scenario, the sale price of all crops was standardised to those expected for the 1998 harvest. The 1998 prices were considerably lower than those obtained during the course of the TALISMAN study and represent the continuing fall of prices towards world market levels following the reform of European Union price support measures and the changes to the General Agreement on Tariffs and Trade (GATT) in 1993. The following projected 1998 sale prices were used to re-calculate the gross margins:

Winter wheat	£80/tonne
Spring wheat	£80/tonne
Winter barley	£77/tonne
Spring barley	£77/tonne
Winter triticale	£77/tonne
Winter oats	£68/tonne
Winter beans	£90/tonne
Spring beans	£90/tonne

Winter oilseed rape	£166/tonne
Spring oilseed rape	£166/tonne
Winter linseed	£100/tonne

Area Aid Payments and the price of variable costs that were in force during the year of harvest were left unaltered in the analysis of Scenario 1. As was expected, the drop in crop sale prices used in Scenario 1 resulted in lower financial outputs. The average gross margin of the cereal and break crops fell by 31% and 26% respectively compared with actual values (**Tables 2.8.3–5**). The relative financial performance of the All Low pesticide regime generally improved in comparison with the All High regime under Scenario 1. In cereals, the gross margin from the All Low pesticide regime was 6% greater than the All High, compared with a 2% gain using actual values. A similar pattern was evident in the break crops, where the gross margin from the All Low regime exceeded the All High by 1% using actual values, whilst this figure increased to 4% under Scenario 1.

These results demonstrate how savings in pesticide costs can have a greater beneficial effect on gross margins when financial output is reduced by lower crop prices. As arable farm businesses are put under pressure by falling crop prices, growers may respond by striving to maintain maximum yields. However, the TALISMAN results indicate the strategic importance and potential benefits of rationalising pesticide use in these circumstances. Although the results have shown how average yields have decreased in association with low-input pesticide use, there is clearly not the same threat to gross margins provided pesticide inputs are managed prudently.

Financial scenario 2: variable cost increase

In this scenario, variable costs (seed, fertiliser and pesticides) were increased by an across-the-board value of 25% to represent a general projected trend of increasing input costs. These increases could, in practice, arise through general inflationary pressure or via the introduction of a pesticide tax or levy (Anon., 1999). The TALISMAN gross margins were re-analysed using the revised input costs, whilst the sale prices and area aid payments in force during the year of harvest were left unaltered.

The impact of increasing variable costs in Scenario 2 was not as great as that of the reduced prices applied in Scenario 1. Increasing the variable costs resulted in an overall drop of 6% in cereal and break crop gross margins, compared with actual values (**Tables 2.8.3–5**). The relative financial performance of the All Low pesticide regime in Scenario 2 generally improved in comparison with actual values, although the effect was not as pronounced as that seen in Scenario 1. In cereals, the gross margin from the All Low pesticide regime was 5% greater than the All High under Scenario 2, compared with a 2% gain using actual values. A similar pattern was evident in the break crops, where the gross margin from the All Low regime exceeded the All High by 1% using actual values, whilst this figure increased to 3% under Scenario 2.

When variable costs, including those of pesticides, increase, then so does their relative impact on gross margins. The financial savings gained from reducing pesticide use make a greater contribution to gross margins when pesticide prices are high and the output value of the crop remains low. Therefore, the elevated pesticide costs in Scenario 2 increased the financial incentives to reduce pesticide use, reflecting a similar pattern to that revealed by the lower crop prices applied in Scenario 1.

Conclusions

As with all experiments, great care must be taken in the interpretation of results. In the cases of winter barley, spring wheat, spring oats and spring oilseed rape, only two crops of each were grown in TALISMAN and their results must, therefore, be treated with caution. At the other extreme, 28 crops of winter wheat were grown and this data set should be a reliable indication of how this crop responds to low-input pesticide use.

Taken overall, TALISMAN has shown that there is scope to increase profitability from reducing pesticide use. The results suggest there is greatest potential to achieve this with fungicides, followed by herbicides and, to a lesser extent, insecticides. 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.

Pesticide use was tailored to the local needs of each site and clear differences in pesticide demand emerged at the three sites (see Chapter 2.1). The perceptions of risk and the need to maintain farm income are key factors in determining the scale of pesticide use. The contrasting site differences in approach to pesticide use were heavily influenced by local perceptions of risk and by localised weed, pest or disease problems. These differences realistically reflected the contrasting economic demands of individual farms, where each farm has a distinct set of crop protection needs influenced by a variety of local factors, e.g. climate, soil type, crop rotation and weed populations. This observation highlighted the value of studying a range of contrasting geographical locations in large-scale agricultural experiments such as TALISMAN.

At Drayton, there was an overall cautious approach to the control of problematical weeds and slugs, leading to a relatively high use of pesticides which was not always economically justified. In contrast, High Mowthorpe appeared to be the most responsive site to pesticide inputs. Therefore, greater financial gains were made at Drayton than at High Mowthorpe. Conventional pesticide use at High Mowthorpe would appear to have been at near optimum level and cutting below this level was not generally cost-effective. Favourable gross margins were not observed in association with low-input pesticide use in winter wheat or in winter and spring beans at this site. However, spring and winter barley and spring linseed responded favourably to low-input pesticide use at High Mowthorpe. In comparison, the gross margins from crops grown at Boxworth and, notably, Drayton, responded far more favourably to the low-input use of pesticides.

Looking to the future, the TALISMAN results remain highly relevant to the profitability of arable crops. The economic scenarios presented demonstrated how the financial incentives to adopt low-input pesticide use can improve under more stringent financial conditions imposed by falling sale prices or increases in variable costs.

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 not all sites and crops are suitable for use in conjunction with low-input pesticide use strategies. Low-input strategies can be profitable at some sites and in some types of crops. Finding the right combination is essential to success and this may mean locally modifying rotations to find the right mix of crops best suited to low-input pesticide use. 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.

References

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Table 2.8.1. The average yields of crops grown in TALISMAN, 1991–1996 in comparison with national averages (t/ha).

Crop (& number grown)	National average yield*	TALISMAN average yield**
Cereals		
Winter wheat (28)	7.75	7.51 (-3)
Winter triticale (6)	6.00	5.28 (-12)
Spring barley (6)	5.40	5.46 (+1)
Winter barley (2)	6.35	7.76 (+22)
Spring wheat (2)	5.80	5.61 (-3)
Spring oats (2)	5.75	4.76 (-17)
Breaks		
Winter oilseed rape (4)	3.00	2.45 (-18)
Spring oilseed rape (2)	2.10	0.53 (-75)
Winter beans (6)	3.40	4.34 (+28)
Spring beans (5)	3.20	3.20 (0)
Spring linseed (3)	1.50	2.03 (+35)

* Predicted 1998 figures from Nix's Farm Management Pocketbook (Nix, 1997).
** Data in parentheses show percentage difference of TALISMAN from Nix's average.

Table 2.8.2. The average gross margins from crops harvested in TALISMAN, 1991–1996 in comparison with national averages (t/ha).

Crop (& number grown)	National average gross margin*	TALISMAN average gross margin**
Cereals		
Winter wheat (28)	661	837 (+27)
Winter triticale (6)	547	505 (-8)
Spring barley (6)	514	545 (+6)
Winter barley (2)	550	823 (+50)
Spring wheat (2)	586	748 (+28)
Spring oats (2)	574	494 (-14)
All cereals (46)	572	753 (+32)
Breaks		
Winter oilseed rape (4)	680	487 (-28)
Spring oilseed rape (2)	610	341 (-44)
Winter beans (6)	578	661 (+14)
Spring beans (5)	562	519 (-8)
Spring linseed (3)	530	621 (+17)
All breaks (20)	592	547 (-8)
All crops (66)	588	685 (+16)

* Predicted 1998 figures from Nix's Farm Management Pocketbook (Nix, 1997).
** Data in parentheses show percentage difference of TALISMAN from Nix's average.

Table 2.8.3. The effect of reduced sale prices (Scenario 1) and increased input costs (Scenario 2) on the average gross margins from cereal crops grown in TALISMAN, 1991–1996 (£/ha).

Crop & scenario	Pesticide sub-treatment		SED	All Low as % of All High
	All High	All Low		
Winter wheat (651 d.f.)				
Actual	827.3	836.4	4.16***	101
Scenario 1	543.8	570.1	2.85***	105
Scenario 2	770.6	795.2	4.13***	103
Winter triticale (120 d.f.)				
Actual	470.6	542.1	8.62***	115
Scenario 1	320.3	394.0	6.27***	123
Scenario 2	404.8	496.1	8.60***	122
Spring barley (118 d.f.)				
Actual	534.0	564.1	14.07	106
Scenario 1	415.8	448.1	11.13*	108
Scenario 2	485.5	525.6	14.09	108
Winter barley (32 d.f.)				
Actual	820.4	844.2	19.98	103
Scenario 1	648.5	677.9	15.46	105
Scenario 2	778.6	815.1	19.99	105
Spring wheat (47 d.f.)				
Actual	776.6	720.3	17.10***	93
Scenario 1	500.4	474.7	10.80***	95
Scenario 2	732.3	683.1	17.10***	93

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

Table 2.8.4. The effect of reduced sale prices (Scenario 1) and increased input costs (Scenario 2) on the average gross margins from break crops grown in TALISMAN, 1991\1996 (£/ha).

Crop & scenario	Pesticide sub-treatment		SED	All Low as % of All High
	All High	All Low		
Winter beans (112 d.f.)				
Actual	641.7	672.0	8.00***	105
Scenario 1	437.4	468.6	4.67***	107
Scenario 2	609.5	647.8	8.02***	106
Winter oilseed rape (71 d.f.)				
Actual	484.1	450.9	23.23**	93
Scenario 1	303.5	298.5	15.45**	98
Scenario 2	435.0	413.9	23.23**	95
Spring oilseed rape (40 d.f.)				
Actual	336.9	355.5	12.43	106
Scenario 1	328.8	349.0	11.45	106
Scenario 2	294.5	324.4	12.43	110
Spring linseed (55 d.f.)				
Actual	618.3	623.8	4.99	101
Scenario 1	593.3	599.2	4.13	101
Scenario 2	577.7	584.7	4.99	101
Spring beans (81 d.f.)				
Actual	519.1	522.4	9.54	101
Scenario 1	362.3	379.7	6.76***	105
Scenario 2	478.9	492.7	9.54*	103
Spring oats (32 d.f.)				
Actual	504.4	491.0	12.11	97
Scenario 1	302.6	299.9	7.91	99
Scenario 2	471.9	463.4	12.11	98

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 2.8.5. The effect of reduced sale prices (Scenario 1) and increased input costs (Scenario 2) on the average gross margins from TALISMAN crops grouped overall as cereals, breaks and all crops (£/ha).

Crop & scenario	Pesticide sub-treatment		SED	All Low as % of All High
	All High	All Low		
Cereal crops (1048 d.f.)				
Actual	742.9	759.5	3.83***	102
Scenario 1	501.8	532.0	2.78***	106
Scenario 2	687.4	718.7	3.84***	105
Break crops (519 d.f.)				
Actual	541.7	546.0	6.08	101
Scenario 1	396.4	410.3	4.08**	104
Scenario 2	502.4	515.1	6.11*	103
All crops (1567 d.f.)				
Actual	675.8	688.3	3.26***	102
Scenario 1	466.7	491.4	2.30***	105
Scenario 2	625.8	650.8	3.27***	104

* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.