



Unilever

# The Colworth Farm Project

PUTTING SUSTAINABLE AGRICULTURE TO THE TEST



Centre for Ecology & Hydrology

NATURAL ENVIRONMENT RESEARCH COUNCIL

## Introducing Colworth



Colworth in Bedfordshire, United Kingdom, is one of Unilever's key research and development centres. Founded in 1948, Colworth has been at the leading edge of industrial research for over half a century, and provided much of the early innovation to support Unilever's expanding interests in agribusiness and frozen foods. Research programmes here bring together scientists from biological, behavioural, chemical, physical, engineering and food science to develop new products to meet the everyday needs of people everywhere. A key research area in Unilever's quest for new industry-defining innovation is agriculture, with major research programmes based at Colworth farm.



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# SUMMARY

The 500-hectare commercially-run farm at Unilever's Colworth research site in Sharnbrook, Bedfordshire, England, plays an important role in the company's Sustainable Agriculture Initiative. Since 1999, a 60-hectare section of the farm has been used as an experimental site for the Colworth Farm Project.



During the Colworth project the Unilever team has worked with wildlife organisations, farmers, farm consultants, government organisations and academics, to validate and compare 'conventional' and 'experimental' – potentially more sustainable – agricultural practices in a farm business environment. This involved risk to crops, which would not otherwise have been possible to test in a commercial environment. While some of the scenarios tested might not currently be practical for commercial farms, they were designed to challenge received wisdom and suggest insights into practical alternatives to conventional thinking and practice.

The Colworth project is proactive in its nature, in that it attempts to find practical solutions to environmental challenges currently being considered by governments, academics and non-governmental organisations. Significant legislative changes are already taking effect and will influence farming practice in the future.

## The approach

Various aspects of farming were investigated and incorporated into the experimental programme. The aim was to provide representative information on crops relevant to Unilever (peas and oilseed rape) within a six-year commercial rotation which in the UK is typically cereal-dominated. The project's key focus was to examine the impact of six scenarios:

- Spring versus winter cropping
- Reduced nitrogen fertiliser
- Mixed rotation and cover crops
- Reduced pesticide applications
- Mechanical weeding
- Field margin management

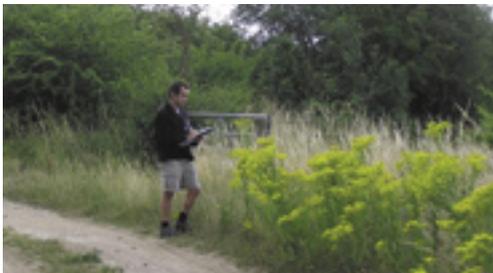
To assess the impact of the various scenarios, the project team monitored the abundance and diversity of birds, plants and insects; levels of nitrate, phosphate and pesticides

in surface water; crop yields and profits – all parameters included in the Unilever Sustainability Indicators. The environmental, financial and social costs and benefits of adopting potentially more sustainable practices have been assessed, and improvements identified.

## The people

The project has a partnership approach at its heart. Working with individuals and organisations who have different skills and approaches but shared common objectives allows us to accelerate our progress towards sustainability. Moreover, the project continues to raise awareness and influence stakeholders' views and behaviour, both externally and within our own business.

The work on the Colworth farm continues to be shared with the agricultural community with the aim of encouraging the development of sustainable agricultural systems. We have therefore put our approach and methodology in the public domain and are extending our dialogue with an ever-growing number of stakeholders.



*“The Colworth project has been instructive to the BTO in channelling our ideas towards those agricultural features that impact most on bird populations. For instance, we’ve learned much about ways to use crop rotations to encourage birds: a more complex rotation including oilseed rape, peas, and weedy set aside cut later than the norm, all benefited Colworth bird populations significantly. Hopefully this type of research is picked up by the government and other policy makers, as well as farmers who want to enhance their landscape and operate more sustainably.”*

Ian Henderson  
British Trust for Ornithology

## Key findings and outcomes

- Spring cropping offered environmental benefits, through a reduction of inputs, elevated bird numbers and improved potential for weed control.
- Lower nitrogen rates reduced crop yield by an average of 19% but reduced leaching potential by 11% and improved weed control.
- Reducing nitrogen fertiliser did not reduce nitrate concentrations to a level below the 50 mg/l EC Directive limit for surface and ground waters. Other mitigation approaches, such as cover crops, offer opportunities to make further reductions.
- Diverse rotations, including broad-leaved crops, fallows and cover crops, improved habitats for birds, mammals and invertebrates. Growing cover crops also substantially reduced nitrate leaching.
- Band spraying has the potential to reduce pesticide leaching losses by more than the reduction in application rate – in the project pesticide concentrations in field drains were reduced by more than 50%.
- Reduced pesticide inputs enhanced both biodiversity and the potential for the natural control of pest invertebrates. However constant reduction of herbicides led to dense pernicious weed populations that impacted on both crops and biodiversity.
- Mechanical weeding had little impact on pernicious weeds in high nutrient scenarios, and may damage populations of soil invertebrates. However, it worked well in low-fertility situations, and provided N-mineralisation benefits.
- Sympathetic hedgerow and field margin management increased bird and invertebrate numbers and improved crop pest control through its impacts on predatory invertebrates.
- Experimental yields were reduced by up to 60%. But in crops where experimental management was successful, wheat yields were comparable with those managed conventionally, and often provided better gross margins.
- The project has naturally evolved into a series of externally-funded sustainability projects, including trials of Controlled Traffic Farming and an initiative to monitor nitrate leaching at catchment level.
- The project has attracted a wide variety of local, national and international visitors, including farmers, policy-makers, academics and school children. ■

# Rationale

## Unilever and Sustainability

Unilever relies heavily on natural raw materials for use in its products, and it is therefore in its business interests to ensure sustainable supplies of these materials. Since the mid-1990s Unilever has worked with stakeholders in the area of sustainability in fisheries and water, as well as agriculture.

In 1998, Unilever translated the concept of agricultural sustainability into ten operational indicators (*Appendix I, page 26*). Parameters were identified for selected key crops around the world (peas, tea, palm oil, spinach and tomatoes), and a monitoring system was developed for the measurement and collection of baseline data against the ten indicators. The aim was to understand and agree the ecological, social and economic conditions that sustainable agriculture must meet to implement best practice.

## Colworth Farm Project

The Colworth Farm Project (the project) is one of the Lead Agriculture Programmes within the Unilever Sustainable Agriculture Initiative (SAI).

The farm allows the assessment of new agricultural methods and practices in a real commercial situation and a relatively risk free environment. The research programme is relevant to the farming of a range of European crops used by Unilever, including oil seed rape, linseed, cereals, vining peas and mustard.

The Colworth Farm is a 500-hectare estate, comprising 400 ha of arable land of predominantly heavy clay (Hanslope series) and 100 ha of semi-ancient and natural woodland. Sixty hectares consisting of eight fields were dedicated to the project (*Figure 1*). The aim was to provide

Figure 1: Colworth Farm Project site diagram



## HOW WE MEASURE THE ECONOMIC PERFORMANCE OF CROPS AT COLWORTH

The Colworth Farm uses gross margin analysis to periodically review its activities. Gross margin is the gross output of an enterprise minus the variable costs directly attached to it, e.g. seed, pesticide, fertiliser. It enables comparison of the efficiency of different agricultural systems and shows the likely effects of changes to that system. It is not an indication of profit, as it does not account for fixed costs, e.g. labour, machinery, rent.



In an arable system, two factors affect gross output – crop yield and the sale price of the produce. Both factors can vary tremendously as a result of management, climate, crop grown, contract agreements, world markets and currency fluctuations. It is therefore important when comparing gross margins from different seasons that these factors are taken into account. Variable costs also vary from season to season, e.g. fertiliser price rises due to increases in oil price.

There are several important points to note in relation to the use of gross margin analysis in this project:

- Small experimental block sizes make some systems appear less efficient than others, e.g. an

output per hour measurement for a mechanical weeder decreases disproportionately compared to a conventional sprayer.

- The true costs of mechanical weeding were difficult to estimate, since equipment and labour (fixed costs) were already available at Colworth, and were therefore not included in the gross margin calculation.
- Gross margin may underestimate the potential savings associated with how a particular treatment works within the farm as a whole, e.g. spreading labour requirements over the year to avoid seasonal

peaks in the case of spring cropping.

- Experimental treatments, and hence the associated variable costs, evolved during the project, making it difficult to account for in the analysis. The gross margin for the 'conventional' control used in the project also changed, due to improvements resulting in higher gross output and margin.

However, gross margin remains the most useful measure for comparing averages over a number of seasons and demonstrates the economic consequences of different project scenarios.



*"This project has provided an excellent opportunity to study how farming practices affect nutrient and pesticide leaching losses within a hydrologically defined catchment. The information gathered highlights the need for both an integrated approach to pollution control, and the value of catchment based studies. The interaction between scientists in this project has been particularly rewarding."*

Simon Groves  
ADAS

representative information on two Unilever crops (peas and oilseed rape) within a typical cereal-dominated rotation, over a sequence of years. This would identify, at the whole-farm level, both the practical and impractical implications of alternative practices that may be used to influence key stakeholders, internally and externally, on critical issues required for the sustainable production of raw materials.

The objectives of the project include:

- To measure the long-term impact of conventional farm practice compared to experimental, potentially more sustainable, alternatives
- To assess and improve biodiversity in a modern agricultural farm context
- To understand the economic consequences of these experimental agricultural practices.

### The approach – testing boundaries and interactions

The project was designed to provide more than a ‘snapshot’ view of ecological processes in arable farming. Short-term assessments of organisms responding to farm management and weather are often misleading, and the project was specifically designed to provide representative conclusions from several years of observations. This allowed an assessment of both the magnitude and speed of the response by organisms to changing management practices. It was recognised from the beginning that the knowledge of response-times was critical for planning future sustainability scenarios.

The project therefore aimed to assess a crop rotation of six years. Most importantly, this would separate the effects of crops from field characteristics that influence both the distribution of organisms and the propensity to ‘leak’ nutrients or pesticides. It also set out to elicit the maximum response of animals and plants to changing management practices by deliberately adopting drastic reductions in input levels and other significant changes. This procedure involved risk to crops, which would not otherwise have been possible to test in a commercial environment. While some of the scenarios tested might not currently be practical for commercial farms, they were designed to challenge and provide an insight into practical alternatives to conventional thinking and practice.

Neither the conventional nor the experimental practices were static. They evolved throughout the project. This allowed the project continually to reflect current thinking and learnings.

The project investigated the impacts of the following six farm management scenarios on the ten indicators used by Unilever in their agricultural sustainability programme:

- Spring versus winter cropping
- Reduced nitrogen fertilisers
- Mixed rotation and cover crops
- Reduced pesticide applications
- Mechanical weeding
- Field margin management

Six of the fields shown in *Figure 1*, were split into quarters, with two sets of paired treatments in each: e.g. conventional versus reduced pesticides, and conventional versus reduced nitrogen fertiliser. The other two fields were split in two, with all six experimental practices compared to all conventional practices.

The effects of ploughing and changes in cultivation were also investigated. However, because the frequency of ploughing on the Colworth farm had already been reduced and non-inversion techniques used, conditions were considered equivalent to ‘minimum tillage’ on similar soil types. A more radical approach was therefore adopted with the intention of improving soil structure and health. On a separate part of the farm Controlled Traffic Farming, where tramlines are set using Global Positioning System technology and remain in place for four years, has been introduced and its effects are currently being assessed. There is strong evidence from the United States and Australia for this innovative approach to improve soil structure and associated health over time, and the Colworth programme has already attracted wide interest. ■



*“The Colworth project has provided exceptional detail on the dynamics of weeds in crops and their roles in influencing invertebrates that will aid the natural protection of crops. And of course, this will help other biodiversity, such as birds, by providing food. It is to be hoped that this information will lead to more imaginative crop management techniques being developed by farmers.”*

**Neil Ravenscroft**  
Ecological Research Associates

# Policy and legislative framework

Although many farmers accept the need for change to ensure overall sustainability of their farming systems, the impact of legislation as key drivers for change should not be underestimated – farming, like any other business, is significantly affected by government regulation. Unilever, as a major purchaser of agricultural produce, is also affected. This project provided an opportunity to understand the potential impact of certain pieces of legislation on European agricultural supply chains and to investigate ways of satisfying future legislative requirements. Some of the major policy areas considered during the project are described below.

## Common Agricultural Policy (CAP) Reform

The 2003 Common Agricultural Policy (CAP) reform was probably the most radical reform since the CAP's inception. The principle of 'decoupling' support payments from production and 'recoupling' them to environmental management practices through cross-compliance has changed the focus of land management throughout Europe. Furthermore, the introduction of Europe-wide modulation (re-adjustment of funds within budgets), and the diversion of funds into the agri-environment, emphasises the breadth and depth of this new focus.

The UK has been one of the leading reformers of all European Union (EU) Member States. The implementation of the new reform in 2005 has varied from State to State and from region to region because of the flexibility inherent within the reform package, but arguably the UK has pioneered the application of decoupling, particularly in England. The next CAP reform in 2009 is very likely to force full decoupling in all EU states.

The UK is also the only EU state to apply national modulation, promoting it specifically for an agri-environment scheme called the Environmental Stewardship Entry Level Scheme. It is not clear whether other EU states will introduce their own national modulation schemes, but various assessments have shown that the UK leads on agri-environment schemes within the Rural Development Regulation. Few Member States have focused on farmland biodiversity, particularly farmland birds, as the UK has.

Agri-environmental research in the UK is thus of particular relevance to other Member States. The results will inform other states as they develop their own agri-environment programmes.

## The Water Framework Directive

Since adoption into UK law in 2004, the European Water Framework Directive (WFD) has become the main legislative

driver for controlling diffuse pollution. The rationale for its introduction is that nutrient concentrations in freshwaters are elevated far above natural levels causing excessive algae and plant blooms, leading to low oxygen levels. This affects both fisheries and biodiversity. The Directive includes two major aims:

- To protect and enhance the ecological status of aquatic ecosystems and wetlands,
- To improve the chemical status of surface and ground waters

The overall aim is to achieve "good ecological and good chemical status" of surface and ground waters by 2015. Currently 80% of rivers, 50% of lakes, 25% of estuaries and 75% of ground waters in England and Wales are at risk of not meeting WFD objectives, according to Environment Agency characterisation.

To some extent this process is already underway with the introduction of Nitrate Vulnerable Zones (NVZ), which limit organic manure and nitrogen fertiliser use on over 55% of the land in England. Other legislative drivers to tackle diffuse pollution include the Freshwater Fish and Bathing Waters Directives.

The Colworth project includes a government-funded initiative to measure nitrate losses from small catchments to support the Directive monitoring requirements. Automated chemical sampling was strategically installed along field drains and streams, and the data used to test and refine computer models that predict the impact of agricultural practices on nitrate losses across whole river basins. The site has also been used to develop the PSYCHIC (Phosphorus and Sediment Yield CHaracterisation In Catchments) decision support system for predicting P losses on a catchment scale.

## Biodiversity Targets

A commitment by the UK Government, aims to reverse the long-term downward trend in farmland birds by 2020. To achieve this, reformation of the agricultural landscape is inevitable, with repercussions for management practices across the industry. Sustainable initiatives will maintain a viable industry within new legislative and political frameworks. Clearly, an understanding of the ecological consequences of farming methods will place the industry in an advantageous position, able to respond effectively to policy changes and contribute towards national or even international targets. ■

Results from the Colworth Farm Project are summarised on the following pages under the six experimental management scenarios listed on *page 2*. Icons referring to Unilever’s ten sustainable agriculture indicators (*Appendix 1, page 26*) are shown in the summary boxes. Their presence highlights those management practices that had an impact on that indicator.

## Spring versus winter cropping



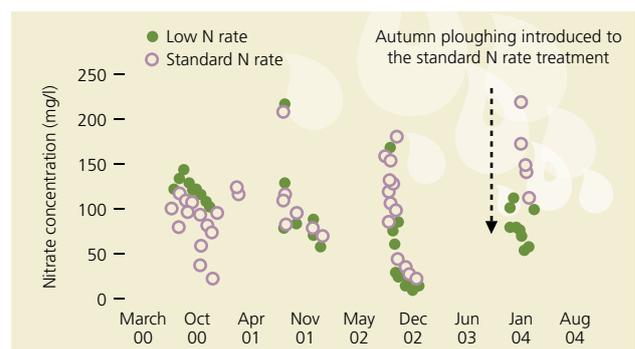
Value chain  
Biodiversity  
Water

- Spring cereals supported a greater diversity of low-impact weeds such as speedwells and groundsel that are important sources of food for birds. Pernicious weeds such as cleavers and black grass occurred more frequently in winter crops.
- The inclusion of spring cropping allowed the introduction of weedy winter stubble and cover crops, creating a more varied crop mosaic. This has been the single most important improvement for birds. Winter cover crops also reduced nitrate leaching losses.
- Autumn ploughing and cultivation of spring crops increased nitrate leaching losses. This had a greater effect than the different nitrate fertiliser rates.
- Spring crops extended the opportunities into late summer for birds such as skylarks to breed and forage, long after winter-sown crops had become impenetrable.
- Where pesticide inputs were low spring wheat yielded better than winter wheat.

### Nitrate leaching

In spring cropping, land can either be ploughed in autumn or left undisturbed until spring. Ploughing incorporates crop residues and aerates the soil, thereby enhancing the microbiological processes by which nitrogen in the soil organic matter is mineralised into plant-available forms such as nitrate. During the first three years of the project, spring-cropped land was left undisturbed in both the experimental and conventional treatments in winter prior to sowing. In 2003, autumn ploughing was introduced into the conventional treatment. The data in *Figure 2* show that, when autumn ploughing was introduced, leaching losses appeared higher than when the land was left undisturbed. This suggests that autumn cultivation released nitrates which, in the absence of a growing crop, were leached during the winter months. It is important to note that the introduction of autumn ploughing had a greater influence on winter nitrate leaching loss than the different nitrogen fertiliser rates applied.

Other published work has suggested that ploughing can increase winter nitrate leaching losses by 25 kg N/ha



**Figure 2: Effect of autumn ploughing on nitrate leaching losses**

compared with zero or reduced cultivation options. In this study, the difference between the total N loss was 10 kg N/ha with mean nitrate concentrations in drainage water differing by 89 mg/l.

For winter-sown crops, a major contribution to nitrate leaching is the release of nitrate that follows autumn cultivations. Losses can be limited by ensuring that crops are established early so that nitrate released is captured rather

than allowed to leach during the following winter. Nitrogen uptake by an autumn-sown crop can vary between 5 and 50 kg N/ha depending on crop type and density (typically <20 kg N/ha). Although these figures may appear small, 17 kg N/ha leached from the soil profile during an average winter in eastern England, with 150 mm of drainage, would cause average nitrate concentrations in drainage water to breach the 50 mg nitrate/l EC Directive limit.

Although leaving the land undisturbed in autumn prior to spring cropping may have reduced N losses, the heavy soil texture at Colworth presented many practical problems when trying to achieve a suitable seedbed. Therefore the advantages in terms of reduced N loss from not ploughing in the autumn must be balanced against potential damage to soil structure associated with early spring cultivations on heavy wet soils. These problems should not be underestimated, as compaction, capping and soil erosion may cause greater environmental damage than the extra nitrogen released from autumn ploughing.

## Biodiversity

### Plants

Spring-sown wheat crops supported a higher diversity of low-impact weeds such as speedwells, groundsel and knotgrass, that are important as bird food. Winter-sown crops tended to support more pernicious weeds such as cleavers and grasses, in particular black grass. As a consequence, the spring-sown plots generally only required a single application of herbicide compared with several applications in the winter-sown crop. The long-term cost savings, however, are unclear and depend on market opportunities. Crop rotation played a part, as wheat crops following oil-seed rape tended to support high densities of rye grass, chickweed and cleavers.

Differences between spring and winter-sown plots were especially pronounced where pesticides were reduced. In winter-sown plots, reduced pesticides led to greater populations of pernicious weeds and a 47% reduction in yield (an average of 4.5t/ha, compared with 8.5t/ha in conventional winter wheat). In these plots mechanical weeding failed to reduce the impact of pernicious weeds. On the other hand, pernicious weeds were largely absent in spring crops (*see Box, page 10*), where the only treatment required was an application of non-selective herbicide before drilling, and yield was only reduced by 18% (average 5.5 t/ha with reduced pesticides compared with 6.7 t/ha in conventional plots).

There were also large differences between winter and spring-sown wheat following set-aside. Under similar pesticide regimes, weeds were almost absent in the winter plot, yet high densities of some low-impact weeds persisted in spring wheat, in particular meadow grass, knotgrass and groundsel.

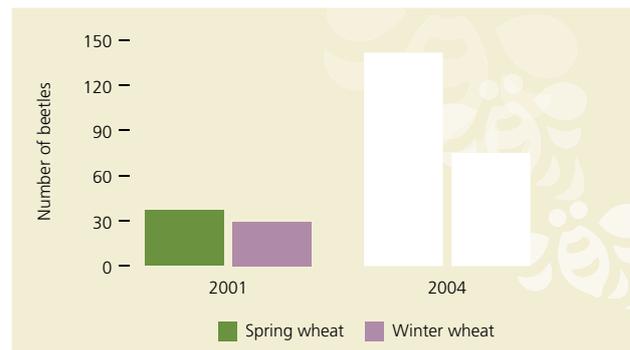


Figure 3: Density of ground beetles 25m into the crop with spring and winter cropping

### Invertebrates

In some years, winter-sown crops supported greater populations of invertebrates than spring-sown, especially spiders and ground beetles. Ground-hunting wolf-spiders and two early-summer beetles were notably abundant. The abundance of invertebrates may have been due to the presence of winter crop cover and the associated microclimate afforded by the grass cover in these plots. Differences in invertebrate populations in spring and winter-sown plots were more pronounced in the absence of pesticides, as grass cover increased in the latter. But there were no differences in invertebrate abundance under wheat crops following set-aside. This may have been a reflection of the relative cleanliness of the winter-sown plots following set-aside, indicating that weed cover is important to invertebrates as well as crop cover. There were indications that greater numbers of invertebrates occurred further into the crop after four years of spring cropping, perhaps reflecting the open structure of the crop earlier in the season, or the different weed flora (*Figure 3*).

### Birds

Due to the relatively late development of spring crops, breeding skylarks continued to breed and forage during June and July, after winter-sown crops had become too tall and dense to allow access. Spring cereals, set-aside and peas would allow skylarks the opportunity to fulfil their breeding potential, unlike winter-sown crops.

### Soil health implications

Seasonal timing of cultivation and the regularity and depth of ploughing are crucial to soil health. Most agriculturally-relevant earthworm species are inactive during winter and high summer, when, to avoid freezing or desiccation, they create deep burrows, aestivate or produce cocoons. The least harmful time to plough is during winter or high summer (i.e. when soils are below 4°C or very dry). Therefore, spring cropping, where the soil is left undisturbed after autumn harvest and ploughed in spring, is likely to

## FACTORS AFFECTING WEEDS IN CROPS AT COLWORTH



Weed diversity and abundance were recorded in quadrants along transects into crops. Crop type and location were the primary influence on the weed flora in any particular field. Fields located to the west of the study area and both conventional and experimental wheat crops supported the greatest diversity and abundance of weeds. Up to 80 species were found, including some plants of conservation interest, but among the most frequent and widespread were the pernicious weeds black grass, cleavers and fat hen.

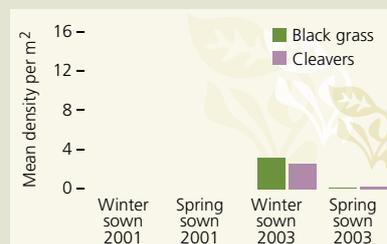
There were large differences in the diversity and abundance of weeds where nitrogen and pesticide inputs were altered and under different cultivation and crop timing regimes.

**Fertiliser** Pernicious weeds were more abundant under high nitrogen

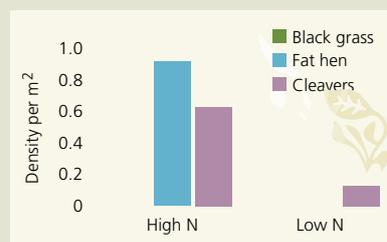
applications (*above, right*). Black grass, fat hen and cleavers were more or less absent from low nitrogen parts of wheat crops (*above, left*).

**Pesticides** Herbicide reductions, particularly in tandem with normal nitrogen applications, produced high densities of weeds and severely damaged some crops. These problems became worse through the rotation as plants such as wild oat and cleavers became established (earlier in the experiment low pesticides coupled with low nitrogen produced crops as clean as conventional treatments). Mechanical weeding in lieu of pesticides was unable to control these weeds in wheat crops, but was more successful in pea crops.

**Crop timing** This produced perhaps the most valuable change in landscape as spring-sown crops



Density of pernicious weeds in wheat



Effect of N application rate on pernicious weeds in 2003

supported occasionally large densities of low impact weeds (depending on other aspects of management) such as speedwells and groundsel, that germinated in the open ground available in spring. The development of pernicious weeds, in particular black grass, was confined largely to winter crops.

be harmful to invertebrate communities. Winter cropping, where the soil is only disturbed in autumn (particularly when ploughing takes place soon after harvest) may be the least harmful.

### Agronomy

Ploughing and non-inversion tillage were equally effective in creating a good seedbed in autumn for winter crops. Achieving good results for spring crops, however, still required a primary cultivation, via ploughing, in autumn, and subsequent cultivation on the weathered surface in spring. Our experience indicates that there is little advantage in attempting to plough on heavy land in spring.

Over-wintered ploughing does provide the opportunity to establish spring crops in good seedbeds after limited secondary cultivations. Spring cropping allows the farmer to spread labour requirements over the year, and increases market opportunities for farm businesses. In addition, many of the newly emerging markets for farmers - energy, fuel, fibre and pharmaceutical crops - are likely to stimulate the inclusion of spring crops in the rotation. These novel crops were, however, not included in the project rotation.

At Colworth, spring wheat yielded better under the low pesticide regime than winter wheat (which normally exceeds yields in conventional spring wheat by 25%) and gave a higher gross margin by entering a premium market. This illustrates the importance of securing a market for the crop before it is planted.

# Reduced nitrogen fertiliser



Pest management  
Nutrients  
Water

- The effect of large reductions in nitrogen fertiliser applied on nitrate leaching loss varied substantially from field to field. Yield loss was also highly variable with an average reduction of 19%.
- On average, reducing nitrogen fertiliser rates reduced leaching potential by 11%.
- Reducing nitrogen inputs lowered the levels of pernicious weeds in crops.
- Monitoring soil mineral nitrogen provides a useful tool for managing nitrogen inputs.

## Nitrate Leaching

Nitrate leaching losses were measured in selected fields, where either conventional nitrogen fertiliser rates were applied (as defined by government guidelines), or where rates were substantially reduced (2000-2003, 33%; 2004 66% of conventional rates). Autumn Soil Mineral Nitrogen (SMN) levels, as an indicator of potential overwintering leaching risk, were measured in all fields and in all seasons. The purpose of these treatments was primarily to study the influence of N rate on leaching losses, but also to study how N rate interacted with weed growth, canopy density and biodiversity.

When considering the impact of nitrogen fertiliser rates on N losses, it is important to separate applications above the economic optimum rate for the crop from those below the optimum. In this study we only considered rates at or below the economic optimum. Other studies have shown that application rates above the economic optimum are associated with substantial N losses. In reality, determining the economic optimum with precision is impossible as growth is affected by other factors such as the weather, pests, diseases, etc, which impact the crop after fertilisers have been applied. The intention of reducing the N application rate in the project was to reduce the risk of over-fertilisation and evaluate the impact of substantially lower rates on nitrate leaching loss.

The effect of N rate varied between different fields. *Figures 4a & 4b* show data from sections of the same field. *Figure 4a* shows the effect of N rate on a winter cropping regime, and *Figure 4b* the effect on a spring cropping regime. Factors other than N rate were common in the experimental and conventional treatments.

In 2000/2001 there was little impact of N rate in either comparison. However, from winter 2001/2002 onwards,

nitrate concentration began to decline in one comparison (*a*) where a lower rate of N had been applied, but not the other (*b*). The amount of nitrogen fertiliser applied is therefore only one factor affecting nitrate-leaching loss. Other management and field factors that affect the release of leachable N from the organic matter in the soil, or from crop residues prior to winter, will also affect losses. Predicting the effect of nitrogen rate on leaching losses on

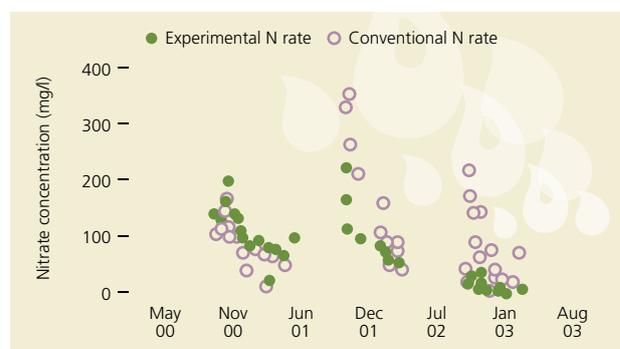


Figure 4a: Winter cropping – nitrate leaching with different N fertiliser rates

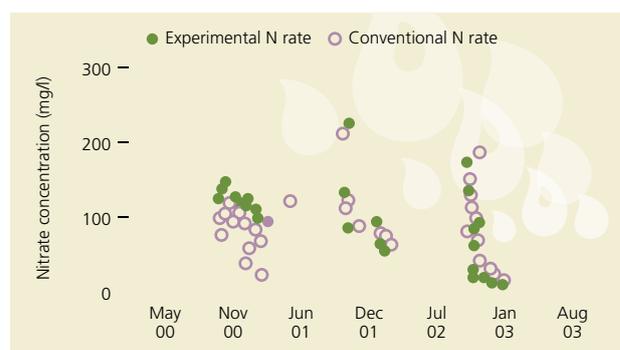


Figure 4b: Spring cropping – nitrate leaching with different N fertiliser rates

## PRINCIPAL RESEARCH TOPICS

a field-by-field basis can therefore be difficult. However, it is more important to view leaching losses on a catchment scale as environmental outcomes such as eutrophication, operate at this level. Autumn SMN data were therefore used to measure the 'leaching potential' in the catchment at Colworth. This is less precise than measuring actual leaching loss, but is a good indicator of leachable N in the soil at the start of winter and how much N is likely to be lost during winter drainage.

**Figure 5** plots the autumn SMN level for the conventional and low rate nitrogen halves of each field against each other. Although there is some scatter in the data, showing variation from field to field, there is still a strong relationship between the sets of data. Statistical analysis show that SMN levels were 11% lower where reduced rates of N had been applied. At low rates of N application the crop takes up most of the nitrate present in the soil together with that applied in nitrogen fertilisers. At higher application rates the efficiency of uptake declines and at rates substantially above the economic optimum, virtually all the excess nitrogen is left unused in the soil at the end of the season.

Another important factor in nitrate leaching is its relationship with soil organic matter (SOM). Although not measured in this project, a strong correlation has been found between SOM content and nitrate concentrations in drainage water, as shown in (**Figure 6**). This challenges the common understanding that high SOM levels are good per se, and this relationship should be taken into account when planning fertiliser strategies.

Reducing nitrogen fertiliser rates also lowers emissions of nitrous oxide (N<sub>2</sub>O), a powerful greenhouse gas. 50% of UK total emissions of N<sub>2</sub>O come from agricultural soils, of which around 77% comes directly from nitrogen fertiliser applications. Although N<sub>2</sub>O emissions were not measured in the project, it is safe to conclude that a reduction in nitrogen fertiliser rate would give a pro-rata reduction in N<sub>2</sub>O emissions.

It is important not to ignore the potential effects of dramatic N rate reductions on crop growth. Where N supply is restricted, crops that are vulnerable to poor

establishment and disease pressure for example, may be severely compromised. This may cause other environmental problems, such as the need for additional pesticide applications to limit weed competition. In the event of complete crop failure, any applied nitrogen fertiliser may be leached the following winter.

## Biodiversity

### Plants

There were slightly lower weed burdens in reduced nitrogen fertiliser plots, especially in 2003 when no problem weeds occurred, whereas fat hen and cleavers were apparent with conventional nitrogen fertiliser rates despite higher pesticide inputs (*see Box, page 10*). In other years, there were no differences between the two treatments. In the absence of herbicides, both plots became exceptionally weedy, and, although the density and diversity of weeds were initially greater in conventional nitrogen fertiliser plots, reduced nitrogen fertiliser plots eventually became more weedy as the rotation progressed.

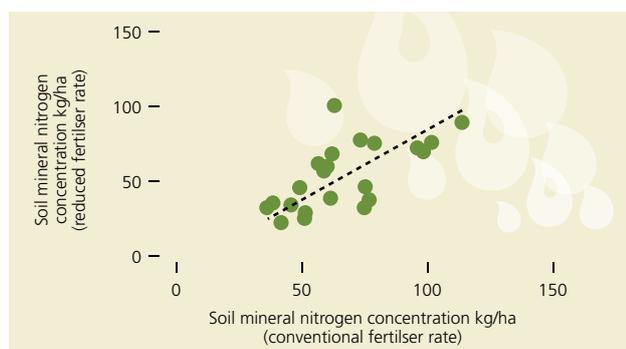
The most abundant weeds were the pernicious black grass and cleavers, populations of which had severely damaged crops after three years of the experiment. Populations of these weeds were suppressed by minimum tillage of the soil before drilling.

### Invertebrates

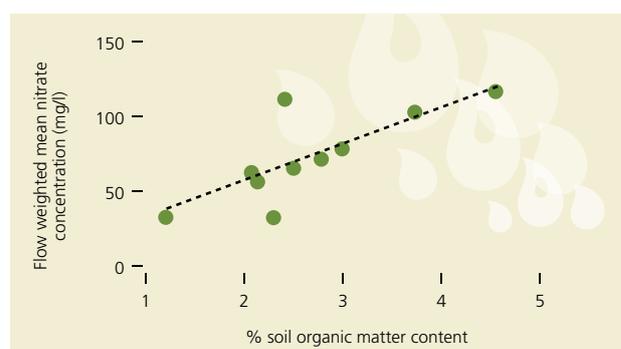
There were no clear responses of invertebrates to low fertiliser treatments, except where lower herbicides produced a greater diversity of weeds. Here, there were strong responses and larger invertebrate populations (*see Reduced pesticide applications, page 16*).

### Birds

There was no clear response to low nitrogen fertiliser rates although the combined effect of low nutrients and low herbicide inputs supported higher densities. This combined effect was probably a response to higher weed diversity rather than abundance.



**Figure 5: Effect of fertiliser rate on autumn soil mineral nitrogen concentration**



**Figure 6: Effect of soil organic matter content on nitrate concentration in drainage water**

### Soil Health

It is often intuitively expected that lower inputs increase the number and activity of key beneficial indicator soil invertebrates (such as earthworms). Counts of earthworm numbers, biomass and diversity showed that this is not necessarily so. Earthworm communities showed slight increases under the reduced input regimes (see Figure 7), but a major increase should only be expected after a period of years. No direct impacts of nitrogen fertiliser on earthworms were identified.

### Agronomy

Conventional farm practice at Colworth relies on an array of synthetic nutrient inputs to improve the quantity and often the quality of the final crop. As well as influencing crop development, these inputs inadvertently increase the competitive ability of certain weeds, and foliar diseases gain greater prevalence due to increased gross leaf area.

As the Colworth farm falls within a Nitrate Vulnerable Zone, timing and quantity of fertiliser use are subject to strict guidelines. The project reduced application rates of nitrogen beyond these guidelines. Samples were taken

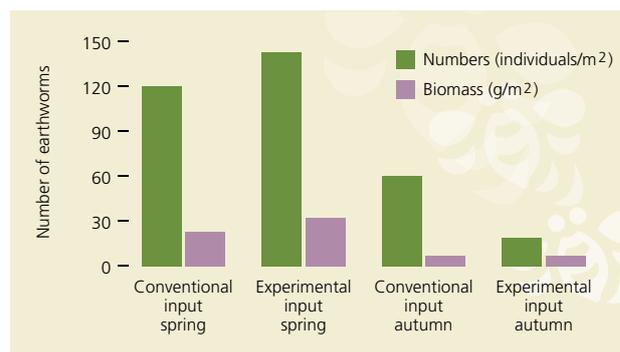


Figure 7: Effect of reduced input regimes on earthworm populations

from each field in both autumn and spring, to provide an accurate picture of available SMN. This allowed subsequent applications of nitrogen fertiliser to be adjusted to match crop needs. SMN monitoring provides another useful tool for managing nitrogen inputs, and is now used routinely on the Colworth farm.

## Mixed rotation and cover crops



Biodiversity  
Value chain  
Water

- Crop diversification helped to provide better habitats and food supplies for birds through impacts on structure, weeds and invertebrates. There has been a consistent 30% increase in bird numbers and breeding populations on the farm between 2000 and 2004.
- Winter cover crops can substantially reduce nitrate leaching losses.
- The inclusion of weedy fallows and broad-leaved crops in the rotation such as oilseed rape and peas has been particularly effective in increasing numbers of birds that are of conservation concern.
- Capital requirements and relationships with other crops in the rotation affect the choice of crops for a mixed rotation.

### Nitrate Leaching

The diffuse pollution of rivers and ground water by agriculture is a result of leaching losses accumulated over a wide geographical area or catchment. One of the factors influencing the scale of pollution is the mix of crops grown in it, as different crops are associated with different diffuse pollution risks. Although nitrate leaching from different

crops was not measured in the Colworth project, Figure 8, page 14 presents data from another Unilever project focusing on peas as part of a rotation that measured nitrate leaching loss from a range of crops at a number of farms over a 5-year period. The results show a substantial range, with three break crops (peas, potatoes and winter oilseed rape) linked to the highest losses. There are many

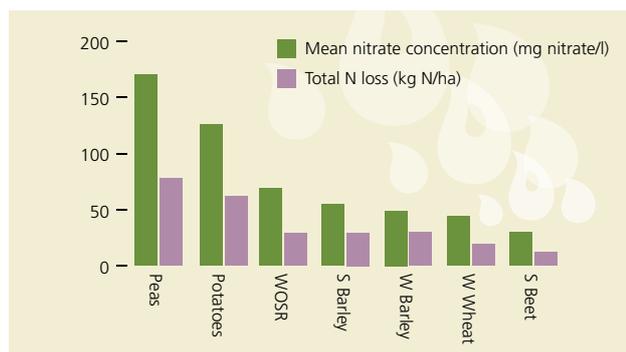


Figure 8: Nitrate leaching under different crops in a pea rotation

factors that give rise to these differences. In general higher leaching losses occur where substantial N in crop residue is returned (as with peas), where the land is cultivated early, and where crop residues are incorporated before winter.

The mixed rotation in the Colworth project may therefore have influenced nitrate leaching losses. Cover crops and cultivation timing are two techniques that can be used to reduce nitrate losses after some break crops. Further research on the Unilever pea project showed that delaying cultivation until just before the following wheat crop was sown, rather than ploughing straight after the pea harvest, reduced the amount of N leaching loss by 26%. When a cover crop was established after the pea harvest, there was a further 44% reduction in losses (70% in total) (Figure 9).

## Biodiversity

### Birds

The project demonstrated a strong and surprisingly rapid response by a wide range of bird species to changing management practices. In total, the population of a representative group of indicator bird species increased by 31%, and the population of species of high conservation concern increased by 45% in five years (Figure 10 and Appendix 2, page 28). For example, grey partridge increased from one to three pairs, skylarks on average from 10 to 20 pairs, yellow wagtails began to breed in the fourth year, by which time even lapwings had attempted to breed on the site when this species had not been seen as a breeding species for many years. Successes with all of these species pertain to improved conditions within the cropped environment. Over 50% of the foraging trips made by yellowhammers, a boundary species, were into crops, so a very significant proportion of their summer diet was obtained there.

Interestingly, approximately 70% of the total 5-year increase occurred within two years of the experiment starting, suggesting that some species are able to recover rapidly under appropriate circumstances. Seed-eating bird species, such as finches and buntings, were quicker to respond than insectivorous species, inferring that seed resources in winter

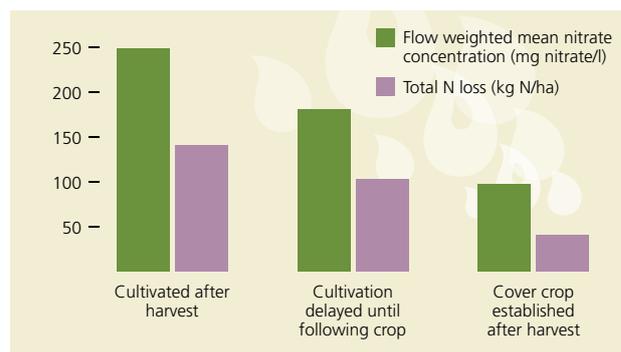


Figure 9: Effect of cover crops and timing of cultivation on nitrate leaching

became more quickly available than summer invertebrate resources that are used by virtually all bird species.

**Structural components of the landscape** (boundaries, crops and margins) were highly significant in determining bird densities and changes in bird populations (See Box, page 15). The sustained increase in bird population size at Colworth was a consequence of two components: large-scale habitat availability resulting from greater complexity in the crop mosaic, and changes to habitat quality due to herbicide restrictions on crops and fallows (discussed under **Reduced pesticide applications**, page 16). Greater crop complexity had three consequences:

**Habitat availability:** preferred crops, such as oilseed rape, weedy fallows and peas were especially important in providing food and breeding sites for birds, at up to five times (in rape) the density of winter wheat (Figure 11). Oilseed rape (whitethroat and buntings), weedy set-aside (skylark and seed-eating bird species) and to a lesser extent peas (skylarks and thrushes) provided complementary opportunities for birds to forage and/or breed.

**Landscape variability:** a mixed crop rotation provided options and opportunities for birds to forage and breed throughout the summer season (and in winter), due to the differential development of crop types.

**Coincidence of preferred conditions:** the mixed rotation meant that the coincidence of preferred field content and preferred field location occurred in at least two of the four experimental years – 2002 and 2004 (Figure 10). In between the peaks, sub-optimal combinations of crop type and crop location were still an improvement on blanket coverage by one crop, especially winter wheat (Figure 11).

Since high-quality habitats such as weedy set-aside rarely occupy more than 10% of the land area, and good margins 5% of the land area, including crops such as oilseed rape and peas in the rotation can double or triple potential habitat available to some species. For example, the complementary Unilever project mentioned above showed that pea crops could provide good breeding conditions for lapwings, in otherwise unsuitable cereal landscapes. Small changes in the quality of expansive landscapes potentially affect large numbers of birds, and as open monocultures

### KEY FACTORS AFFECTING BIRDS AT COLWORTH

Bird indicator species and species of high conservation concern increased by up to 31% and 45% respectively. This was against a neutral regional trend (Figure 10). The change was due to landscape improvements (crops), which provided birds with nesting and feeding options, and habitat quality improvements due to reduced herbicides and food-rich crops (rape, fallows and peas).

**Landscape improvements:** cereals were reduced from 81% to 47% coverage.

**'Crop' diversification:** monoculture fields support only a fraction of their potential biodiversity. Compared to winter wheat, oilseed rape, peas and weedy fallows (available to birds in 2002 and 2004; see Figure 11) were critical contributing factors for improving bird populations.

**Boundary structure:** most birds, except skylarks, preferred a more structured landscape. Abundance was related to hedge availability – peaking at around 100 meters of 'good' hedge per hectare of field. Hedges were mainly tall (2-3m) and thick (2-3m) with grass/flower margins as a buffer to crop management.

**Reduced herbicides** contributed to the increase in bird populations (See Figure 15, page 17). The contrast between weedy fallows sprayed in June, and cereal stubbles sprayed in April, was unequivocal (Figure 11).

**Key requirements** include a varied landscape, with food and access provided within and between crops.



The yellowhammer is one of the species benefiting from the sustainable practices at Colworth. Yellowhammers spend over 50% of forage time in crops.

only support a fraction of their potential biodiversity, important structural variation can be created by using crops to maintain a mosaic. The project has demonstrated that conventionally managed, viable crops can also be legitimate habitats for birds. This, together with high quality habitats, such as boundaries and field margins, will support stronger bird populations with minimal consequences for crop management. The principle of creating a mosaic of cropped and out-cropped areas can be applied to virtually any agricultural system where sufficient knowledge is available on the local ecology of flora and fauna.

### Soil health

It was difficult to distinguish between effects of separate treatments. However, some work suggests that increased above-ground diversity may increase soil invertebrate diversity.

### Agronomy

Traditionally a mixed rotation provided a 'break' in the cycle of various weeds, pests and diseases, which if left unchecked would seriously damage following crops. This remains an important factor in the adoption of mixed rotations.

Other factors which affect the adoption of a mixed rotation include the relationship with other crops in the rotation, such the transfer of diseases or pests between crops, or the timing of operations. In some cases, a late-harvested

crop can affect the establishment of following crops. Capital requirements also need to be considered according to whether potential crops fit with existing machinery, processing and storage facilities.

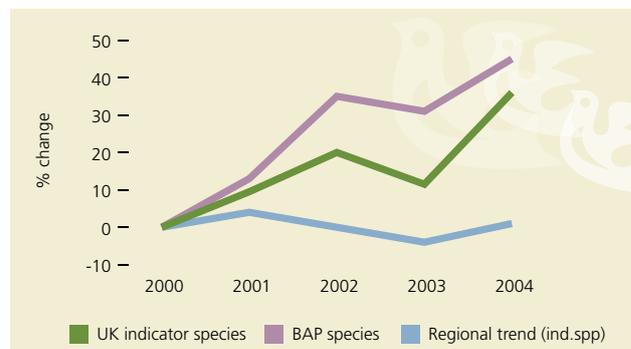


Figure 10: Trends in breeding pairs of bird species

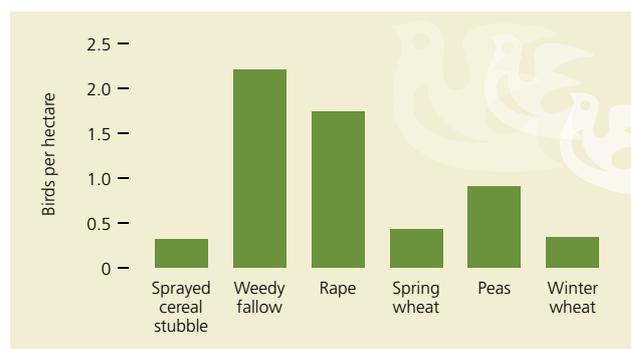


Figure 11: Bird densities by field 'content'

## Reduced pesticide applications



Pest management  
Biodiversity  
Water

- Band spraying has the potential to reduce pesticide leaching losses by more than the reduction in application rate – in the project pesticide concentrations in field drains were reduced by more than 50%.
- Reduced herbicides in crops and fallows had positive effects on bird abundance.
- Earthworm communities showed slight increases under reduced inputs, but reducing the use of pesticides was unlikely to increase soil invertebrate communities significantly.
- Reduced rates of herbicides encouraged a greater diversity of weeds in some crops, which correlated strongly with the presence of predatory invertebrates. Butterfly populations were also enhanced by weed diversity though not necessarily abundance.
- Consistently reduced herbicides created problems in subsequent crops. Crops that were swamped with pernicious weeds reduced accessibility to birds and lowered overall biodiversity. Weed control was found to be difficult without early applications of herbicide.

### Pesticide Leaching

Band spraying was used in one field to investigate whether this approach would reduce pesticide leaching. In spring 2004, herbicide was applied at the standard concentration in the conventional treatment using a conventional sprayer. On the same day herbicide was applied at the same concentration to a different section of the same field using a band sprayer in conjunction with mechanical weeding. This treatment received half the volume of herbicide per hectare applied in the conventional treatment plot. During the following 13-day period 50mm of rain were recorded at the site. Mean concentrations of herbicide in the soil water close to the field drains on 3 occasions during this period suggest that there were lower levels following band spraying (**Figure 12**). These data, although tentative at this stage, are encouraging as they suggest that although the

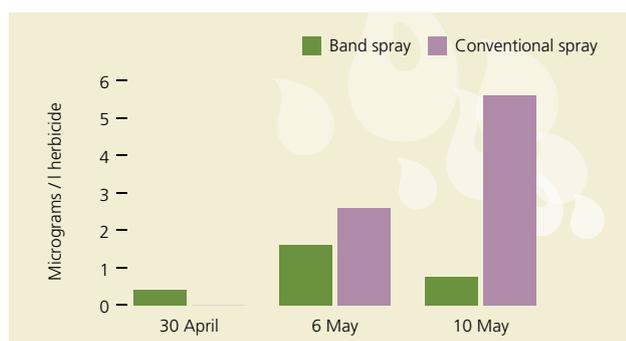


Figure 12: Effect of band spraying on pesticide leaching

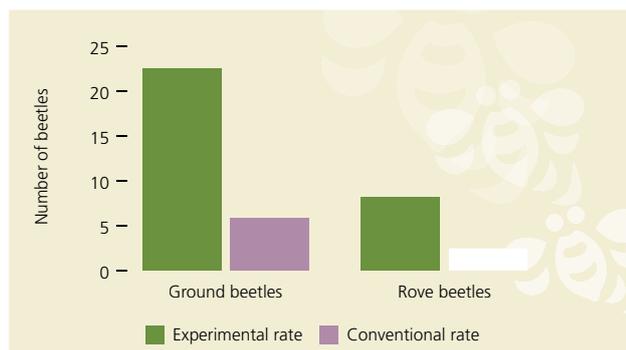
amount of active ingredient applied in the band spraying treatment was half that in the conventional section, the concentrations at drain depth were substantially less than half. This result suggests that targeting the spray on to the crop and weed leaf surfaces, but away from the soil, may provide additional benefits over and above the reduction of active ingredient used.

### Biodiversity

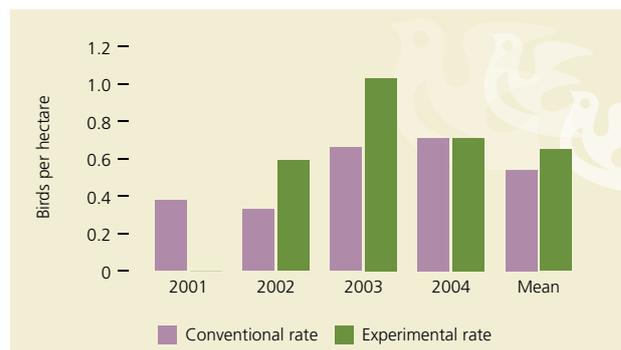
#### Plants and invertebrates

Weed build-up occurred in reduced pesticide plots. The use of mechanical weeding in 2002-03 had only a limited impact on weed populations, and would need to be carried out much more frequently to have a pronounced effect (crops were weeded once in autumn and once in early spring). There were large populations of low-impact weeds that are important as food to birds in all crops with reduced inputs, especially wheat. Small flowering weeds such as field speedwell, field forget-me-not and cut-leaved crane's-bill provided diversity and cover for invertebrates close to the ground in most crops.

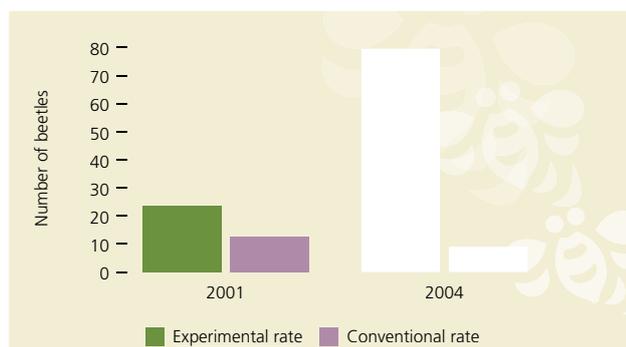
The majority of ground predatory invertebrates e.g. beetles were more abundant in wheat plots with reduced herbicides (**Figure 13**). Consistent reductions of pesticides over the course of the rotation produced greater densities of invertebrates further into the crop (**Figure 14**). It is possible that the winter ground cover afforded by these



**Figure 13: The overall densities of beetles in fields under varying pesticide regimes**



**Figure 15: Bird densities in crops under varying pesticide regimes**



**Figure 14: Density of ground beetles 25m into the crop under varying pesticide regimes**



**Figure 16: Effect of high weed densities in 2003 on skylark population**

crops was attractive. An interesting observation was that small increases in invertebrate diversity led to much larger increases in the overall abundance of invertebrate predators in the crop. More importantly, the density and abundance of these predators was strongly correlated with the weed diversity in the crop, not weed abundance (See Box, page 18). Butterflies showed similar responses, with greater diversity in fields with more diverse weed populations – butterflies such as common blues, skippers and marbled whites started using weeds in crops to feed. This suggests that it is the presence of the additional low-impact weeds in the crop, not the abundance of pernicious weeds, that promotes predatory invertebrates – fields choked with black grass and cleavers appeared not to promote invertebrate activity. Developing means of maintaining small populations of low-impact weeds in crops may promote large populations of beneficial arthropods, enhancing both the natural control of crop pests, biodiversity, and the availability of invertebrate prey for birds.

### Birds

There was strong evidence that reduced herbicides were significant in sustaining bird populations at a higher equilibrium than would have occurred due to habitat availability alone (Figure 15). The gradual response to low herbicides shown by birds in crops, was rapid and unequivocal in fallows (Figure 11, page 15). Conventional early (April) weed-control in cereal stubbles consistently led to the lowest densities of birds of any field type, including

winter cereals, in contrast to fallows where weeds persisted until at least early June. Overall densities of bird species such as skylarks, whitethroat, linnet and yellowhammer, were higher in low pesticide plots. This relationship was especially significant for skylark and linnet, whose abundance was related to invertebrate and weed populations respectively. Generally there were consistent associations between birds in crops and certain low-impact weed species, especially geranium and speedwell, fat hen, groundsel, *sinapis* and *myosotis* species. In contrast, an abundance of pernicious weeds in some crops was detrimental to birds, as well as to overall levels of biodiversity. For skylarks, dense patches of black grass and wild oats shortened the breeding season in 2003 compared to earlier years (Figure 16). The dense mat of weeds prevented access to the ground, and this prevented skylarks from producing vital late summer broods.

### Soil health

Soil health is notoriously difficult to define and therefore measure. To estimate the effect on total soil invertebrate activity, a novel approach to estimating soil health was pioneered at Colworth – the Bait Lamina assay (see Box, page 19). The Bait Lamina assay indicated that reducing inputs of the agrochemicals deployed on the farm was unlikely to significantly increase soil invertebrate communities. Other studies have concluded that switching from 'conventional' to 'organic' regimes alone does not increase earthworm density.

### Agronomy

The project showed that reducing herbicides cut variable costs by approximately 50% (equivalent to around £125/€180 per ha), but caused yield losses of around 65% (equivalent to around £420/€610 per/ha gross margin). The cost/benefit differential would therefore only be viable in a depressed market where the cost of yield losses was relatively low. In addition, pernicious weeds accumulated causing significant yield reductions in subsequent crops.

Data on accumulated impacts of low herbicide rates over four years was very instructive, as both crops and biodiversity were adversely affected.

Generating a high diversity of low-impact weeds in crops is expensive since it requires the use of selective products. However, intermediate levels of pesticide use were not tested and may provide opportunities. Benefits may also come from outcropped areas or the physical manipulation of crops to create structural variation (not investigated within the project) or from mixed cropping (see above). Since pressure to protect water resources from diffuse pollution sources may reduce the availability of chemical crop protection products in the future, crops should be managed using all the 'tools' at the farmer's disposal.

### FACTORS AFFECTING PREDATORY INVERTEBRATES IN CROPS AT COLWORTH

Three groups of ground invertebrates were studied in the crops at Colworth: spiders, ground beetles (carabids) and rove beetles (staphylinids). Pitfall samples were taken in May and July to account for the seasonality of species, and in the same location as weed quadrants so data could be related. Colworth Farm supports a diverse and relatively strong invertebrate population and by 2004, 99 species of spiders, 60 species of ground beetles and 80 species of rove beetles had been recorded. Changes in fertiliser and cultivation had little impact on populations. There were some indications that winter crops support greater numbers of invertebrates, but only where these had some weed cover – clean winter crops were poor habitats. The greatest influences on the diversity and abundance of these groups and on individual species were pesticide inputs and the presence of weeds.

#### Pesticides

The densities of all three groups were clearly elevated in parts of fields where pesticide inputs were lowered. Some species were virtually absent in crops with conventional pesticide applications. Butterflies too (mainly white butterflies, meadow browns and gatekeepers) were more abundant in crops with reduced pesticides.

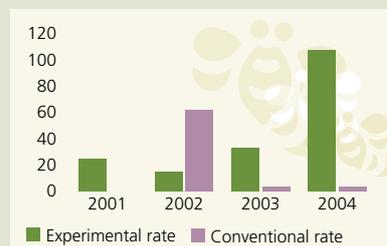
#### Weed diversity and abundance

There were strong overall relationships between the numbers of all groups of invertebrates (including butterflies) with the diversity of weeds in fields but not always with their abundance. Very dense weed burdens were not beneficial. Spiders (especially those building aerial webs) responded most to the presence of grasses. The presence of chickweed and other small weeds such as speedwells and cranesbills provided ground cover for ground-hunting spiders and beetles and were often correlated strongly with abundance and diversity of these groups.

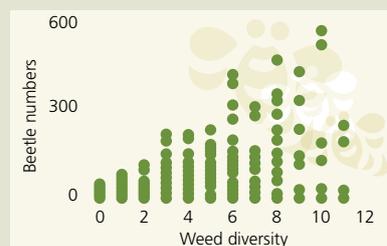
Practices that produce small increases in the diversity of weeds in crops are likely to have large impacts on the presence of predatory invertebrates. In this project, small boosts in the diversity of invertebrates produced large increases in the numbers of predators in the crop – this is likely to have pronounced impacts on the pest management of crops.



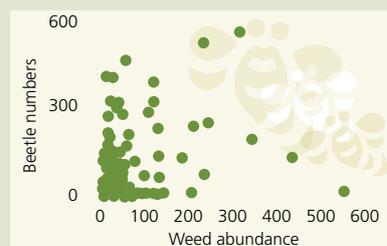
Effect of pesticide rate on rove beetles



Effect of pesticide rate on ground beetles



Effect of weed diversity on beetle numbers



Effect of weed abundance on beetle numbers

## MEASURING SOIL HEALTH THE EASY WAY USING THE BAIT LAMINA ASSAY

Soil health can be measured in many ways; using productivity, composition or biological indicators (such as numbers of earthworms). A recent approach has been to measure the rate at which food ('bait') attractive to the majority of soil invertebrates is removed from containers placed in the soil. The bait lamina assay has been purpose-designed for such studies. The bait consists of a mix of powdered wheat bran, cellulose and carbon powder, which is pasted into holes drilled in simple plastic strips (16cm x 0.5cm). Each bait stick allows 16 spots of bait to be inserted vertically into the soil. After a period (typically two weeks), the strips are removed and the amount of bait spots removed is counted. Removal equates to feeding activity of soil organisms, which can be directly related to biological activity, and therefore soil health status. As the strips are pushed vertically into the soil, it is also possible to examine biological activity down the soil profile.

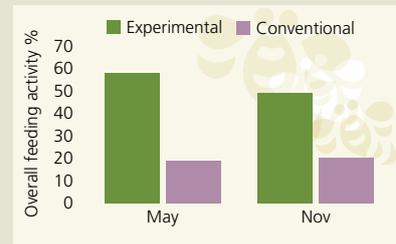
At the farm, strips were placed together (each 2 centimetres apart)

in a group of twelve to make one sample point. This allows for variation at the small scale in biological activity to be taken into account. In four of the fields, ten sample points were established on each half of the field to measure biological health under each regime. This was carried out in different seasons.

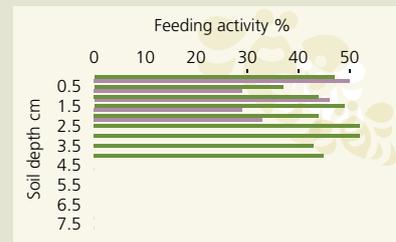
Findings for soil biological activity:

- Soil health can be reduced when mechanical weeding is used to replace herbicides.
- Biological activity is highest in early autumn, but extreme temperatures or rainfall disrupts this.
- The crop grown is less important (in the short term), than soil characteristics for soil health.
- Bait Lamina is a quick and cheap screening assay of soil health and needs no specialised skills to allow comparative assessments.

In the example results (above *right*), green bars are results from experimental input regimes, and purple bars are conventional regimes.



Feeding activity under the two regimes in two seasons



Feeding activity by soil depth



A typical sample point (above). The empty holes in the bait strips (left) indicate significant biological activity. Where they remain full there has been no feeding by soil organisms.



# Mechanical weeding



Soil fertility/health  
Nutrients  
Pest management

- Mechanical weeding had little impact on pernicious weed populations, especially in high nutrient scenarios.
- Mechanical weeding worked well in low fertility situations, and improved the mineralisation of nitrogen in the soil.
- Communities of soil invertebrates may be negatively affected.

Mechanical weeding was examined as an alternative to reliance on herbicides. Technology developed by the Silsoe Research Institute allowed accurate positioning of tines between rows, used software to improve operator accuracy, and allowed a band sprayer to be attached. Different tines could be attached for different functions in the crop.

## Biodiversity

Mechanical weeding requires relatively more passes per field than chemical spraying. Depending on the time of year, this could pose additional risk to ground nesting birds.

The potential impact on birds was not measured at Colworth. The window for effective weed control - early autumn/early spring - would usually be outside the critical phase of nesting May to July. Equally, this has to be balanced with the known direct impacts of pesticides on birds, such as food scarcity as a consequence of highly efficient herbicides and insecticides and the topical contact with spray solutions. For minimal impact weeding would ideally be completed by the end of April.

## Soil health

Mechanical weeding may also affect soil invertebrates. Earthworms, as the largest soil-dwelling invertebrates are most likely to be affected by direct physical damage. Disruption of moisture and feeding regimes are also possible. The only time at which minimal impact on earthworms is possible is during winter or high summer (i.e. when soils are below 4°C or very dry). Most species will be adversely affected by soil disruption at any time.

## Agronomy

The tool worked well in lower fertility situations and improved the mineralisation of nitrogen in the soil where a double pass over the crop had occurred. However, the process was more time consuming than spraying, particularly on Colworth's heavy soils, and required more passes per field and in the long-term problem weeds proved difficult to control mechanically in high nitrogen scenarios. Timing is also important, as hot dry weather is best to desiccate disturbed weeds.

# Field margin management



Biodiversity  
Pest management

- Field margins are relatively easy to establish and when managed properly can enhance biodiversity and maintain farm profitability.
- Good field margin management can increase the frequency of effective natural aphid control, allowing a potential reduction in pesticide use.
- Annual costs of field margins range between £15/ha (€20/ha) to £80/ha (€115/ha), depending on the type of margin, the establishment and management costs, and the expected 'life' of the margin.

Field margins – uncultivated areas around the edge of a field – provide a valuable wildlife habitat when sown with an appropriate mixture of grasses, legumes and/or wildflowers. They can be created quickly and produce a rapid rise in biodiversity. Field margins can also boost natural pest control by attracting beneficial insects that eat pests.

Field margins have always been a practical management option for adding biodiversity value to the farming landscape. However, their composition and management is highly variable, and the Colworth project has aimed to optimise field margin management, in partnership with the two complementary projects described below.

In addition, the project has gained three years of valuable experience on the establishment and maintenance of field margins, and associated costs. A comparison of the annual costs for four different types of margins – all of which were tested – is shown below:

## Field margin cost comparison

Type of margin	'Lifespan' of margin (years)	Annual cost in £/ha/yr €/ha/yr
Grass and wildflower mix	10	£70 €100
Pollen and nectar mix	5	£80 €115
Tussocky grass	10	£15 €20
Natural vegetation	1	£25 €35

## The BUZZ Project

In response to the loss of biodiversity from agricultural landscapes over the last 50 years, governments have introduced a number of agri-environment schemes. These schemes have the potential to increase dramatically the provision of habitats for farmland wildlife over a large scale. However, it is essential that the habitats created are both of high quality for biodiversity and practical for farmers to establish and manage – this has been the focus of the BUZZ project.

The project compared six margin options at six different sites (including Colworth). Margins were monitored for populations of bumblebees, butterflies, ground and canopy-dwelling invertebrates. In the final year of the project small mammals, birds and soil invertebrates were also included:

- Crop (control): conventional arable crop management
- Conservation headland: arable crop management with restricted herbicide and insecticide application
- Natural regeneration: uncropped margin with annual autumn cultivation and no inputs
- Tussocky grass: uncropped margin sown with five grass species
- Wildflower: uncropped margin sown with 21 species of native wildflower and four species of fine grass
- Pollen and nectar: uncropped margin sown with four species of agricultural legume and four species of fine grass.

In addition, a plot of 0.3ha in the centre of each field was sown annually with a 'wild bird seed mixture' of four seed-bearing cover crops to provide food and cover for farmland birds throughout the winter.

## PRINCIPAL RESEARCH TOPICS

Over the course of the project (2001-04) results showed that:

- Habitats of high biodiversity value can be recreated on arable land using existing farming skills, provided a simple set of management prescriptions is followed.
- Abundance and diversity of invertebrate and vertebrate groups increased dramatically, even in the first year of the project (see Figure 17). This was maintained over the course of the project.
- No single treatment or habitat type was preferred by all the groups studied, suggesting that a diversity of high quality habitats is important for conserving farmland wildlife.
- The new UK Environmental Stewardship Schemes offer this diversity of habitat types, but their success is likely to depend on the uptake and management of the various options.

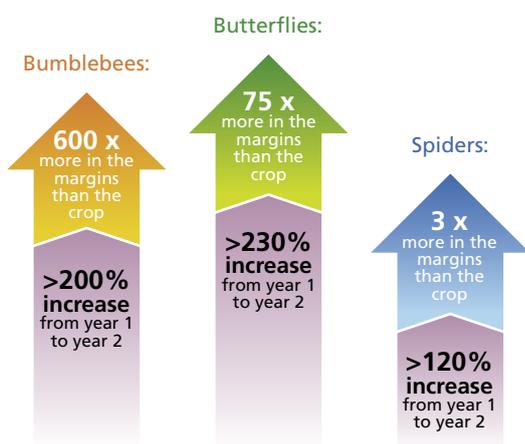


Figure 17: Increase in abundance of invertebrates from Year 1 to Year 2 of the BUZZ project

### 3D Farming Project

The project aimed to use flower margin management to increase the abundance and diversity of beneficial insects and spiders for aphid control in wheat crops. Flower margins were 4m wide, containing diverse perennial wildflowers to attract the maximum number of aphid predators, such as hoverflies. Pheromones were placed in the field margin to attract aphid predators such as parasitoid wasps. Monitoring of pests and predator species was undertaken each summer, using water and pitfall traps within the field margins and up to 100m into the crop.

Over the four site included in the project, results showed that:

- Field margins containing wildflower/grass mixtures reduced aphid densities in adjacent cereal crops in two (2001 & 2002) out of three years. The first year of trialling, 2000, did not give effective control, as the

margin was not fully established. In 2001, when aphid numbers were high, the aphid densities in the field with the flower margin were 25% lower than the control.

- Pheromone deployment was only tried in 2001 and 2002. 2001 was too wet and parasitoid populations developed too late to affect the cereal crop. Pheromone treatment reduced numbers of aphids at peak infestation in the 2002 cereal crop, by 50% compared to the control (see Figure 18). The experiment proved that by deploying pheromones in the autumn, predator populations could be synchronised with pest populations the following spring, resulting in effective natural control.
- Umbellifer-like flowers, such as cow parsley, hogweed and yarrow provided the best food resources for adult hoverflies. These flowers are common in most field margins, meaning the planting of expensive wild flower margins is not necessarily the only solution.
- Cornflowers, rough hawkbit and field scabious were the next best preference, selected 60% of the time by hoverflies for feeding. These flowers are less common in field margins, but were found to establish easily at Colworth. For the first time, flower margins were proven to reduce pest populations. ■

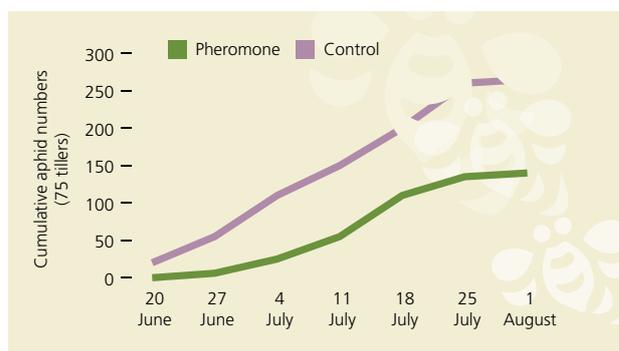


Figure 18: Effect of aphid sex pheromone on cereal aphid populations in a commercial winter wheat field

## HOW THE DIFFERENT SCENARIOS COMPARED ECONOMICALLY

Scenario	2002	2003	2004	Average
Conventional	£540	£685	£605	£610
	€785	€995	€880	€890
Reduced pesticides	£515	£380	–	£445
	€750	€555		€650
Reduced nitrogen fertiliser	–	£605	£340	£475
		€880	€495	€690
Spring vs. Winter cropping	–	£635	£535	£585
		€930	€785	€860
Reduced pesticides and fertiliser	£575	£335	£565	£490
	€835	€495	€815	€710

The above table shows the range of gross margin attained over three years of the project for different scenarios in winter wheat.

#### Spring vs. winter cropping

The relatively high gross margin achieved with spring cropping was maintained by selling spring wheat into milling markets, often receiving a £20€30/t premium, and through the reduced input costs of spring wheat compared to winter wheat (£170€250/ha compared with £230€335/ha).

#### Reduced pesticides

Pesticides usually account for 50% of variable costs in winter wheat production (£115€170/ha), and can be higher on farms such as Colworth where grassweed pressure is high. The removal of pesticides from the system therefore reduced variable costs substantially. However, subsequent weed build-up dramatically reduced crop yield and quality, and hence gross margin.

Example 1; 2003 winter wheat was sold at £75€110/tonne from both the *conventional* block and the

*reduced pesticides* block. The blocks yielded 9.8t/ha and 4.2t/ha, giving gross margins of £730€1065/ha and £310€455/ha, respectively.

#### Reduced nitrogen fertiliser

Fertiliser costs usually account for only 30% of the total variable costs, so their removal or reduction therefore results in smaller variable cost savings than for pesticides. Whilst crop yields were reduced and difficulties experienced in reaching quality parameters for spring milling wheat crops, the overall effect on output was not as great as for pesticide reduction, as reflected in the gross margin figures.

Gross margin for winter wheat varied widely in 2003 and 2004, mainly because of significant yield variation. In 2003, reducing fertiliser reduced yield from 9.8t/ha (£735€1065/ha) to 7.5t/ha (£565€820/ha), a 23% reduction in both yield and gross margin, whereas in 2004 lower fertiliser reduced yields from 8.2t/ha (£530€770/ha) to 4.9t/ha (£370€540/ha), a 40% reduction in physical yield and 29% reduction in gross margin.

#### Reduced pesticides and nitrogen fertiliser (combined treatment)

In general, lowering fertiliser inputs reduced yields, but it also reduced the abundance of pernicious weeds, meaning less competition for the crop and less reliance on pesticide (particularly herbicide) inputs. Yields were therefore higher than when pesticides alone were reduced. Meanwhile, greater variable cost savings were made than in the reduced nitrogen fertiliser scenario, and overall gross margin was higher than for each of the input reductions alone.

It was also observed that when the winter wheat commodity price was low, the combined lower input regime provided a more favourable GM than the conventional crop. In 2002 for example, conventional plots yielded 8.8t/ha (GM £570€825/ha), whereas combined treatment plots yielded 6.3t/ha (GM of £575€835/ha) selling into the same market. This is worthy of note, especially as the low-input crop did not attract premium prices in this case.

# CONCLUSIONS

By adopting bold changes in conventional farming practice, the Colworth Farm Project pushed the boundaries and tested some radical approaches. Our research has identified impractical as well as practical elements of farm management.



**Trials of Controlled Traffic farming for improved soil health where the front and back wheels of the tractor run over the same tram lines over a four year period (left); visiting farmers and scientists discussing research progress at Colworth (bottom left); measuring nitrate leaching losses (below) helps optimise fertiliser management and prevent water pollution.**



The results of the Colworth project suggest that critical components of successful sustainable farming projects include management to create a more diverse landscape, and close attention to the timing and frequency of chemical pest control. Both factors were significant in supporting higher levels of biodiversity on the farm, the former with low impact on crop yields.

Landscape diversification is a pragmatic option for delivering more sustainable practices on farms, allowing the incorporation of conventionally managed crops to increase the availability of habitats for wildlife, without affecting crop yields. Market conditions and future legislation for the control of diffuse water pollution may constrain farmer flexibility in designing mixed rotations. However, the deregulation of crop subsidies and the move towards single farm payments with stronger environmental requirements, may remove some of these constraints. Future research

should focus on the optimal arrangements of mixed rotations in winter and summer, to achieve water pollution control and higher levels of biodiversity under different environmental circumstances. Winter cover crops are a particular area of promise that deserves greater attention.

Pest control was difficult to manipulate in a way that would allow 'acceptable' populations of weeds or invertebrates to thrive without damaging crops. Intermediate levels of pest control were not tested, however, and this area should attract serious further investigation. Future development of more selective herbicides may also help. For example, if pernicious weeds could be selectively removed, the outcomes for biodiversity would be positive. Generic rules for chemical pest control across changing conditions of climate and soil may be difficult, but under specific circumstances substantially reduced levels of chemical pest control could be achieved when integrated within a mixed rotation.

The project also highlighted the practical difficulties associated with growing profitable crops whilst achieving the 50mg/l nitrate limit set out in EU legislation. Reducing nitrate fertiliser alone has not achieved this goal and in some circumstances has jeopardised crop growth to the point of commercial failure. Using other approaches in combination offers the potential for substantially reduced nitrate losses, and future studies would ideally test various combinations to optimise control. These should include use of cover crops, cultivation timing, careful control of nitrogen fertiliser, and possible changes to crop rotation. There were encouraging indications that pesticide leaching losses can be substantially reduced by the use of band spraying in combination with mechanical weeding. Although there remain practical issues to resolve with the use of this system on heavy clay soils, this practice remains a valuable tool worthy of further research.

Clearly there are practical and economic issues to consider when changing any management practices. The effects of experimental scenarios on crop yields varied widely, but at their worst led to 60% reductions. At other times yields were only slightly reduced and gross margins were actually higher for experimental plots. Reducing pesticides had the greatest effect on yield, especially in winter-sown crops. Reducing nitrogen inputs had less of an effect, but despite reduced input costs, gross margins were still adversely affected. It should be noted that comparing gross margins assumes similar fixed costs across the same farming system, whereas our project scenarios effectively represent different farming systems. Gross margin data, whilst offering an empirical indication of major differences in financial viability of the imposed treatments, should not be relied upon as the sole measure (*See Box, page 5*). A more detailed financial analysis would take into account either fixed costs (e.g. labour/machinery) or 'externality' costs (e.g. nitrate leaching). The cost-benefit differential for sustainable practices depends not only on market, legislative and practical factors, but also on capital and capability investment. These issues need to be considered carefully alongside technical/feasibility factors.

The Colworth farm project has achieved and exceeded its original aims. It has proven the potential for clear benefit, and highlighted practices that need more work before they can be implemented. It has accentuated the need to consider the whole farming system when looking at sustainability measures, and shown us links between different parts of that system. It has provided Unilever with some helpful management techniques that can be introduced into its supply chains, and others that can be developed further. The multi-disciplinary project team and the tangible results the project has produced have led to mutual learning and understanding as well as generating considerable interest in the wider community.

The project has also provided a platform for further sustainability research. Examples include:

- Controlled Traffic Farming, where trials are underway for improving soil health. The approach has generated much interest in the international farming community, and the Colworth farm is pioneering the use of the technology in Europe.
- Other parts of the experimental programme have been adopted and continued by other organisations – nitrate monitoring, for example, has led to a government-funded initiative to measure nitrate losses at catchment level to support the Nitrates Directive monitoring requirements.
- Bird data from Colworth will also contribute to the government debate on how best to achieve its target for national bird population recovery on farmland by 2020.

We intend that the Colworth farm will continue to explore boundaries, and drive the continuous development of innovative sustainable farming practices. The farm team aims to build on the high levels of interest both within and outside the farming community, and continues to introduce both the concept and practice of sustainability to an ever-growing number of stakeholders. ■

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## The ten sustainable agriculture indicators

Parameters in **bold** are examples of measurements in the Colworth project



### 1. Soil fertility/health

Soil is fundamental to agricultural systems, and a rich soil ecosystem contributes to crop and livestock performance. Sustainable practices can improve beneficial components of the soil's ecosystem.

Parameters: **Number of beneficial organisms (e.g. earthworms per square metre)**; number of predatory mites; number of beneficial micro-organisms; soil organic matter (measure of healthy soil structure).



### 2. Soil loss

Soil eroded by water and wind can lose both structure and organic matter, diminishing the assets of an agricultural system. Sustainable practices can reduce soil erosion.

Parameters: Soil cover index (proportion of time soil is covered with crop; protects against leaching and erosion, promotes water binding); soil erosion (loss of top soil in percentage per annum or in t/ha/annum).



### 3. Nutrients

Crops and livestock need a balance of nutrients. Some of these can be created locally (e.g. nitrogen), and some must be imported. Nutrients are lost through cropping, erosion and emissions to the air. Sustainable practices can enhance locally produced nutrients and reduce losses.

Parameters: **Amount of inorganic Nitrogen (N)/ Phosphates (P)/ Potassium (K) applied (per ha or per tonne of product)**; proportion of N fixed on site/imported; **balance of N/P/K over crop rotations**; emissions of N-compounds to air.



### 4. Pest management

When pesticides are applied to crops or livestock, a small but significant proportion can escape to water and air, or accumulate in foods, thus affecting human health and ecosystems. Sustainable agriculture practices can substitute natural controls for some pesticides, so reducing dependence on externally introduced substances. The ultimate aim is to develop Integrated Pest Management strategies for all crops.

Parameters: Level achieved of bringing crop under IPM (checklist approach); **amount of pesticides (active ingredient) applied (per ha or per ton of product)**; **type applied (profiling, positive list, weighting factor)**.



### 5. Biodiversity

Agriculture has shaped most ecosystems in the world, and biodiversity can be improved or reduced by agricultural practices. Some biodiversity is highly beneficial for agriculture. Sustainable practices can improve biodiversity - by 'greening the middle' of fields as well as 'greening the edge'.

Parameters: **Level of biodiversity on site: number of species (e.g. birds, butterflies); farm landscape; habitat for natural predator systems (e.g. hedgerows, ponds, non-cropped areas)**; level of biodiversity off-site: cross-boundary effects.



### 6. Value chain

Value chain is the term for the sum total of all value adding activities which lead to putting a product on the market. For food products, farm economics is an integral part of the value chain. Farmers should develop a firm grasp of what influences the economics of their farm and what non-economic value they produce. Sustainable practices should be able to maintain or improve farm economics and add to nature values and eco-system service values.

Parameters: **Total value of produce per ha**; farm income trends; conformance to quality specifications – nutritional value, including minerals, pesticide residues, foreign bodies, etc; ratio of solid waste re-used/recycled over solid waste disposed to landfill; marginal costs for various crops and various fields/plots; financial risk management and solvency; nature value and eco-system service value created.



### 7. Energy

Although the energy of sunlight is a fundamental input to agriculture, the energy balance of agricultural systems depends on the additional energy supplied from non-renewable sources to power machinery. Sustainable practices can improve the energy balance and ensure that it remains positive - there is more energy coming out than going in.

Parameters: Balance: total energy input/total energy output, including transport where relevant; ratio renewable over non-renewable energy inputs; emissions to air (greenhouse and pollutant gases).



### 8. Water

Some agricultural systems make use of water for irrigation, some pollute or contaminate ground or surface water with pesticides, nutrients or soil. Sustainable practices can make targeted use of inputs, and reduce losses.

Parameters: Amount of water used per ha or tonne of product for irrigation; **leaching and runoff of pesticides to surface and ground water; leaching and runoff of N/P/K (nutrients) to surface and ground water.**



### 9. Social/human capital

The challenge of using natural resources sustainably is fundamentally a social one. It requires collective action, the sharing of new knowledge and continuous innovation. Sustainable agriculture practices can improve both social and human capital in order to ensure normal outputs. The prime responsibility for this should remain with the local community, leading to realistic and actionable targets.

Parameters: **Group dynamics/organisational density (farmer groups);** (rural) community awareness of relevance and benefits of sustainable practices/**connectivity to society at large;** rate of innovation.



### 10. Local economy

Agricultural inputs (goods, labour, services) can be sourced from many places, but when they come from the local economy, the expenditure helps to sustain local businesses and livelihoods. Sustainable agriculture practices can help to make the best use of local and available resources in order to increase efficiency.

Parameters: Amount of money/profit reinvested locally; percentage of goods/labour/services sourced locally; employment level in local community.

## Added 2005



### 11. Animal welfare

Animal husbandry systems are becoming ever more specialised and therefore further removed from the natural habitat the (farm) animal came from. Treatment of animals in these artificial environments is a major ethical concern. Care must be taken that the animals can live in harmony with their environment.

Parameters: Feeding; housing; treatment of diseases; watering; freedom from abuse.

## Change in the breeding abundance of bird species at Colworth



Skylark (far left), yellow wagtail (centre) and lapwing (left) are three species that show signs of benefiting from the experimental practices at Colworth.

Species name	Change at Colworth		Species status			
	Increase + or decrease -	Comment	UK farmland bird index	Biodiversity Action Plan	Insectivorous Group	Seed-eating group
Kestrel	=		Yes			
Lapwing	+	Breeding attempt	Yes	Yes		
Grey partridge	++	300%	Yes	Yes		
Turtle dove	=		Yes	Yes		
Stock dove	=		Yes			
Woodpigeon	=		Yes			
Skylark	+	15%	Yes	Yes		
Yellow wagtail	+	Now breeding	Yes	Yes	Yes	
Whitethroat	=/+	Small +	Yes		Yes	
Dunnock	=/+	Small +			Yes	
Blackbird	+	10%			Yes	
Song thrush	=					
Jackdaw	+	Small +	Yes			
Rook	(+)	Winter only	Yes			
Starling	= / -		Yes	Yes		
Tree sparrow	+	Now breeding (++) in winter)	Yes	Yes		Yes
Goldfinch	=		Yes			Yes
Linnet	+	21%	Yes	Yes		Yes
Greenfinch	=	15%	Yes			Yes
Reed bunting	+	31%	Yes	Yes		Yes
Yellowhammer	+	20%	Yes	Yes		Yes
Raptors and crow	=/+	Small increase				

Further reading

Unilever sustainability initiatives



**Growing for the future II**

Unilever and sustainable agriculture (2002)



**Growing for the future III**

Unilever and sustainable agriculture (available 2006)

Unilever Sustainable Agriculture Initiatives (SAIs)



**Tea – a popular beverage**

Journey to a sustainable future (2002)



**Palm oil**

A sustainable future (2001)



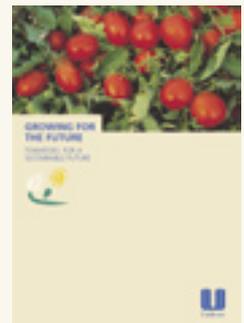
**In pursuit of the sustainable pea**

Forum for the Future in collaboration with Birds Eye (2002)



**Growing for the future**

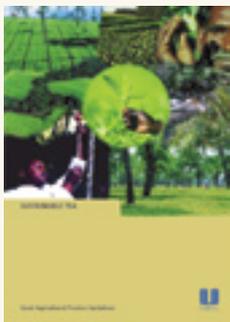
Spinach: for a sustainable future (2003)



**Growing for the future**

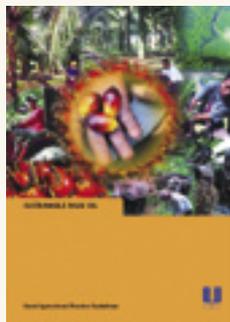
Tomatoes: for a sustainable future (2003)

Good agricultural practice guidelines



**Sustainable tea**

Good agricultural practice guidelines (2002)



**Sustainable palm oil**

Good agricultural practice guidelines (2003)



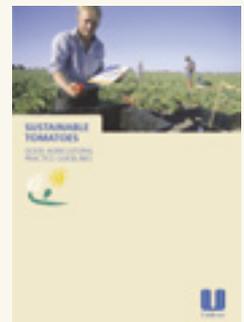
**Sustainable vining peas**

Good agricultural practice guidelines (2003)



**Sustainable spinach**

Good agricultural practice guidelines (2003)



**Sustainable tomatoes**

Good agricultural practice guidelines (2003)



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