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CONSERVATION AGRICULTURE IN EUROPE

An approach to sustainable crop production by protecting soil and water?

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FUNDING ORGANISATIONS

PARTNERS

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FOREWORD

"Man - despite his artistic pretensions, his sophistication, and his many accomplishments - owes his existence to a 15 cm layer of topsoil and the fact that it rains" Anon

Soil and water: feeding the human population depends on these natural resources, and on the skills and technology of farmers around the world. While food production has kept pace with population growth over recent decades, it has also been partly responsible for the deterioration of the world's natural capital on which future generations will depend.

The Millennium Ecosystem Assessment (http://www.millenniumassessment.org) highlights that we are "living beyond our means". So, what can we do about it? The Assessment proposes that better protection of natural resources like soil and water "will require co-ordinated efforts across all sections of governments, businesses and international institutions".

This book represents our "co-ordinated effort". By reviewing experiences of Conservation Agriculture approaches to crop production, our aim is to present a balanced view of its advantages and limitations, primarily for those concerned with advising on and formulating European policies on environmental protection and agricultural support mechanisms.

Soil and water are the basis for productive cropping systems and thriving, diverse ecosystems. They are key to "maintaining the conditions for a decent, healthy and secure life".

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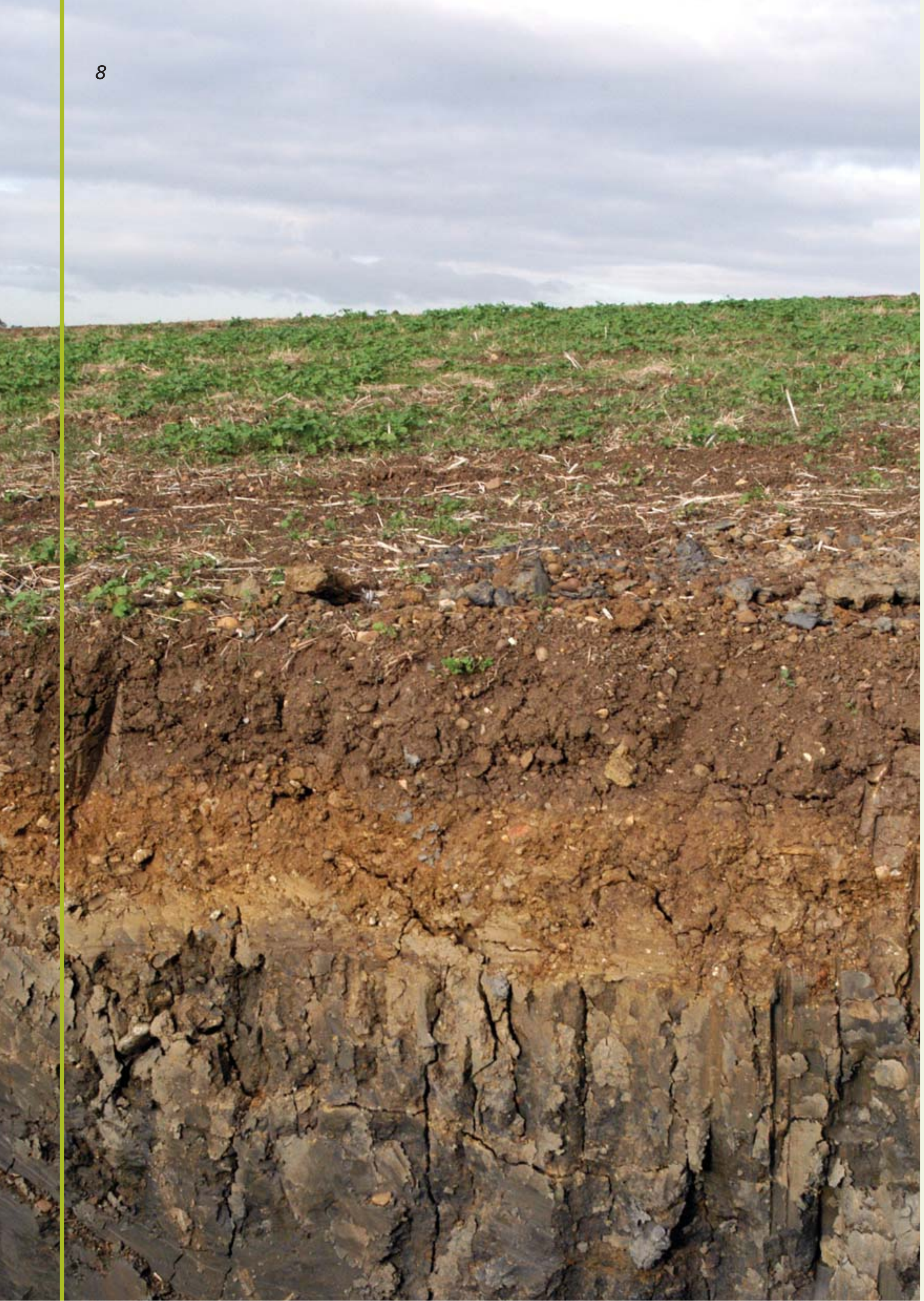


EXECUTIVE SUMMARY

Does Conservation Agriculture have the potential to protect soil and water while enhancing crop production and encouraging biodiversity in Europe?

The aim of this review is to present the current knowledge and practical experiences of Conservation Agriculture, and allow the reader to assess whether, in the context of the evolving EU legislative framework to protect soil and water, Conservation Agriculture is an approach which should be encouraged.

There are two parts to this book. The earlier sections present experiences of Conservation Agriculture worldwide and the context for any wider implementation in Europe. These are followed by a general guide to the practical introduction of its methods across the range of European cropping systems and the implications for biodiversity.

Conservation Agriculture is not a rigid, formalised system, but a flexible set of guiding principles based on:

- Minimum soil disturbance through conservation tillage rather than mouldboard ploughing
- Permanent plant or crop residue cover
- Diverse crop rotations to reduce the need for inputs

Its aim is to ensure farming is profitable and sustainable, consistently achieving high productivity and economic success while protecting the environment.

The three elements of Conservation Agriculture are sparsely monitored and recorded, with the best data on its uptake available for conservation tillage.

Currently, about 15% of farmland in Europe is under conservation tillage, either no-till or non-inversion reduced tillage systems, but uptake has been higher elsewhere, particularly in the Americas.

Greater statutory protection of water and soil (*eg* the Water Framework Directive and forthcoming Soil Framework Directive) may be significant drivers for the implementation of Conservation Agriculture. Water quality can be improved by reducing soil and nutrient loss from farmland and a range of threats to soil, particularly erosion, can be mitigated.

Application of Conservation Agriculture principles should be adapted to fit the needs and capabilities of the farm and farmer. On arable farms the evidence suggests that a wider implementation of Conservation Agriculture would significantly reduce soil erosion and improve soil structure and fertility, reduce diffuse pollution of water bodies and enhance biodiversity. In the shorter term there are challenges, for instance, the need to invest in specialist drills to cope with sowing crops through straw residues. In the long run, profitability usually increases because of substantial savings in time and cost because of faster crop establishment and reduced inputs overall, despite sometimes lower yields. Even if certain soil types may not be suitable for no-till or other conservation tillage practices, paying attention to the other principles such as introducing more non-cereal crops into the rotation to enhance soil fertility and reduce the pressures from weeds, pests and diseases should help to reduce the need for external inputs.

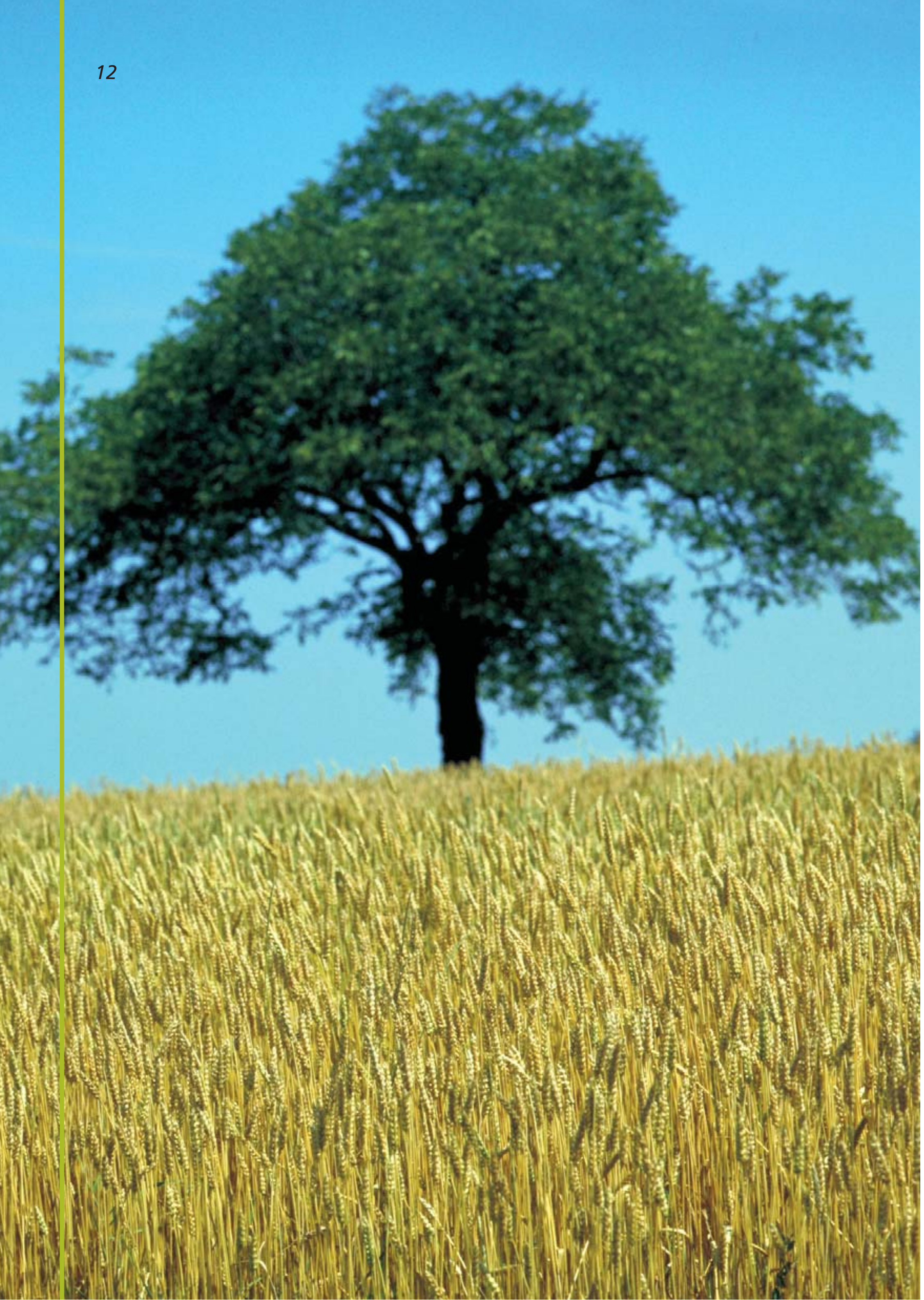
Perennial crops, the majority of which are grown around the Mediterranean, present different challenges and the principles of Conservation Agriculture have to be adapted, not least because there are no rotations and cultivations are restricted to the inter-row area. Olives and vines are often grown on hillsides, and in these situations the potential for soil erosion can be very great. The benefits of Conservation Agriculture are generally similar to those in arable crops, although the greater importance of cover crops presents some problems. Cover crops or natural vegetation growing in the inter-row strips must be managed to avoid competing with the crop.

For grassland, applying Conservation Agriculture, in general, means reducing pressures associated with animal and machinery traffic, better use of organic fertilizer and encouraging a diversity of species in the sward.

Field vegetables represent a diverse, high value category of crops. Cultivations necessary for root vegetables can make the use of Conservation Agriculture principles difficult. However, for many other crops, a range of different rotations can be used and practices such as Integrated Pest Management can be successfully applied.

Conservation Agriculture can also help counter the decrease in farmland biodiversity suffered as agriculture has intensified. By minimising soil disturbance, soil biodiversity is encouraged, providing greater food resources throughout the food web. Diverse rotations and permanent ground cover also increase habitat and food availability. Ground-nesting birds such as the skylark are particular beneficiaries.

In summary, Conservation Agriculture, if applied in the correct way, can bring significant benefits to farmers, the environment and society across the range of farm types and climatic regions found in Europe. However, because of the need to match the methods used to individual situations, more knowledge of how best to do this is needed. This must be gained through European, regional and local initiatives. Ultimately, effective dissemination is important to enable the wider adoption of Conservation Agriculture to protect soil and water while enhancing biodiversity, productivity, and profitability.



INTRODUCTION

The 21st century is already proving a time of great change for European farmers and land managers. Agricultural commodity prices are low, financial support structures are in a state of flux and the prospect of ever lower barriers to global trade will put further pressure on the economic viability and competitiveness of European farming systems. Farmers are not only producers of food, but also have responsibilities towards caring for the countryside.

Conservation Agriculture is an approach to growing crops which sets out to achieve high and sustainable productivity for economic viability, while conserving the environment, in particular, soil and water. The emphasis is on enhancing natural biological processes above and below the ground principally by minimising tillage, maintaining soil cover throughout the year, and using effective crop rotations which help to minimise inputs and loss of agrochemicals and fertilizers.

Protecting air, water and biodiversity has been at the forefront of environmental initiatives, but the need to protect soil in its own right has only recently become a priority. Soils are, of course, vital for agricultural productivity. A 'normal' rate of soil formation is estimated to be between half and one tonne per hectare annually. This means it may take a century or more to produce just one centimetre of new topsoil: soil must therefore be regarded as a largely non-renewable resource. Similarly, clean fresh water is essential for life, and both quality and quantity of supply are under increasing pressure. Agriculture around the world consumes some 70% of our available water.

European Union legislation reflects both environmental concerns and helps to determine how they are addressed. The most recent reforms of the Common Agricultural Policy (CAP) have focused on improving the environmental performance of farming in return for payments, leaving food production to market forces. To qualify for the new single payment, farmers have to demonstrate compliance with a number of environmental standards.

The **Water Framework Directive**, which came into force in 2000, aims at achieving *good status* for all water by 2015. The most distinctive feature of the Directive is the concept of maintaining ecological quality which is determined by the quality of the biological community and the chemical status of the water body.

In order to achieve some of its objectives, the Water Framework Directive will require the reduction and control of pollution from all sources including agriculture. In September 2005 the London Conference, hosted under the UK Presidency of the EU, highlighted the fact that many water bodies across the EU are at risk of not meeting the environmental objectives of the Directive and that agriculture is one of the main causes.

Proposals for a **Soil Framework Directive** are currently under discussion. In April 2002, the EU acted for the first time to protect soil in its own right with the issue of a Communication on Soil Protection, in which agriculture received specific attention:

> *"Agricultural soil is a precious and limited resource...Irreversible degradation of this resource implies not only ruining the main asset of current farmers, but also reducing the farming opportunities of future generations. Therefore, soil protection policies need to have a special focus on sustainable use and management of agricultural soils, with a view to safeguarding the fertility and agronomic value of agricultural land".*

Soil protection will also help achieve the objectives of the Water Framework Directive (preventing diffuse pollution), the Habitats Directive (addressing soil biodiversity) and the Kyoto Protocol (sequestering carbon).

The question now facing farmers and policymakers alike is how to deliver the legislative requirements for the protection of soil and water, whilst retaining and strengthening the competitiveness of European agriculture. There is evidence that Conservation Agriculture can provide practical solutions.

In early 2006, the EC funded KASSA (Knowledge Assessment and Sharing on Sustainable Agriculture) project concluded an 18 month review, noting that there are major knowledge gaps with respect to the impact of Conservation Agriculture on soil and water management, and on the

profitability of crop production. For farmers profitability is the most important incentive for any change to their management practices.

> *"Nothing affects the voluntary uptake of Conservation Agriculture more than crop yields and the net returns earned by practising farmers, regardless of government or other incentives"*
>
> (Baker *et al*, 2001)

Conservation Agriculture has been described as

> *"the greatest soil conservation practice to come along in the 20th century"*
>
> (Lal, 1989)

but uptake in Europe has been limited. Given its success in other parts of the world, this raises several questions:

- Can Conservation Agriculture protect soil and water in Europe, and enhance crop production and biodiversity?
- Are there particular limitations to the effectiveness of Conservation Agriculture or constraints on its implementation?
- Does Conservation Agriculture have the potential for wider adoption in Europe and what are the ways forward?

This book seeks to address these questions. The principles of Conservation Agriculture are explained, and its current adoption and fit are examined in terms of drivers and constraints, together with its benefits and any disadvantages. Considering the recognised threats to soil and water, a broad and balanced guide to the application and implementation of these principles in European cropping systems is presented. The ultimate aim is to have laid out the evidence as to whether Conservation Agriculture can deliver both legislative requirements for soil and water protection, and profitable, sustainable farming.

OVERVIEW OF CONSERVATION AGRICULTURE IN EUROPE

What is Conservation Agriculture?

Conservation Agriculture is an approach to growing crops that strives to achieve high and sustainable productivity, quality and economic viability, while also respecting the environment. Protecting soil and water are at the heart of this approach.

In this section, the extent to which Conservation Agriculture has been adopted globally and in Europe will be considered. What are the driving and constraining factors, and the acknowledged benefits and downsides associated with its practice?

Conservation Agriculture is based on enhancing natural, biological processes above and below the soil surface. Soil tillage should be reduced to a minimum, and agrochemicals and fertilizers must be applied at optimal rates to limit their impact on biological processes.

Conservation Agriculture is based on three interlinked principles which need to be adapted to particular cropping systems:

- **Minimum mechanical soil disturbance**

Conservation tillage, ideally no-tillage (or 'no-till' where the soil is not disturbed other than to plant the seed), or minimal, non-inversion tillage is strongly preferred to conventional mouldboard ploughing (where the soil is inverted). However, the type and degree of soil disturbance should be appropriate to soil type, crop and weather conditions. It may be better, for instance, to choose

Ploughing

Non-inversion tillage by discing

No-till

cultivation implements with either discs or tines if it is not possible to drill directly into undisturbed soil.

Permanent soil cover

Keeping a vegetative cover over the soil in the absence of a crop has an important role in protecting the soil and enhancing its properties.

Discing-in cover crop

In annual crops this cover can be achieved by chopping and spreading the residues of the harvested crop, or by planting a cover crop which will either be incorporated or desiccated before drilling the next crop. In some instances (see the maize example in the Arable section) the new crop may be drilled directly into the cover crop.

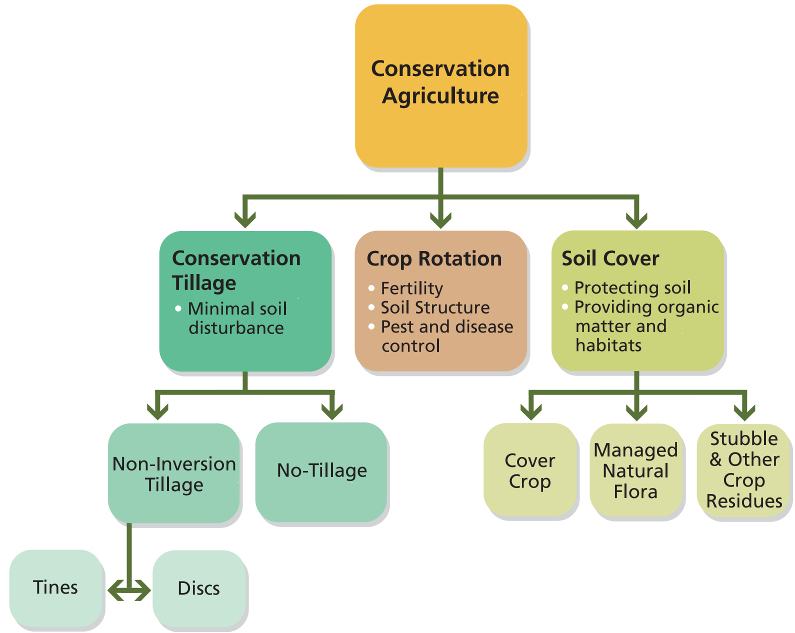
In perennial crops, necessarily planted in wide rows, the inter-row strips are either planted with a cover crop, or allowed to grow a natural, but subsequently managed, 'weed' flora, or may be spread with chopped crop residues, *eg* prunings.

These covers protect soil from the impact of raindrops and wind which lead to erosion, and enhance its properties by adding organic matter to improve its structure and fertility.

Inter-row cover crop in olives Photo by J Gómez

Diversified crop rotations

Appropriate sequences of crops will reduce the impact of weeds, pests and diseases on a single crop type and give opportunities for alternative methods of control or reduce the need for external inputs. Legume crops have bacteria associated with their roots which take nitrogen from the air and turn it into forms plants can use, so reducing the need for fertilizers.



Adoption of Conservation Agriculture

The term Conservation Agriculture is widely used and often misused or misunderstood. Several interpretations exist, so care should be taken when comparing information from different sources. Frequently, it is only discussed in the context of arable crops, but in this book the implementation of Conservation Agriculture in annual crops (both arable crops and field vegetables) and perennial crops (fruit trees and vines, and grassland in livestock farming systems) is explored.

The change in tillage has been the most readily researched and reported of the Conservation Agriculture principles, to the extent that, frequently, the terms *conservation tillage* and *Conservation Agriculture* appear interchangeable. For adopting arable farmers, the change in tillage will be foremost in their minds, particularly if accompanied by the purchase of new machinery. This may mean that other modifications to their crop production system, like changing rotation, may be less significant or accepted as a consequence of conservation tillage rather than an integral part of the system itself. Data on arable rotations are lacking, but trends in areas of individual crops suggest little change in Europe over the past 20 years apart from a fall in the area of cereals with the advent of set-aside.

Therefore, information on the extent and practice of Conservation Agriculture is frequently described by the degree of tillage and often insufficient detail is available to determine whether the work described fulfils all the Conservation Agriculture principles.

No-till is carried out on more than 94 million ha worldwide. The US has the biggest area under no-till – over 25 million hectares – but this represents only 21% of its cropland and only 10–12% of this area is permanently untilled. Uptake is greater in South America with about 50% of Brazilian cropland under no-till (23.6 million ha) and more than 90% of this is permanently no-tilled.

Currently, about 15% of European arable land is believed to be under conservation tillage, but only around 1% is under no-till (Table 1). Finland and the UK have the highest proportions of land under conservation tillage, followed by a group comprising other, largely, western European countries. In general, uptake is lower in southern and eastern Europe.

Table 1. Area of arable land in Europe under Conservation Agriculture (2005) (Basch 2005, M Javurek *pers comm*)

Country	Total under Conservation Tillage (1000 ha)	% Arable land under Conservation Tillage	% Arable land under No-Till
Belgium	140	17.2	-
Czech Republic	350	11.0	-
Denmark	230	10.1	-
Finland	1,150	52.3	6.8
France	3,870	21.1	0.7
Germany	2,500	21.2	1.7
Greece	430	10.8	7.4
Hungary	500	10.9	0.2
Ireland	10	0.9	-
Italy	560	7.0	1.0
Portugal	418	21.1	2.3
Slovak Republic	179	12.6	2.6
Spain	2,400	18.0	4.5
Switzerland	102	25.4	2.9
UK	2,680	45.6	3.1
Total	**30,669**	**15.4**	**1.1**

In general, for perennial crops Conservation Agriculture means replacing frequent ploughing between the crop rows with no soil disturbance and the planting of a cover crop. There is little information on cover crop use, but it should be noted that over half a million hectares of Spanish olives are grown with green plant cover between the olive rows.

Ploughed area (left) and no-till area (right)

If the benefits of Conservation Agriculture are to be fully exploited by all farmers, regardless of their crop production system, changing tillage is not in itself sufficient:

> *"Conservation tillage cannot be adopted in isolation. It is a basic management tool"*
> (Lal, 1989)

This is the position adopted in this book. All three principles must be considered and implemented flexibly according to each individual situation; there are no blueprints.

In future, for a full and meaningful analysis of the performance of Conservation Agriculture on farm economics, the environment and its wider impact on society, surveys of extent and uptake should report on all three principles rather than tillage alone.

No-till drilling Photo by P Alexander

Driving and Constraining Factors

Forces affecting the adoption of Conservation Agriculture relate to environmental issues, the technologies and economics of farming practice, and society and culture.

Environment

A major driver behind the spread of Conservation Agriculture has often been the need to find solutions to problems of soil erosion and loss of fertility. In some cases, *eg* in Western Australia and Brazil, farmers have had little choice but to adopt conservation tillage. In Europe, there are similar situations where the need for water conservation is crucial.

In a number of countries, agri-environment payments to implement erosion control measures using, *eg* cover crops or crop residues, have also provided incentives for farmers to practice elements of Conservation Agriculture.

However, some soils (sandy and poorly structured soils) may not be suitable for long-term no-till, although non-inversion tillage may still be a viable option on some heavier soils. Modifications like strip tillage, where only narrow bands

Cotton established by strip tillage Photo by G Basch

- **Soil Erosion Problems:** the total annual cost of erosion from European agriculture is approximately €85.5/ha (ECAF, 2003)
- **Soil Protection Incentives:** In Austria, payments of €145-799 per ha have been available to vine growers to implement soil erosion control measures like cover crops (SCAPE, 2004)
- **Economies of Scale:** In semi-arid central Spain no-tillage has enabled arable farmers to manage 4 times more land than that possible under ploughing (Sanchez-Giron *et al*, 2004)

into which seed is to be drilled are tilled, may extend the range of soils on which conservation tillage can be practised.

There are some challenges. For instance, covered soil warms up and dries more slowly than bare soil, slowing germination and early crop growth during spring in cooler regions. Also, with conservation tillage, nutrient stratification is common. Without inversion, most lime and fertilizer are concentrated near the soil surface but both need to be mixed with soil for greatest efficiency. There may also be an increased demand for nitrogen in the first years of conservation tillage, as nitrogen can be immobilized (used by soil micro-organisms) during the decomposition of plant residues.

Crop Production Technology and Economics

Early uptake of Conservation Agriculture in Europe was voluntary and driven by the need to reduce arable crop establishment costs. The capacity for Conservation Agriculture to improve cost effectiveness and save both time and labour has been seen by European farmers as an important way to maintain the competitiveness of their businesses (see also Arable and Perennial sections). In addition, as the trend towards larger farm units, lower labour intensity and fewer and larger machines continues, this will continue the move away from traditional mouldboard plough-based cultivations.

It can be more difficult for smaller farms to adopt Conservation Agriculture practice. Larger farms might be expected to derive maximum benefit by being able to fully utilise a large tractor with non-inversion tillage equipment. In the Czech Republic, co-operatives have been more likely to adopt the technology, partly because of their greater spending power. In Italy, Switzerland and Germany, the role of agricultural contractors is increasing because of the high acquisition cost of machinery.

The cushion of CAP subsidies (in EU15) and lingering effects of central planning in some newer EU Member States may also have limited spread of the technology.

Farmer-owners may be more likely to have greater flexibility to adopt Conservation Agriculture and be more willing to invest in new equipment than tenants who may need to get approval from the land owner.

However, in a survey of European experts the fear of reduced yields was considered to be the primary constraint to greater uptake. In contrast, farmers themselves, focused on their lack of experience with the technology. In particular, the transition period from an intensely cultivated system, which has been called "l'apprentissage" of conservation tillage, can be demanding because of a lack of familiarity with the new techniques, and may last for many years.

Crop residues help to control erosion, yet present Conservation Agriculture with one its biggest challenges: the development of effective drills for successful sowing. Avoiding drill blockages with residues and achieving consistent seeding depth for uniform crop emergence are some of the greatest problems to overcome.

Residues can pose problems for drilling

There are also difficulties with the inclusion of root crops in Conservation Agriculture rotations. For example, removing stones from soil for potatoes is required for quality production.

Society and Culture

Support from established networks can help farmers adopt Conservation Agriculture. The European Conservation Agriculture Federation (ECAF) was founded in 1999 by seven national associations, and has been promoting Conservation Agriculture in Europe, running two EU-Life Environment projects. By 2005, 15 country organisations were members of the Federation.

The tradition associated with mouldboard ploughing can mean that older farmers in particular are reluctant to try the technology. The appearance of clean ploughed land is still percieved to be the norm. In contrast, Conservation Agriculture fields with plant residues on the soil surface can often look badly managed to neighbouring farmers.

Members of the European Conservation Agriculture Federation

Perceptions exist and need to be overcome. In the more arid parts of Europe, farmers need to be convinced that a cover crop can be managed to prevent competition for water. In Romania, the majority of farmers cannot contemplate farming without the plough in many situations, yet it is almost general practice to only disc before planting winter wheat because of the limited time available. Despite all these real and perceived constraints it is frequently the attitude to risk and preferences of the individual farmer which drive uptake.

Benefits and Limitations of Conservation Agriculture

As with the drivers, the benefits and disadvantages of Conservation Agriculture can be reviewed in terms of environmental, crop production and societal perspectives.

Environment

> *"There is no justification for ignoring Conservation Agriculture's soil management potential at erosion vulnerable locations"*
> (El Titi, 2003)

Soil erosion in arable crops can be decreased by 60-90% by non-inversion tillage and by over 90% by no-tillage (see crop sections for more information). However, long-term use of conservation tillage can lead to soil compaction, particularly in heavy wet soils.

Water run-off causing erosion in cereal crop

Increased soil organic matter in Conservation Agriculture systems can improve soil structure, leading to better water infiltration and storage, and also a reduced threat of downstream flooding. Plant residues limit evaporation and by doing so conserve moisture. Because Conservation Agriculture can reduce the run-off of water from land, there are benefits to the quality of water courses through reduced sedimentation and contamination by agrochemicals and nutrients. While Conservation Agriculture techniques help retain agrochemicals in the field, the potentially greater activity of soil microbes in Conservation Agriculture soils may also facilitate their breakdown.

Conservation tillage means that soils can sequester carbon until a new equilibrium is reached to counter balance greenhouse gas emissions: carbon dioxide fluxes from soils are directly related to the volume of soil disturbed. The ability of Conservation Agriculture soils to sequester carbon

- **Less Soil Erosion:** If Conservation Agriculture was practised on 70% of EU arable land it has been estimated that soil erosion would be reduced by almost 50% (Basch and Tebrugge, 1993). In experiments in Spanish olive groves, erosion has been reduced from 8.5 t/ha in ploughed groves to 1 t/ha with a cover crop (Gómez *et al*, 2004)
- **Less Water Run-off:** Conservation Agriculture can reduce run-off by 40-69%, with consequent decreases in herbicide, nitrate and soluble phosphate content of surface waters (70%, 85% and 65% respectively) (Jordan and Hutcheon, 1997; www.sowap.org; www.ecaf.org)
- **Carbon Trading:** In 2005, Canadian no-till farmers could earn almost € 10/ha to help offset Canada's greenhouse gas emissions (SSCA, 2006)
- **Saving Costs:** Growing arable crops under a no-till regime in southern Europe was cheaper by € 40-60/ha (ECAF, 2006)
- **Weed Control Problems:** Herbicide costs were 15% higher under no-till in long-term trials with a rotation of 75% winter cereals (Tebrugge and Bohrensen, 1997a)
- **Lower Yields:** Winter barley, winter wheat and spring oats yielded similarly or slightly better under no-till, but spring barley and maize yields were down 15% and sugarbeet yields down 20% in Belgium (Cannell and Hawes, 1994)

presents farmers with additional business opportunities to enter carbon trading schemes such as in Canada.

It has, though, been estimated that greater emissions of nitrous oxide from Conservation Agriculture soils than from ploughed soils reduce carbon sequestration benefits by 50-60%. Nitrous oxide has a far higher greenhouse gas effect than carbon dioxide. However, it appears that nitrous oxide emissions are sporadic and are determined by an interaction between soil and climate factors that affect soil aeration.

There are significant biodiversity benefits: earthworm numbers generally increase and Conservation Agriculture fields appear to provide better habitats for insects, birds and mammals (see also Biodiversity section). There are also reports of some cereal diseases and viruses being suppressed under Conservation Agriculture. By reducing pest and disease levels agrochemical inputs may be decreased.

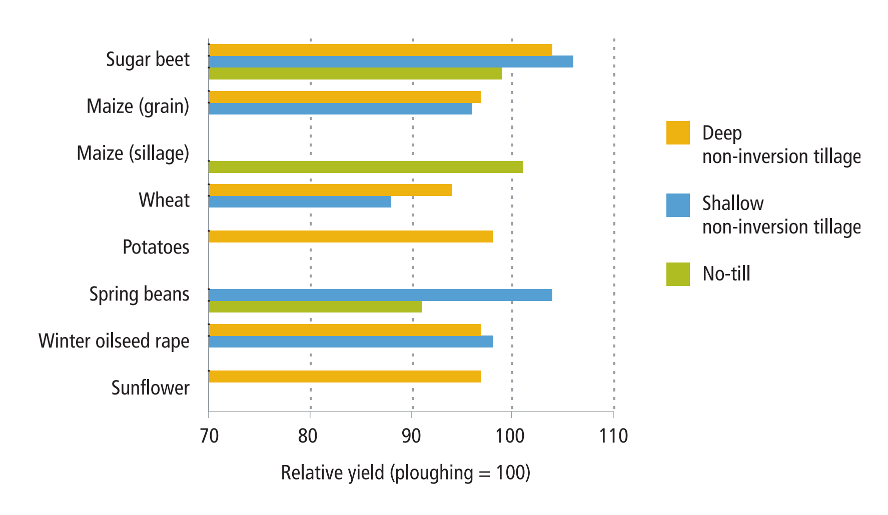
Crop Production Technology and Economics

Quicker land preparation, with more ground cultivated per day and fewer operations to create a seedbed, or none at all under no-till, improves the timeliness of farm operations. This allows earlier planting and better windows of opportunity for fertilizer and crop protection interventions. Reductions in cost, fuel consumption, working time and labour requirements have all been demonstrated in the UK, France, Germany and Brazil.

Considering crop protection, weed management issues are often highlighted. There are many reports of greater weed problems and increased herbicide costs. With increasing use, herbicide resistance is possibly more likely to occur. In temperate climates, molluscs and some types of insects are often encouraged by conservation tillage. Appropriate rotations must be used though, for conservation tillage may favour certain crop diseases, *eg Fusarium* in wheat after maize, but in most cases there is no increased risk.

Grass weeds such as blackgrass (Alopecurus myosuroides) can be a problem without ploughing

Figure 1. Yields from conservation tillage crops relative to the yield from crops established by ploughing. Data are means from several trial sites in the SOWAP project



Yields from crops established by conservation tillage are often, but not always, slightly lower than those established after ploughing (Fig 1). Yield is determined by many interacting factors and effects of tillage regime are neither consistent nor predictable. Regardless, reduced overall inputs are likely in the long term, offsetting any yield reductions.

Society and Culture

Many farmers cite a 'better quality of life' as a major advantage of Conservation Agriculture. With less time spent on land preparation, land managers are presented with the opportunity to take on additional acreage, diversify their operations or farm under marginal conditions. As Conservation Agriculture tends to be adopted by pioneering farmers, it may further the development of new technologies and practices like Controlled Traffic Farming in which wheelings are always confined to the same areas.

Finally, Conservation Agriculture builds the technical knowledge and management skills of farmers, so

contributing to the longer-term sustainability of rural livelihoods. The environmental benefits may also improve the public image of farming.

SOWAP and ProTerra projects hold regular farmer meetings to discuss aspects of Conservation Agriculture

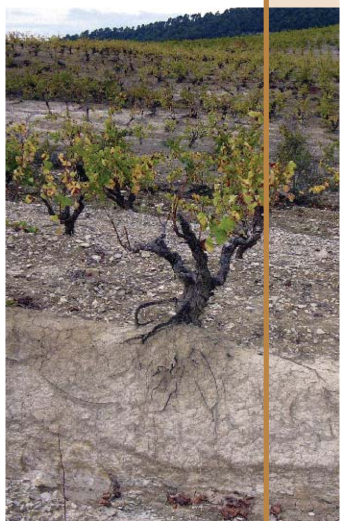
THREATS TO SOIL AND WATER AND THEIR MITIGATION

Soil

A recent official communication from the European Commission identified eight threats to soil (Van-Camp *et al*, 2004). These are: soil erosion, loss of organic matter, compaction, contamination, landslides and flooding, salinisation, soil sealing and decline in soil biodiversity. This section discusses these threats in the general context of soil degradation and identifies mitigation strategies in which Conservation Agriculture can play a part.

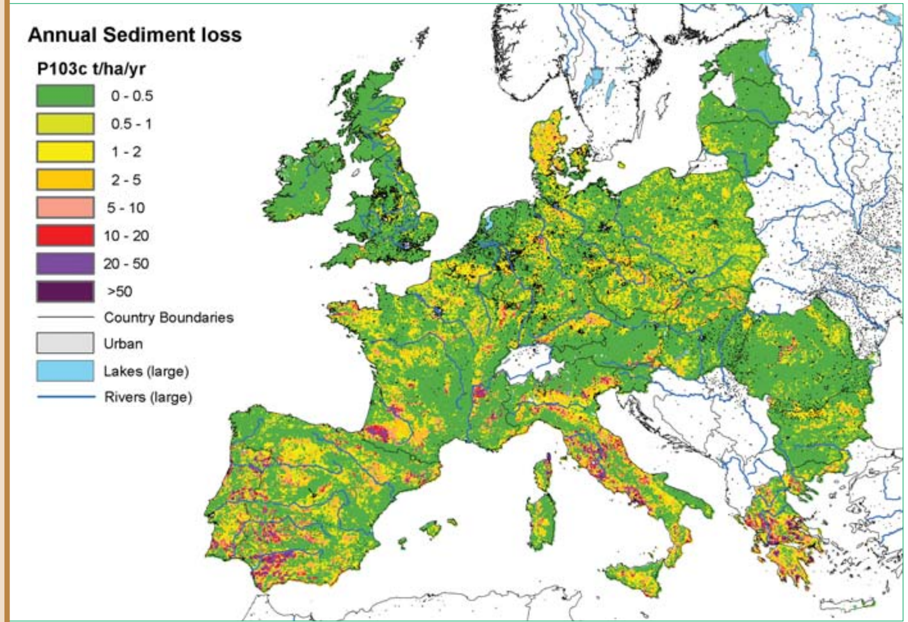
Erosion

Soil erosion is the wearing away of the land surface by physical forces such as rainfall, flowing water, and wind that remove material from one point to be deposited elsewhere. It is a natural process, largely responsible for shaping today's physical landscape. However, accelerated erosion, where the natural rate has been significantly increased by human activities, is a serious concern. These activities include the removal of natural vegetation and intensive cultivations in crop production. Erosion is regarded as one of the most widespread forms of soil degradation and can potentially severely limit sustainable land use in Europe.



Severe erosion exposing vine roots

Erosion by water takes several forms and results from heavy rainfall, snowmelt and the action of streams and rivers gouging soil from river banks and the shores of lakes. Water is the key cause of soil erosion in Europe. Wind erosion occurs in areas where soil is mostly sandy or silty and where it is dry and not stabilised by plant roots.



Risks of soil erosion in Europe as mapped by the Pan European Soil Erosion Risk Assessment Project (PESERA)

Climate, topography and soil characteristics are important physical factors affecting the amount of soil removed. The Mediterranean region is particularly vulnerable to accelerated soil erosion because it is subject to long dry periods, followed by heavy bursts of rain falling on steep slopes, often with shallow soils low in organic matter. The area affected by erosion in northern Europe is extensive, if less severe, but is, nevertheless, still a serious problem, particularly in terms of off-site effects such as sedimentation and eutrophication in water bodies.

Measurements of soil loss show average rates from less than 0.5 t/ha/yr to more than 200 t/ha/yr. The highest losses, sometimes as high as 500 t/ha/yr, have been measured following short intense storms with heavy rain falling on bare soil surfaces.

By reducing soil disturbance and encouraging plant cover, Conservation Agriculture can reduce erosion. In contrast,

mouldboard ploughing removes vegetation cover and loosens the upper soil layer facilitating the removal of soil particles by water, wind, or both. Land ploughed in the autumn with no vegetative cover during the winter is very vulnerable to erosion forces.

Loss of Organic Matter

An imbalance between the build-up of soil organic matter and rates of decomposition is leading to a decline in soil organic matter in many parts of Europe. The presence of organic matter is extremely important in all soil processes, storing nutrients, enhancing soil fertility, contributing to soil aeration, and ensuring good structure. Water infiltration rates and the storage capacity for water also improve.

Soil profile indicating a topsoil rich in organic matter

Inherent levels of soil organic matter are determined by natural factors, *eg* climate, vegetative cover and geology, and human factors, *eg* land use and management. Declines in organic matter frequently stem from human activity such as conversion of grassland, forests and natural vegetation to arable land, deep ploughing of arable soils, overgrazing and forest fires.

High temperatures in southern Europe also accelerate organic matter decline. In the future, the countries of northern Europe could be similarly affected should global warming continue.

Some Conservation Agriculture practices can stabilise and increase the organic matter content of topsoils. Minimising the degree of tillage reduces the oxygen available for decomposition and can make it easier to maintain good soil structure.

Compaction

Compaction occurs when soil is subject to mechanical pressure through the use of heavy machinery or dense stocking with grazing animals, especially in wet soil conditions. Compaction reduces the pore space between soil particles. The soil then partially or fully loses its capacity to absorb water and air. Compaction can occur at the surface or in subsoil horizons. The overall deterioration in soil structure that may result can:

- Increase the risk of soil erosion on sloping land
- Accelerate run-off from and within catchments
- Have an indirect impact on contamination through transfer of pollutants
- Reduce crop yields

Surface compaction can be rectified relatively easily by cultivation and hence it is a less serious problem in the medium to long-term. But, once subsoil compaction occurs, it can be extremely difficult and expensive to alleviate. The risk of subsoil compaction grows with the use of larger and heavier equipment and more passes over the land.

Mouldboard ploughing can result in compaction occurring at the base of the plough layer, as a 'plough pan' typically at 25-30 cm depth. The compacted soil must be broken by deep subsoiling equipment which is slow and very demanding on tractor power and fuel use. Subsoil treatments are only successful under optimum conditions and thus timing is critical. Using powerful and therefore heavy tractors risks further compaction of both subsoil and topsoil. Conservation tillage makes fewer passes of machinery and can reduce the incidence of compaction providing the soil is not wet and allowed to smear.

Contamination

Contamination is the occurance of a substance in soil above a certain level deemed to be harmful or potentially dangerous. Many human activities can contribute towards the contamination of soil, including industrial production, motor traffic, agricultural farming practices and waste disposal, all of which may pose risks. The most contaminated areas of soil in Europe are found in the north-west, in northern France, Belgium, the Rhine-Ruhr valleys in Germany, the Netherlands and around the large cities in the UK. Conservation Agriculture can help to avoid contamination by potentially reducing the inputs of agrochemicals and fertilizers, and encouraging a better structured and 'healthier' soil, optimising its capacity to degrade and withstand contaminants.

Landslides & Flooding

Landslides and floods are mainly natural hazards, closely related to soil and land management. Floods and landslides are not a threat to soils in the same way as soil erosion, but they can result in part from compaction or sealing of soils. However, soil erosion itself leads to a thinner soil layer, which in the long term reduces the soil water storage capacity, leading to increased surface and subsurface run-off which in turn enhances the likelihood of landslides and floods.

However, many of the floods that occur cannot be reduced or avoided by changing land management practices alone. Nevertheless, Conservation Agriculture may help reduce the risk of flooding by encouraging better soil structure, thereby reducing erosion and run-off, maintaining water storage capacity and preventing a decline in organic matter.

Flooding has a very direct impact on the public

Salinisation

Salinisation is the accumulation in soils of soluble salts of sodium, magnesium, and calcium to the extent that soil fertility is severely reduced. This process is often associated with irrigation and Conservation Agriculture has little mitigating effect.

Sealing

In this context, soil sealing means covering the soil surface by impervious materials, *eg* concrete, tarmac and plastic. The main causes of soil sealing are building development and transport. It is probably the most serious threat to soil in industrialised countries, but Conservation Agriculture cannot make a contribution to alleviating this problem.

Decline in Soil Biodiversity

Decline in soil biodiversity is the reduction in forms of life living in the soil both in terms of their quantity and variety. This is addressed in the section on Biodiversity.

Water

Agriculture in general has two main potentially negative impacts on surface water and groundwater:

- Diffuse pollution caused by sediments, nutrients and pesticides entering water bodies
- Physical damage to wetland habitats, *eg* wetland drainage, infilling of ponds

The following discussion examines these impacts and highlights the possibility of mitigation by Conservation Agriculture.

Diffuse Pollution

There are three principal types of agricultural pollutant: sediment, nutrients (from manures and inorganic fertilizers) and agrochemicals.

Sediments

Soil particles can transport nutrients, particularly bound phosphorus, and alter stream-bed habitats by covering coarser substrates with fine particles.

In general, Conservation Agriculture reduces sediment loss, particularly on soils which are easily eroded. For example, on Belgian loess soils conservation tillage reduced sediment loss from fields overall by 90%.

Nutrients

Nitrogen, phosphorus and other nutrients enter water bodies either as dissolved or particle-borne materials, and cause major changes in standing water ecosystems, typically by promoting the growth of algae at the expense of large water plants. Effects also occur in running waters but are less well understood.

Conservation Agriculture leads to reduced nutrient run-off in many situations. Effects may be seen for both nitrogen and phosphorus, and reductions of 50% or more have been observed in field drainage water (Fig 2) and surface run-off. As with sediment losses, there is considerable variability, with some studies showing no effects or even increased nutrient losses.

Algal bloom caused by excessive levels of nutrients

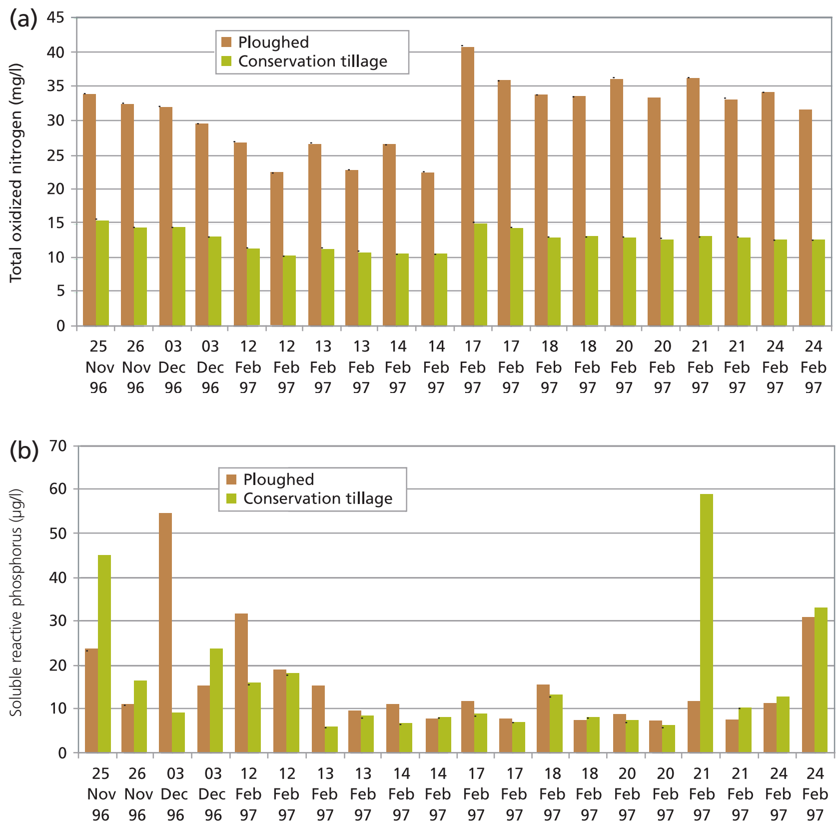
Agrochemicals

A variety of agrochemicals may enter water by spray drift, water run-off from fields or bound to soil particles. They may have impacts on all biotic groups, the nature of which will depend on the type of agrochemical, level of exposure and species sensitivity. However, modern agrochemicals are tightly regulated and although their relative contribution to the overall degradation of water courses by agriculture is poorly understood, their impact is generally thought to be relatively small.

Rational agrochemical use and the potential for improved agrochemical breakdown in soils of Conservation Agriculture systems will act to mitigate against any impacts.

Overall, it is difficult to determine which of the three main diffuse pollution sources associated with agriculture has most impact on aquatic ecosystems; indeed it is often impossible to separate these effects because all tend to occur together, particularly in arable landscapes.

Figure 2. Comparison of the effect on drain flow nutrient concentration under ploughing and conservation tillage: (a) total oxidized nitrogen (b) soluble reactive phosphorus
(Jordan and Hutcheon 1997)



Physical Damage

Agriculture typically increases the range of water flow rates through the year, creating more extreme hydrological conditions with lower flows in summer, and higher flows in winter. In draining land to make agriculture viable, many watercourses have been deepened, widened and straightened (to increase drainage efficiency), water tables lowered (draining ponds and springs) and ponds and wetlands infilled. Taken together these decrease the availability of wetland habitat, particularly eliminating temporary waters, reducing the connectivity of rivers and their floodplains and creating more hydrologically stressful conditions for aquatic organisms.

Although Conservation Agriculture cannot reverse the effects of land drainage, it may bring about some benefits in reducing extremes of run-off.

WHAT DOES THIS MEAN IN PRACTICE?

Conservation Agriculture can have valuable environmental and economic advantages. These have driven its significant and increasing uptake in certain parts of the world. Experience has shown that the most important threats to soil and water can generally be mitigated by applying the principles of Conservation Agriculture.

However, if Conservation Agriculture is to be encouraged across Europe then there needs to be a clear understanding of what can be achieved, where it may or may not be appropriate, and how it can be implemented.

The key to successful Conservation Agriculture in Europe is to adopt its principles to the different crops, soil types, climates and capabilities of the farm and farmer.

The following sections highlight current Conservation Agriculture practices on farms in the major European cropping systems – arable, perennials, grassland and vegetables – and using these experiences and scientific knowledge, lay out broad practical guidelines for implementation, indicating where success and limitations may be found. Both the benefits and difficulties which may be encountered are presented, and case studies illustrate experiences on commercial farms.

ARABLE CROPS

Arable crops cover 40% of the total agricultural area of the EU-25, about 97 million hectares (2003 Eurostat data). Cereals predominate, with wheat being most important. Planting wheat or oilseed rape in autumn has become prevalent, but many crops including maize, barley and sunflowers are planted in spring. CAP reform, continuing low crop prices and the potential for bio-energy crops are likely to have significant effects on arable crop rotations across Europe in the future.

These drivers for change present challenges to farmers, but also opportunities to address the threats to soil and water arising from the intensive cultivation of winter crops.

Conservation Agriculture in Arable Crops

As highlighted in the Overview section, the interpretation of what is or is not Conservation Agriculture is an area of confusion. Of the three principles required to truly practice Conservation Agriculture in arable crops, changes in tillage have been the most researched, reported and adopted on-farm. Frequently, the terms *Conservation Agriculture* and *conservation tillage* have been used interchangeably. In addition, it is unclear from the information available, to what extent the other principles have been taken-up. Therefore, the following account of current Conservation Agriculture practice by European arable farmers is largely limited to describing tillage techniques.

In winter crops, non-inversion tillage, in various forms, is the major Conservation Agriculture practice used at present. Most commonly, ploughing is replaced by disc, tine cultivations, or both, often simply using equipment designed for plough-based systems. Although not as beneficial to soils as no-till, a shallow cultivation makes crop establishment easier. Research at Arvalis - Institut du Végétal in France has even shown that broadcasting cereals into shallowly cultivated stubbles, dispensing with the need for a drill, can be cost-effective.

However, comparisons have also shown that no-till is the by far the cheapest way of establishing cereals. Depreciation costs of a specialist drill and the extra cost of non-selective herbicides are more than off-set by reductions in costs of fuel, labour and additional tractors. Despite this, even though the land considered suitable for no-till in some countries is extensive (Table 2), the uptake of no-till in Europe is still very limited (see Overview section).

Specialist equipment combining non-inversion cultivation tools with a seed drill can be an attractive option, particularly on smaller farms which can not spread the investment in conservation tillage equipment and heavy duty drills over large areas.

Table 2. Arable land considered suitable for the application of no-tillage in several European countries (Tebrügge and Böhrensen, 1997b)

Country	Arable land* (1000 ha)	Arable land suitable for no till (1000 ha)	Arable land suitable for no till %
Switzerland	409	201	49.1
Spain	13,738	6,251	45.5
Portugal	1,990	896	45.0
Denmark	2,276	1,001	44.0
Germany	11,791	4,374	37.1
Greece	2,717	1,005	37.0
France	18,449	5,867	31.8
Netherlands	899	236	26.3
Italy	8,287	1,865	22.5
UK	5,753	1,024	17.8
Total/Average	**66,309**	**22,720**	**34.1**

* Source: FAO

Stale seedbeds to encourage weed germination by light cultivations after harvest are common in the UK. The flush of weeds is then removed by spraying with herbicides before drilling. However, in more northerly countries there is insufficient time between harvest and early autumn frosts for such a practice.

Successful soil cultivation and drilling in conservation tillage systems need dry weather and so tend to occur earlier in the autumn than when the plough is used. Early sowing minimises the risk of soil erosion by providing the cover of an established crop before winter.

Spring crops pose a greater challenge for Conservation Agriculture in the cooler climates of Europe. The soil in spring is usually cold and wet making the decomposition of plant residues slow. This can result in poor germination and slow crop growth.

Lower grain prices have increased the pressure on farmers to reduce costs and this has contributed to the uptake of conservation tillage (see Overview). Cultivation costs are often 40-50% of all labour and machinery costs and dictate manpower and tractor needs. Plough-based systems have been estimated to require 213 kWatt of energy per hour per hectare whereas conservation tillage systems use only 137 kW/hour/ha on average, and also have lower labour requirements (Table 3).

Table 3. Cultivation systems and costs (From 'A Guide to Crop Establishment', *Soil Management Initiative, UK)*

Cultivation Practice	Cost (€/ha)	Labour (hours/ha)
Plough-based system with several passes	135-170	3.4 – 4.2
Non-inversion tillage system (two passes)	120-135	0.9 – 1.1
No-till	55-70	0.4 – 0.6

In conventional production systems rotational crops are selected and grown for a number of reasons, primarily for short-term profitability. In Conservation Agriculture the choice should be determined by broader, longer-term considerations.

The voluntary use of cover crops in arable production systems is limited. However, payments have been available to farmers in a number of countries to plant cover crops, mainly over-winter, to prevent soil erosion and nitrate leaching (see Overview).

Guidelines for Implementation

Conservation Agriculture is a flexible approach to crop production and there are no blueprints for its application. However, its three core principles of soil management, ground cover and crop rotation provide a good framework for a discussion of experiences and issues which can be used as guidelines for successful implementation, tailored to individual circumstances. Also included in the rest of this section are a brief case study from the UK, and a specific focus on maize which has some particular challenges and opportunities.

Soil Management

Ploughing is seen as a consistently reliable operation for all soils, but is generally costly and slow. Typically, only 4 ha of seedbed per day might be achieved on medium land in autumn. Heavy discs alone can create a seedbed and have been the main alternative to the plough for large farms, particularly on medium to heavy land. Two passes can mix in straw ready for drilling, and 20 ha can be cultivated in a day in this way - much faster than ploughing. Tines are another alternative usually more suitable for lighter soils. Farms often span several different soil types and farmers, therefore, need to make compromises in machinery selection.

Discs above, Tines below

Soil conditions need to be assessed before any cultivation. There may be limited opportunities to address any problems later. Sandy, poorly structured soils and those prone to compaction or poor drainage may not be suitable for long-term no-tillage. However, other soils which are difficult to work conventionally may be suitable for conservation tillage. In Scandinavia, best results have been obtained on the heaviest clay soils.

Non-inversion tillage requires relatively dry soil conditions, and so the timing of cultivation, seeding and crop establishment is critical. Short growing seasons, low temperatures and high rainfall can limit tillage options.

Effective drills are vital in Conservation Agriculture systems. Avoiding drill blockages with residues and achieving consistent soil penetration for uniform crop emergence are great challenges.

Owen Dyer, Somerset, UK

> *"Buying the right drill is very important as it enables sowing into residues beyond the capabilities of conventional drills"* (Owen Dyer, UK farmer)

Consolidation after drilling is vital to retain seedbed moisture to encourage germination and crop residue breakdown. Greater moisture retention in soils under Conservation Agriculture can be beneficial in drier regions of Europe. For instance, good results were found growing durum wheat in central Italy. However, care must be taken not to compact the soil. Long-term conservation tillage can, in certain situations, encourage soil compaction.

Compaction, and particularly its restricting effect on root growth, can be difficult to assess. Observing root structure and depth at a time of active growth can be very useful.

> *"When addressing problems of soil degradation, think like a root."* (Shaxson, 2001)

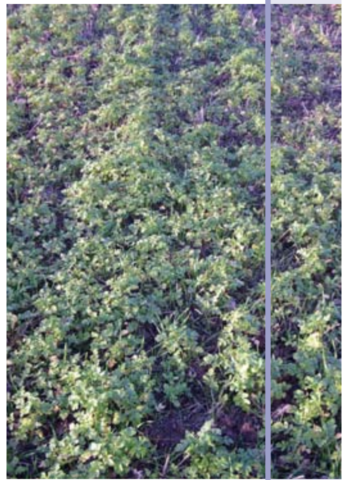
In well structured no-till soils, more roots have been found below 20 cm depth than in ploughed plots, even though bulk density and penetrometer resistance were greater without tillage. Regularly digging holes to identify possible compaction problems is essential.

Compaction can be alleviated by using appropriate equipment in the right soil conditions. A combination of sub-soiling and cover cropping has proved successful with the minimum amount of soil disturbance. For no-till systems, increased organic matter and earthworm activity will improve soil structure over time, but some farmers may feel they cannot afford to wait, and use some cultivation to supplement this.

Ground Cover

Crop residues provide excellent protection against erosion but may adversely affect yields. They help to build up organic matter, but that has to be set against short-term gains from selling straw or using it as feed. Rather than leaving residues, a cover crop may be sown over winter. Typical cover crops include mustard, phacelia, winter barley, or winter rye.

Selecting a cover crop means accounting for factors including the cost of the seed, fit in the rotation, requirement to protect the soil over shorter or longer terms and the need to guard against nitrate leaching. However, legume cover crops may also release nitrogen unpredictably during the following season and some cover crop residues, *eg* rye, can inhibit crop germination and establishment.



Mustard and rye cover crop

In temperate, high rainfall areas, germination and early development may be delayed by plant residue cover, but in warmer climates germination is usually promoted.

In cold, wet climates outside Europe, strip-tilling is used to prepare very narrow strips of soil to loosen, dry and warm it before the use of conventional drills. Alternatively, simply moving the residue from the seed row results in more rapid warming and germination. Modifications like these may extend the range of soils suitable for a no-till regime.

Sunflower crop established by strip tillage
Photo by G Basch

Crop Rotation

Conservation Agriculture systems require balanced rotational cropping, to minimise inputs and reduce soil problems and water pollution. Ideally no single crop species should occupy more than 25% of the farmed area and no crop group (*eg* cereals) more than 50% to provide the necessary diversity.

In designing rotations, the most profitable, market-driven crops for the region need to be identified and prioritised, and their potential role in biological, physical and chemical terms identified in order to fulfil a multifunctional set of demands (Table 4). Good rotations are based on principles which include rotating a core profitable crop such as winter wheat with others which provide various benefits. These may include a source of nitrogen or facilitate crop protection with reduced and more effective use of agrochemicals because they have different pests and diseases, and different competitive pressures on weeds, *eg* wheat – beans – wheat or growing in a sequence in which early harvest allows early drilling, *eg* winter barley followed by winter oilseed rape. Effective rotations may also include crops and pasture plants with strong tap roots able to penetrate and break down compacted soils.

Table 4. Some appropriate multifunctional crop rotations by region. Cereals and oilseed rape (OSR) are winter crops unless noted (Vereijken, 1996)

Position in Rotation	France	Germany	Italy	Poland	Sweden
1	OSR	OSR	Wheat	Sugar Beet	Wheat
2	Wheat	Oats	Beans or Clover	Wheat	Set aside
3	Barley	Wheat	Wheat	Barley or Potatoes	OSR
4	Set aside	Set aside	OSR	Wheat	Wheat
5	Wheat		Sunflower	Spring Barley	Oats
6	Barley			Triticale	Triticale
7				Grass	Peas

The long term profitability and environmental impact over perhaps several turns of the rotation is important, not any one crop.

In Conservation Agriculture the type and timing of fertilizer applications may need adapting to changing nutrient levels in soil and stratification of non-mobile components near the surface. Before implementation, soil nutrients at several depths should be checked and adjusted as necessary. Potassium, phosphorus, magnesium and calcium should be supplied according to the actual demands of the rotation, with nutrient supply balanced with removal. Taking account of organic nitrogen available within the crop rotation is likely to decrease the requirement for off-farm fertilizer inputs.

Nitrogen mineralisation starts more slowly in spring under no-till than with cultivations, but the overall amount during the season is similar. Sub-surface fertilizer placement or banding close to plant rows can increase accessibility of nutrients by plants in conservation tillage. Nitrogen losses (both leaching and gas emissions) are generally reduced by using Conservation Agriculture practices, although there has been some concern of increased emissions of nitrous oxide. Losses of phosphate are generally reduced under conservation tillage because these are mainly associated with erosion.

Greater herbicide use is often needed for effective weed control when Conservation Agriculture is first practised, but can decrease as management systems become established. However, there are examples where herbicide use and costs remain high due to the presence of resistant weeds (eg see Loddington case study). Some residual herbicides can be difficult to fit into Conservation Agriculture systems. The presence of residues on the soil surface may hinder activity, or there may be a risk of carry-over into the next crop, or both. This latter risk is removed by mouldboard ploughing.

Difficulties usually arise because of the failure to integrate the various practices under Conservation Agriculture. Stale seedbeds, correctly timed tillage, targeting grass weeds in broad leaved crops and broad-leaved weeds in cereal crops, modifying planting date, using broad-spectrum herbicides before planting together with other pre- and post-emergence products, are all options which need consideration.

Insects and other pests and virus vectors are often less serious in Conservation Agriculture because of more diverse cropping providing more hosts for predators. Crop damage is usually greater in loose seedbeds, so it is important to ensure the seedbed is consolidated and weeds are killed before drilling. Aphid-transmitted Barley Yellow Dwarf Virus is reduced without ploughing because surface residues deter aphids and provide an ideal habitat for predatory beetles and spiders that reduce aphid numbers and virus spread. In France, conservation tillage does not promote the occurrence of *Fusarium graminearum* (responsible for mycotoxin contamination) in wheat when the previous crop was wheat or sugar beet, but there is a problem when wheat follows maize. Slugs are regarded as a feature of conservation tillage in temperate climates but consolidation, greater sowing depth and, again, a good crop rotation will help reduce any damage.

Soil management systems do not directly affect disease despite variable levels of crop debris on the surface. Although disease inoculum on residues may infect emerging susceptible crops, this rarely leads to increased disease risk that warrants treatment.

Aphids are better controlled by predators in crops established by conservation tillage

CASE STUDY:
The Game Conservancy's Allerton Project, Loddington, Leicestershire, UK.

The Allerton Project is run on a 330 ha mixed arable and livestock farm in the English Midlands on heavy clay to better drained medium loam soils. The farm is set in an undulating landscape with several streams, woodland and permanent pasture. Annual rainfall is typically 600 – 700 mm and the annual mean temperature is 11^{o}C. Cropping includes wheat, oats, oilseed rape and beans. Conservation Agriculture was introduced in 2000.

Non-inversion tillage is standard practice but, where necessary - in wet conditions, for spring beans - ploughing is still used. Seedbeds prepared in the autumn are left rough until just prior to sowing. Where spring crops are to be planted, stubble is left over winter or a stale seedbed is used. Establishing crops based on ploughing cost around € 180/ha in 1999. Conservation tillage has reduced costs of crop establishment by 25% without affecting yields. However, the need to control (herbicide-resistant) blackgrass has increased weed control costs from € 30/ha in 1999 to € 112/ha in 2004. Changing from winter to spring beans has, however, helped grass weed control.

Crop residues are baled and removed or chopped and incorporated. Straw incorporation will be increased, particularly on fields with a tendency to erode. Manure will continue to be brought in, composted and spread. These policies will maintain and hopefully improve organic matter.

The manager and one worker run the farm and machinery has been changed in line with new practices as well as being shared with a neighbouring farm. This ensures sufficient power and capacity to complete work in time and includes equipment with the ability to conduct two operations in one pass, *eg* plough with a furrow press and sub-soil with discing. Improved machinery capabilities and changing to spring beans have enabled more contract work to be done and capital costs to be spread further.

Philip Jarvis, farm manager

Maize

Maize is often criticised for its environmental impact but it is also key to rotations in many European countries, particularly because of its potential to produce biomass above and below ground.

In a Conservation Agriculture system the main advantages of maize include:

- As a spring-sown crop, it spreads work-load from the autumn and allows over-wintered stubbles (see Biodiversity section for more information)
- Weed management allows changes in herbicides used throughout the rotation, so limiting the development of resistance. A very competitive leaf canopy also limits weed growth
- Extensive and deep root system
- Rapid decomposition of crop residues and roots
- Encourages healthy soils through its associations with mycorrhizae and other soil organisms

Planting maize by conservation tillage techniques is easy on well-structured lighter soils, but heavier or compacted soils can present a problem. Solutions may be found in sub-soiling and strip tillage. Soil cover is then allowed to remain between the rows, reducing evaporation and weed growth. Strip-tillage also maintains the load-carrying capacity of the soil and improves its structure and biological activity.

Crop establishment is often slower in no-tillage systems due to reduced mineralisation of nitrogen in spring. However, this actually favours a better grain-to-straw ratio.

Establishment of maize under no-till (left) and a plough-based system (right).
Photo by WG Sturny

Banding fertilizer (nitrogen and phosphorus) at planting and selecting suitable varieties can improve results further.

New techniques in seed placement, *eg* narrower rows, are also being explored. These have implications for harvesting equipment in grain maize, but would be suitable for silage crops.

Good crops demand a lot of water and irrigation is often necessary for optimum yields. Irrigation needs can be reduced under Conservation Agriculture by:

- Cover crops and less soil disturbance reducing evaporation of soil moisture reserves
- Well-structured soils allowing good infiltration of water, higher water-holding capacity and full exploitation of the profile by roots

Maize planted directly into an oat cover crop in France.
Photo by F Thomas

Maize planted directly into a flowering turnip crop in Switzerland (left). The green manure plants are then sprayed off with a non-selective herbicide to provide a favourable microclimate for the maize seedlings and also to protect against, eg erosion, pesticide run-off and nitrate leaching (right). Photos by WG Sturny

Summary of Benefits and Limitations

Evidence from research and practical experience of testing and implementing Conservation Agriculture approaches in Europe shows that these techniques have a number of clear benefits which, with a few caveats, can be used to protect soil and water.

Soil

- Reduces erosion

Evaluation of 68 papers containing 160 single results from temperate climates on effectiveness of conservation tillage practices revealed a high potential of these practices to reduce soil erosion (Strauss, 2003).

- Increases organic matter content
- Improves biodiversity

Water

- Reduces diffuse pollution

In surface and ground waters considerable reductions in all major pollutants have been achieved: total phosphorus loss (81%), available phosphorus loss (73%), total oxidised nitrogen (94%), soluble phosphate (78%) (Jordan *et al*, 2000); also, in no-till, lower herbicide (*eg*, IPU) losses in run-off due to reductions in run-off volumes, better absorption to organic matter on the surface and in topsoil, and faster degradation due to higher microbial activity (Basch *et al*, 1995). Only in the case of highly persistent and low-sorptive chemicals, *eg* clopyralid, could potential for groundwater contamination increase under conservation tillage.

- Improves soil water storage capacity

This can aid germination and means that conservation tillage soils are less prone to drought. In contrast, conservation tillage requires dry conditions and this can be an issue in more temperate climates.

- May reduce run-off volume

Other Benefits and Limitations

Other benefits to the environment include the potential to offset greenhouse gas emissions by sequestering carbon in undisturbed soils (no-till has the greatest effect). However, the possibility of increasing nitrous oxide emissions has been recognised.

Conservation tillage is not suitable for all soil types and can be hard to implement in cool, wet climates. Furthermore, there is always a need to guard against the possibility of compaction. Specialised drills are needed, whatever the soil type, to cope with plant residues and achieve a uniform depth of seeding.

For farm profitability, despite the need to invest in new equipment and often the requirement for more chemical weed control, conservation tillage offers substantial opportunities for considerable cost, time and energy savings.

OLIVES, VINES AND OTHER PERENNIAL CROPS

Olives and vines (grapes) are the major perennial crops grown in the EU, comprising 46% and 33% of the total, respectively. Other perennial crops, like apples, pears, peaches, citrus and nuts are widely grown, covering over 10 million ha before the 2004 enlargement of the EU. The vast majority of these crops are grown under high summer temperatures with variable amounts of rain or irrigation described by four agro-climatic situations:

- Dry, rain-fed conditions: Mediterranean and eastern Europe
- Moist, rain-fed conditions: Western, Central and Northern Europe
- Irrigated systems: where summer drought, high production intensity or crop choice require additional water supply
- Steeply sloping and hilly regions with extensive to semi-intensive systems: in all European countries where perennial crop production is of importance, but mainly used for olives, grapes and almonds.

The major threats to soil posed by growing perennial crops arise from their frequent location on slopes, the possibility of bare soil between crop rows over winter, and the fact that they are grown in areas with generally low levels of soil organic matter.

Water availability can be limiting in many areas of perennial cropping and demands for irrigation are increasing as production intensifies, putting further pressure on an already scarce resource.

Photos in this section are by J Gómez

Conservation Agriculture in Perennial Crops

- **Cover Crops in Vines:** In Germany, it is estimated that only 10% of vineyards are still under conventional management (Fox, 2005)
- **Cover Crops in Orchards:** Planting cover crops in alternate inter-rows is typical in German orchards (Ruess, 2005)

The principles of Conservation Agriculture were mainly developed in arable crops which are established and rotated at least once each year. In perennials, of course, the concept of rotation does not apply because crops are in the ground for decades. Although soil cover and minimum soil disturbance is equally important, Conservation Agriculture techniques are applied not only to establish the crop, but also, and more importantly, while the crop is growing:

- To establish the crop: terracing, planting following contour lines, and minimum soil disturbance
- After the crop is planted:
  - a) Non-inversion tillage used inter-row to manage weeds, following contour lines when possible
  - b) Using cover crops between crop rows, or mulching with on or off-farm materials
  - c) Controlling traffic to eliminate or reduce soil compaction

Traditional soil management is very similar in all established perennial crops and based on the use of different tillage implements between the rows and chemical weed control along the crop row. In Conservation Agriculture, planting cover crops or allowing the regeneration of natural flora between crop rows is the most common practice. Grasses, alone or in mixture with legumes, are typically grown for cover. Cover crop growth is managed to allow the demands of the crop for water to be met, so that, in general, the cover is cut or sprayed with low rates of herbicide to reduce its competitiveness at appropriate intervals.

Conservation Agriculture techniques are most effective when used to complement each other. For instance, contour tillage and the application of pruning residues, terracing and a cover crop, or a cover crop and addition of composted material. However, the effectiveness of one or a

combination of techniques will depend on the farmer's ability to adapt the technology to the specific soil and agro-climatic conditions on the farm and to balance benefits and costs most advantageously.

Soil management in perennials usually differentiates between the row space and the inter-row space. There are several options for both areas. In the inter-row, the soil and its cover can be managed using tillage, mowing or herbicide application, or a combination of the three, depending on the local conditions and management objectives. Weeds are allowed to grow along the crop rows in winter, but are controlled during the growing season to prevent competition with the crop and to allow access for harvesting. Non-systemic herbicides with no residual effects in the soil are recommended. Regrowth or new flushes of germination then ensure that a weed flora re-establishes in late autumn.

Conservation Agriculture can contribute significantly to mitigate erosion, soil degradation and management problems in perennial crop production. However, time savings through the reduction or elimination of tillage may be outweighed by cover crop management requirements (Table 5). Nonetheless, significant improvements of trafficability will contribute to an overall saving in time, fuel and other inputs, due to the timeliness of, and opportunity for, operations.

Table 5. Annual costs of various soil management systems in olives in Spain (Humanes, 1992)

Cultivation Practice	€/ha per annum
Ploughing	141
Non-inversion tillage plus chemical weed control	126
No-till plus chemical weed control	87
Cover crop managed by herbicide	96

Guidelines for Implementation

Each of the four agro-climatic situations described above present Conservation Agriculture with particularly important agronomic and environmental challenges to address, with some common to many situations (Table 6).

Table 6. Key agronomic and environmental challenges in the main agro-climatic regions

Agro-climatic conditions	Objectives for Conservation Agriculture
Dry rain-fed	Restrict competition for water by weeds Increase infiltration and control evaporation Reduce soil degradation and restore or maintain soil fertility
Moist rain-fed	Avoid water logging
Irrigated	Restrict competition for water from weeds Increase infiltration and control evaporation Reduce soil degradation and restore or maintain soil fertility Reduce off-site movement of agrochemicals and sediments
Hilly	Improve soil quality of reduced rooting zone Increase infiltration Avoid mass movement of soils Reduce off-site movement of agrochemicals and sediment

Soil Management

The slope, state of the soil, climate, the need for irrigation and equipment available are important in the management of a farm's soil and water resources.

- Slope: Steepness, length, overall topography
- Soil condition: Structure, texture, organic matter, erodibility, stone content and coverage, depth and density
- Climatic conditions: Total rainfall and its distribution, evapotranspiration, temperature and number of frosts

Contour planting

- Irrigation: Amount and period of required irrigation, available water resources
- Technological resources: Availability and suitability of equipment

Evaluation of these factors and determination of appropriate solutions should be made before and after establishing a new crop.

Before planting a new orchard, grove or vineyard, consider:

- Terracing: On steep slopes and highly erodible soil, where other Conservation Agriculture practices cannot guarantee erosion prevention
- Contour planting: On moderate slopes, rows and all agronomic operations follow contour lines
- Strip tillage: Soil preparation, *ie* deep loosening (sub-soiling) and ameliorative interventions are restricted to strips along the rows parallel to the slope

Most often, adopting a Conservation Agriculture approach will be under consideration for established orchards. Here, conservation tillage techniques (as described in the arable section) or growing cover crops between the crop rows will be most appropriate. Controlling competitive weeds and caring for the soil along the crop rows will be best achieved by using a broad-spectrum, non-systemic and non-residual herbicide to avoid damaging plant roots.

■ **Cover Crops in Olives:** In olive groves the use of cover crops reduced soil loss due to water erosion by 88% on average compared to conventional tillage. There was also a reduction in surface run-off of approximately 70% (Gómez *et al*, 2005)

Ground Cover

A number of materials can be used to cover the soil between the crop rows, including arable crop residues or chipped bark as has been used in the Champagne region of France. However, planting of cover crops, mulching in straw or other plant residues or simply allowing the regeneration of natural vegetation are cost effective options. In southern France, a mixture of grasses (ryegrass and two types of fescue) is sold commercially on its anti-erosion capabilities.

Ground cover in perennials: A) straw mulching in a vineyard; B) cover crop in an olive orchard

The use of cover crops in perennials has been shown to greatly decrease soil and run-off losses and improve topsoil organic matter content and water infiltration.

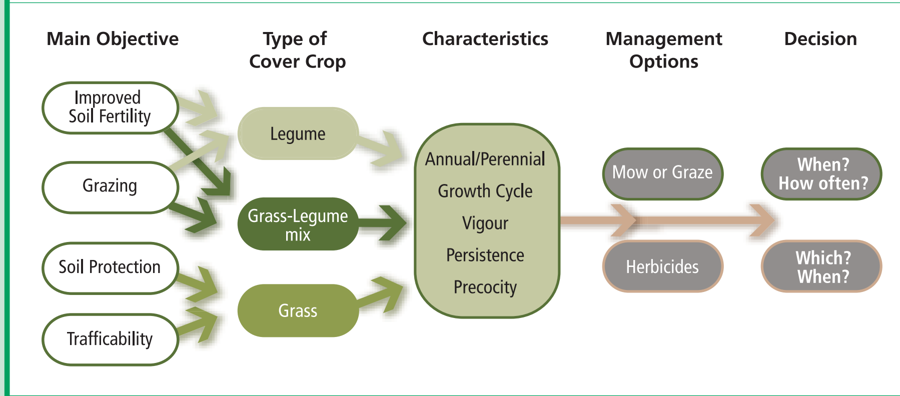
While cover crops do protect the soil they can pose some dilemmas for farmers:

- In orchards and vineyards there may be an increased risk of late frost damage to emerging leaves because of the cooling effect of a vegetative cover
- Growing legumes in vineyards, may have a negative effect on grape quality for wine because of the extra nitrogen available to the crop
- Choosing annual or perennial cover crops strongly depends on the availability of water (rainfall, irrigation or soil reserves) during the growing season of the main crop and whether competition from the cover crop needs to be restricted during this period. If water is scarce, planting an annual species which will mature and set seed before it becomes a limiting factor is the best option. A natural vegetative cover can be allowed to re-establish when the rains come. In addition, re-planting the cover crop every autumn is time-consuming, uneconomic and not very effective. Perennial cover crop species (mainly grasses), however, could also be an option using species with summer dormancy or only planting every second row

Cover crop management depends not only on the species and variety and the main objective for using it, but also on other considerations such as costs, orchard characteristics, weather conditions and irrigation facilities. Typical management options involve mowing or spraying with herbicides.

In general, locally adapted species should be the preferred option, although seed is not always commercially available. This is partly why in some areas, *eg* olive groves in southern Spain, farmers prefer natural vegetation as ground cover. The presence of particular species can be influenced by time and height of mowing. Troublesome species like thistle or bindweed may need additional management to prevent loss of crop yield. Rotating different cover crops has been suggested. Considerations on what species to use and management options are outlined in Fig 3.

Figure 3. Simplified decision tree guiding the choice and management of cover crops in perennials



Cover crops do have limitations. On steep slopes, it may still be difficult to control erosion without careful management and the use of other techniques such as terracing or contour planting. Realising the benefits of Conservation Agriculure depends on proper training and implementation by the farmer.

CASE STUDY:
Santa Marta, Benacazon Spain.

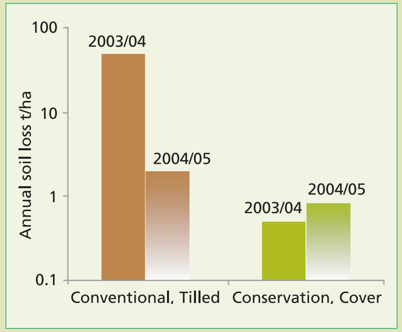
Santa Marta is a 21 ha farm, with 14 ha of orange trees on flat land and 7 ha of olives on hillsides, all under drip irrigation. Until 1995, inter-rows in both areas were cultivated conventionally several times a year to increase infiltration and control weeds. Erosion was a problem after rain (see picture below).

In 1995 a new soil management system was introduced allowing natural vegetation to cover the inter-row area during autumn and winter. This cover was mown in spring to reduce competition for water and the risk of fire. Strips along the olive rows are kept weed-free using herbicides. The only new equipment required was the mower. A visible reduction in soil erosion and the steady improvement in soil condition, improved machinery access and encouraged the farmer to use Conservation Agriculture on the whole farm.

The graph below shows the significant reduction in erosion (2003-2005) achieved by allowing natural vegetation to cover the soil. This was especially great in the wetter 2003/4 season (note the log scale). Run-off and nutrient losses were also reduced.

The left hand photograph shows erosion from unprotected soil after a severe storm. The photograph above shows a plantation utilising good ground cover provided by natural vegetation.

Soil erosion by water, comparing a cover crop and conventionally managed system (Lane *et al*, 2005)



Summary of Benefits and Limitations

The specific approaches to Conservation Agriculture have to be adapted for perennial crops, but the fundamentals are the same as for arable crops.

The evidence reviewed in this section indicates that Conservation Agriculture techniques can be used to protect soil and water in perennial crops:

Soil

- Reduction in erosion

A recent review of research has found that soil erosion from inter-row areas can be reduced by 88% by growing a cover crop (Gómez *et al*, 2005).

- Improved soil structure
- Higher organic matter content

Water

- Generally reduced volumes of run-off

Results from several field experiments in olive groves have found a reduction of 70% in the volume of run-off from land where cover crops were grown in the inter-rows compared with that from tilled areas.

- Reduced diffuse pollution from nutrients and agrochemicals
- Improved infiltration and reduced evaporation

Economic upsides

As with arable crops there are similar other potential benefits to climate change, costs, time and labour requirements, and energy efficiency associated with fewer tillage operations. Importantly, access to the crop is improved through better load bearing of the soil.

Risks and limitations

Against these potential benefits must be off-set some risks associated with cover crops:

- Need to guard against the possibility of compaction
- Growing alongside the main crops, cover crops can compete for water and nutrients, and increase the risk of frost damage
- Higher soil nitrogen can reduce the quality of wine grapes
- Although they can improve biodiversity they can also attract and harbour pests and diseases
- They can present a fire risk when desiccated

There is also a safety risk in the possibility of tractors overturning on steep terrain with contour tillage and planting.

Economic downsides

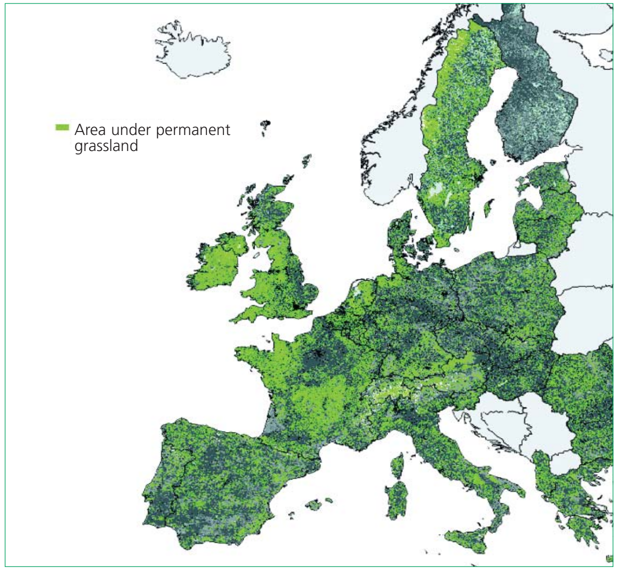
These include:

- Terraces are expensive to build and maintain
- Increased herbicide use
- New equipment may be required

GRASSLAND

In 2003, 35% of the utilised agricultural area in the EU15 was designated as permanent grassland (Fig 4). Although the wetter conditions of northern Europe favour grassland, 51% of sheep, 83% of goats and 18% of beef cattle in the EU are farmed in southern Europe and much of their production relies on grass (Eurostat Census 2000 data for EU15; Eurostat, 2006).

Figure 4. Area under permanent grassland in utilised agricultural area (UAA) in EU15 in 1995 (From: Environmental Signals 2001. Environmental assessment report No 8, EEA, Copenhagen, 2001)



There are many pressures on European grassland. Intensification has been a major development over the last 30 years. Other trends throughout Europe include greater consumption of imported feed and a reduction or loss of grazing in preference to housed animals.

Photo left by JM Garrido

Conservation Agriculture in Grassland

The main categories of grassland agriculture include

- Temporary grassland as part of arable rotation
- Rotational grazing: managed grazing of two or more areas
- Continuous stocking: often in marginal or rough areas

Except for one-year leys, grass is a perennial crop and as noted in the previous section, principles of Conservation Agriculture developed for arable crops do not directly translate to perennial crops. Soil management is equally important, however, and is extended through the life of the crop. After establishment, stocking rates, susceptibility to animal and machinery traffic, and the application of fertilizer and manure all need attention. Cover crops and rotation, however, are not directly relevant, but some of the benefits these give in arable crops can be realised by including clovers or other legumes in swards. As part of an arable crop rotation, temporary grass can be very important for soil structure and fertility.

Soil Erosion: Erosion of topsoil from grassland and arable land contribute on average 46% and 31%, respectively, to the sediment load for 34 catchments throughout the UK (Walling, 2005)

Conservation Agriculture techniques specifically used in grassland farming include extensification of grazing, reliance on organic rather than inorganic fertilizers, and increased diversity of species. Slot seeders are valuable tools in re-establishing grass swards without tillage.

Erosion and compaction are the key threats to grassland soils. Losses of sediment, organic matter, faecal organisms and nutrients are the principal causes of surface and ground water contamination in grassland areas.

Guidelines for Implementation

Where grass is grown in wetter western and northern areas of Europe, the generally high soil moisture promotes greater yield, but can also be a major limiting factor. Soil structure becomes more vulnerable to poaching by animals and compaction as soil water content increases, particularly at high stocking densities. Poaching can also lead to erosion and nutrient loss. Soil erosion from over-grazed and degraded grassland systems may be even greater than that from arable land. This is encouraged by grassland often being situated in high rainfall, hilly areas unsuitable for arable cropping.

The prevention of overgrazing, regulating the number of animals on the land, and stopping large numbers of animals or machinery travelling on wet soil are all important techniques to protect grassland soil. Regulating the access of animals to fields, and feeding and watering points, by careful location of trackways, gates and troughs, should also be carefully planned

Grazing must be carefully controlled to avoid damage to soil structure

Except where soil moisture becomes limiting, small increases in fertility can lead to greater profitability. Fertilizer rates depend on stocking density and nutrient status of the soil.

Slurry application by 'trailing shoe' equipment Photo by D Godwin

Using inorganic nitrogen fertilizers is typical but including legumes (which fix nitrogen) can increase the efficiency of nitrogen use and reduce variability of supply through the season. However, nitrous oxide emissions from legume systems can be high. Manure and slurry can also be cost-effective substitutes for inorganic fertilizer but their nutrient content should be monitored. Reduction in the use of inorganic nitrogen fertilizer will save on direct input costs and indirect use of energy resources for manufacturing and transport.

Fertilizer is best applied when the plants need it during active growth to minimise loss by erosion and leaching. The way in which slurry and manures are applied to the land is important: not applying on wet soils will avoid compaction. Broadcast application gives the highest levels of ammonia loss, but, injecting into the soil can damage the crop. Other methods, *eg* the trailing shoe shown left are safe to crops and reduce contamination.

Ryegrass cropped with clover Photo by G Basch

The choice of grassland species and their management is important for both productivity and the environment. This directly affects the intensity with which the land can be used. For example, permanent pasture usually has a wide range of grass species and often a good soil structure that can take a lot of physical abuse, while temporary grassland of 2 to 3 years is typically less resilient.

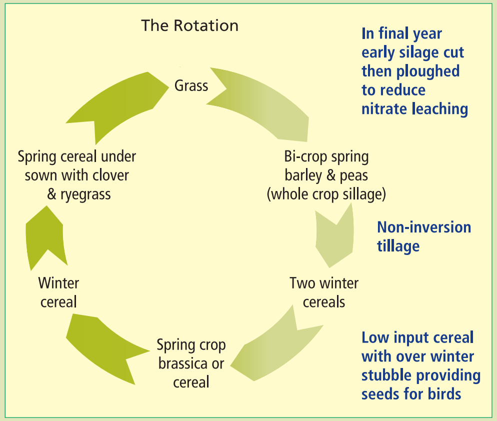
While intensively managed monocultures may support higher yields, there are advantages to be gained from using mixed species. For example, diverse communities can often adapt to environmental changes, and nitrogen leaching may be reduced because fixation and uptake are more evenly balanced; productivity may even be increased. Maintaining and even increasing productivity will be important in reducing costs. A grass-legume mix can be more beneficial than grass alone because of the higher nutritive value.

Heavy grazing is sometimes encouraged to maximise productivity per unit area. However, overgrazing puts soil quality at risk by reducing organic carbon inputs to the soil and increasing the risk of erosion. Undergrazing can also lead to deterioration because of less stimulation to produce new shoots and roots. In the Sierra de Guara Natural Park, Spain, undergrazing has led to an invasion of shrub vegetation and an increased risk of forest fires.

CASE STUDY:
Great Wollaston Farm, UK.

Great Wollaston is a family-run farm of 98 hectares of which 16 hectares is grass or permanent pasture.

The farm has a dairy herd of 110 cows. Manure produced is recycled onto the land and has improved soil fertility and strengthened soil structure. Around 64 hectares of the farm are managed on a rotation of short-term grass/red clover leys for silage, grass/white clover for grazing, and arable crops.



This type of rotation system has both environmental and economic advantages. For example, the introduction of spring cropping and cereals has increased bird numbers and diversity on the farm, and growing peas with the spring barley increased the protein level in animal feed.

Acknowledgement: information for this case study was provided by LEAF (www.leafuk.org)

CASE STUDY:
Herdade dos Esquerdos, Vaiamonte, Monforte, Alentejo, Portugal.

Herdade dos Esquerdos is a 285 hectare cork/holm oak "montado" of 30-40 trees/ha: an agro-silvopastoral system based on cork-oak or holm-oak trees and relying on paid labour. Montado is a very extensive system, well suited to this area where the vegetation is fragile because of the stresses placed on it by summer droughts and heavy winter rainfall, and the soil is prone to erosion.

Until the early 1970s, the estate was farmed traditionally, using a 9-year rotation (6 years pasture), characterised by low yields of cereals and a stocking rate equivalent to less than one sheep per hectare per year. A gradual transition to improved, legume-rich pasture was then made, with 88% of the land used for permanent pasture by the late 1980s, driven by a range of economic factors.

In the 1970s the soil was very poor in phosphorus (less than 2 mg/kg) and organic matter (0.7-1.2%). By 2004 levels of phosphorus in the soil had increased to 11-29 mg/kg, the lowest values being found on the continuously cropped land for hay. Organic matter had also risen considerably to 1.45-4.4%. This has increased the water holding capacity of the soil and significantly reduced soil erosion.

Acknowledgement: Information for this case study was provided by DG Crespo, Fertiprado, 7450-250, Vaiamonte, Portugal

A typical Mediterranean grassland landscape
Photo by J Milgroom

Summary of Benefits and Limitations

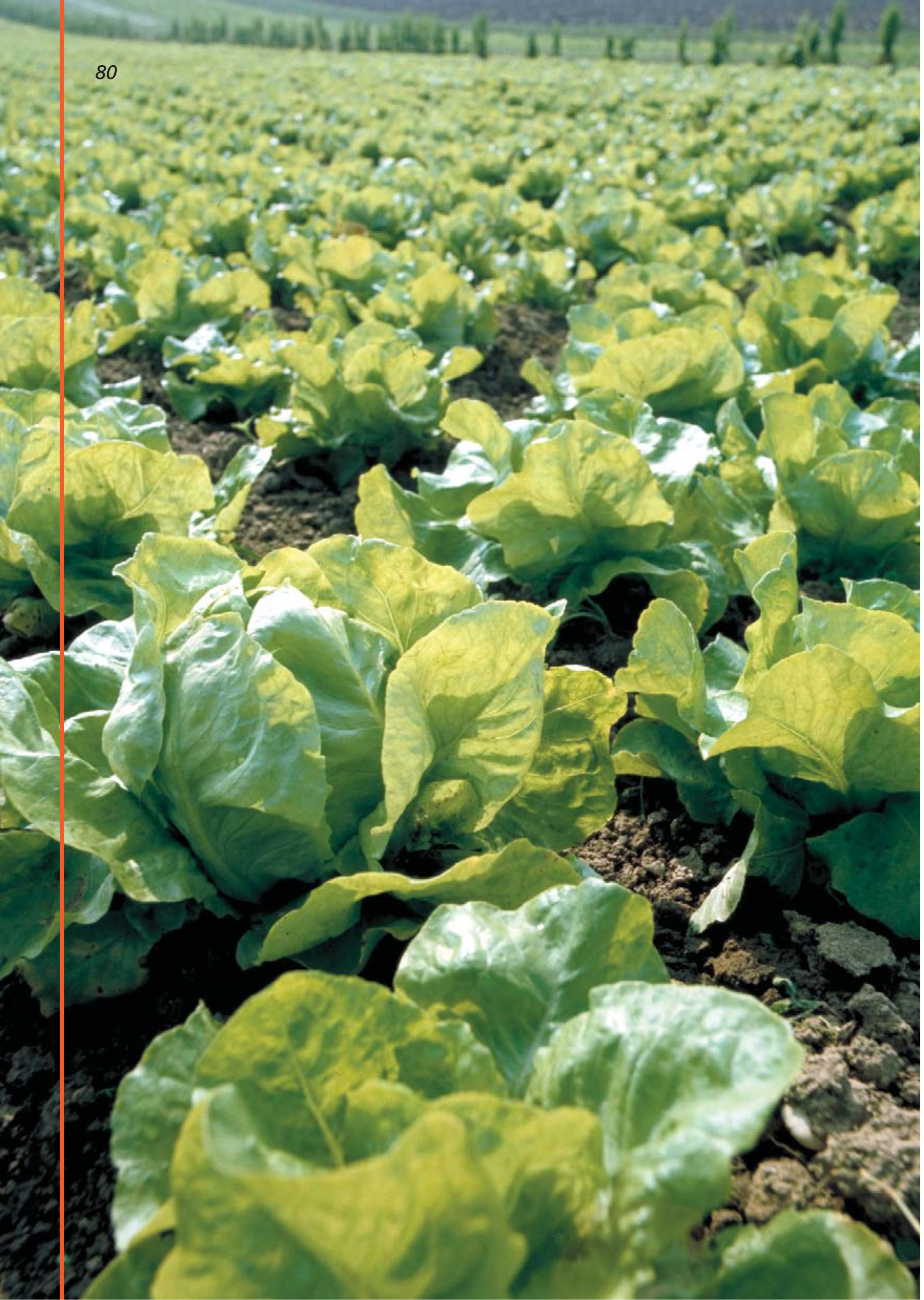
The key principles of successful Conservation Agriculture in grassland involve:

- Reducing pressures associated with animal, machinery and human traffic
- Changing the reliance on inorganic fertilizers to organic fertilizers
- Monitoring soil, manure and slurry nutrient content, and also soil water content
- Encouraging a diversity of species

Particular benefits include:

- Increased resilience and productivity of soils
- Reduced risks of nutrient loss by leaching
- Lower fertilizer costs

Some limitations exist, particularly the potential for reduced biodiversity with the improvement in grassland quality, and the cost of specialized equipment for slurry application.



FIELD VEGETABLES

Field vegetables are not easily defined because, for instance, some can simply be regarded as arable crops, *eg* potatoes, others, *eg* tomatoes, are also grown under glass, and many are grown in the field, but under polythene and are classed as protected crops. Similarly, fruit crops such as strawberries may be farmed in much the same way. However, the agronomic features and issues of crops in this general category are clearly different to those of more mainstream arable crops.

Although small areas are grown (Table 7) vegetables may be very valuable on a per hectare basis. As high-value crops, often with strict quality criteria, management is generally quite intense.

Vegetables are important in the agricultural economy of some European countries. Although vegetables (excluding potatoes) are grown on less than 2% of the cropped area of half of EU-25, they account for 8%, 10% and 11% of all cropland in Italy, Belgium and The Netherlands, respectively. Potatoes are also very important to The Netherlands at 24% of the cropped area.

Consumers are more interested in fresh, frozen or canned vegetables than in arable crops, and international food processors and retailers now set standards for production methods. In addition, they demand carefully planned supplies and insist on high quality and uniformity. Farmers have to

Table 7. Fresh field vegetable crops (>100,000 ha) in EU-25 (FAO data for 2004)

Vegetable Crops	Harvested Area 2004 (ha)	Leading Producers
Potatoes	2,249,240	Poland, Germany, Netherlands, France, UK
Cabbages	151,420	Poland, Germany
Onions	147,382	Poland, Spain
Peas	146,101	UK, France
Lettuce	130,045	Italy, Spain
Carrots	121,327	Poland, Italy
Cauliflower	118,781	France, Spain, Italy

- **Value of Vegetables:** In the UK, the output of wheat in 2004 was valued at £1.2 billion, worth on average £614/ha, while the output of potatoes was £633 million, worth on average more than £4000/ha (Defra, UK)

deliver what customers want, despite sometimes volatile markets.

Important agronomic factors particularly relevant to vegetables include:

- Erosion is more problematic on the lighter soils used for vegetable production. Light soils allow ready and frequent access to fields to meet production schedules, fertilize and protect from weeds, pests and diseases to achieve high yields and quality, and to harvest to demand
- Root vegetables can make a significant contribution to erosion when soil is removed from the field with the crop at harvest
- Light soils are also more prone to leaching of nitrogen and pesticides. These problems are exacerbated when irrigation is not properly planned
- Highly mechanised production with intense tillage and heavy traffic potentially causes soil compaction
- Legumes can have major benefits, particularly for following crops, because of the nitrogen they leave in the soil
- Many vegetable crops, *eg* lettuce, brassicas, are often transplanted out into the field, so some form of tillage is inevitable
- Decision models are widely used to predict the need for irrigation or pesticide sprays, *eg* against potato blight, and can avoid the use of excessive inputs

Several current practices have no effective alternatives in Conservation Agriculture. For example, soil fumigants are used to control, *eg* violet root rot of carrots (*Helicobasidium purpureum*) and potato cyst nematodes (*Globodera pallida* and *G. rostochiensis*). Research on biological control methods for these nematodes is in progress, though. Removing stones before planting root crops can damage soil structure. Lettuce is often grown three or four times per year, with associated cultivations being detrimental to soil fauna and flora as well as soil structure. Many vegetables are grown in wide rows with low crop cover for several weeks during establishment, risking soil erosion.

Conservation Agriculture in Vegetables

Most of the experiences of using Conservation Agriculture approaches in field vegetables come from the areas of intensive production in the valleys of California. There, conservation tillage techniques for vegetables include:

- Equipment to allow several operations to be completed at the same time
- Cultivators and drills matched to bed systems which are kept for several crop cycles
- Machinery capable of coping with cover crops and previous crop residues
- Global Information Systems which allow cultivations and other operations to be precisely positioned

These illustrate the sort of machinery and technology requirements to make widespread adoption feasible.

For more information, the website **www.ipmcenters.org** includes agronomic profiles of many vegetable crops across the US where experiences of implementing Conservation Agriculture have been much more extensive than in Europe.

Guidelines for Implementation

The principles of Conservation Agriculture of minimal soil disturbance, soil cover and good rotations can be adapted for field vegetables, though not always successfully.

■ **Delayed Harvest:** Cabbages transplanted into no-tilled soil grew more slowly and were harvested three weeks later than a crop grown under conventional tillage (Borowy, 2004)

Soil management
In sandy loam soils often used for growing vegetables, conservation tillage has usually improved soil structure and reduced soil erosion. Soils under conservation tillage, though, are slower to warm in spring than ploughed land and this can slow crop development. Although final yields seem generally little affected, delays in harvesting many crops including potatoes, carrots, red beet and cabbages have been reported.

Late harvested root crops like potatoes demand careful soil management

Root crops like potatoes are already often harvested late into the autumn. Heavy harvesting equipment used on wet soils can cause severe compaction problems. Sub-soiling before and after potato crops is common practice. In one system, sub-soiling is confined to the crop row with no-till in the inter-row. This has improved potato yields and soil structure, and reduced soil erosion.

Compaction has led to large reductions in potato yields (around 40%) in The Netherlands, but the level of yield effects depend not only on the nature and degree of compaction, but on soil type, moisture levels, nutrient supply and climate.

Encouraging earthworms in other parts of the rotation may help alleviate compaction. Potato growing is often not, however, conducive to maintaining this advantage. Although earthworm populations were over three times greater in conservation tilled winter wheat grown with a white clover understorey, they were virtually elimated by a combination of ploughing and other soil cultivations used to establish the following potato crop and its subsequent harvesting.

Soil cover
Cover crops grown over winter in vegetable fields have improved soil structure, reduced nitrate leaching and reduced erosion. Straw mulches have also given soil benefits, including raising organic matter levels and some improvement in water-holding capacity.

Rotations
Rotations can help to provide effective crop protection in vegetables. For instance, pest pressure in tomatoes has been reduced when grown in a rotation with maize and cucumber compared to crops grown continuously.

Growing red clover after spring barley has significantly reduced the severity of several soil-borne diseases in following potatoes. Bacteria isolated from conservation tilled soils after red clover have been shown to be more effective at suppressing the growth of these pathogens.

■ **Less Soil Erosion:** Mulching straw into a fine sandy loam cropped with potatoes reduced erosion by 50% (Edwards *et al*, 2000)

■ **Nitrate Leaching Reduced:** Cover crops of rye or phacelia grown between broccoli crops reduced nitrate leaching over winter by up to 70% (Wyland *et al*, 1996)

■ **Crop Protection Benefits:** In Poland, no-tillage and a rye cover crop slowed the growth of weeds and reduced the presence of aphids in carrots (Borowy, 2004)

The heavy use of insecticides in many vegetable crops has raised the serious issue of pest resistance. Robust rotations are most often not sufficient alone to reduce the need for crop protection inputs. Biological control with Bt (*Bacillus thuringiensis*) strains have been alternated with chemical insecticides to control Diamond-backed moth in brassica crops to reduce risks of resistance developing.

Cabbages grown in a no-till system have yielded well, but were late to harvest

Summary of Benefits and Limitations

- Conservation tillage practices and cover crops have major benefits in reducing erosion and compaction and adding organic matter on light soils. They can improve soil structure, reduce infection by soil-borne pests and improve water retention
- However, non-inversion tillage and mulches can slow crop growth and reduce yields or delay harvests
- Integrated methods of pest control, including appropriate crop rotations, can reduce the quantity and frequency of chemical pesticide application and avoid problems of pest resistance
- Legumes have substantial nutritional benefits for other crops in the rotation, but, under some circumstances, the nitrate they release into the soil may be prone to leaching
- As the appearance of produce is very important to supermarkets and consumers, there are considerable cultural barriers to change
- Machinery and associated technology must be readily available and appropriately priced to ensure adoption

ENHANCING BIODIVERSITY

Biodiversity describes the variety and abundance of life within a habitat. More than 50% of European land area is directly affected by agriculture, either being farmed, or in adjacent non-cropped marginal areas, so land management practices have a profound effect on biodiversity. Soil condition has a considerable effect on the biodiversity contained within it, and also a range of direct and indirect effects on higher level flora and fauna.

Successful ecosystems include life at all levels in the food web (Fig 5). Plants grow by photosynthesis. They are consumed by a range of micro-organisms, invertebrates and larger animals. In turn, a number of bird and mammal species are higher-level predators and are often used as 'indicators' of the overall state of biodiversity.

This section considers both terrestrial and aquatic biodiversity and their responses to Conservation Agriculture systems.

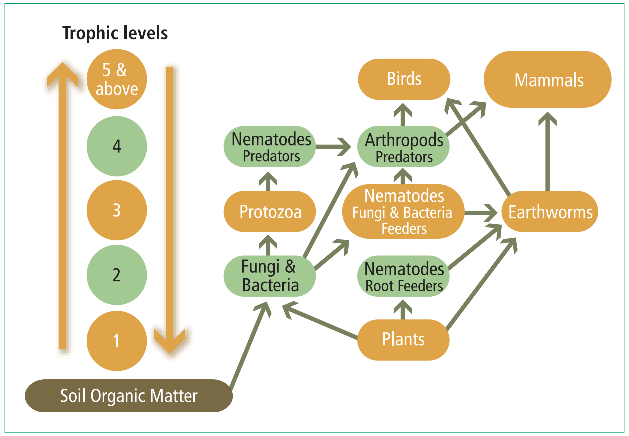


Figure 5. The food web

Terrestrial Biodiversity

Agricultural Intensification and Loss of Biodiversity
There have been sharp declines in farmland bird numbers across Europe in recent decades, most pronounced when farm production has been subsidised in the EU or the former Soviet Bloc. Available data suggest similar patterns of decline for other groups, such as invertebrates and certain flora. It seems clear that the drive for increased productivity has led, unintentionally, to a widespread loss of farmland biodiversity.

Once common, arable weeds like cornflower (Centaurea cyanus) are now rare

Grasslands are important for biodiversity and their loss across Europe has led to the breaking up of habitats. Plant diversity has also been reduced by use of various inputs, re-seeding, land abandonment and changes in grazing and mowing regimes. Careful management of grazing and fertilizer use can be used to provide more suitable environments for a range of plants, invertebrates and birds.

No single element of intensification has been wholly responsible for the declines in biodiversity. Different factors, or combinations, have affected different species or groups of species. Table 8 lists some of these. Consequences can be direct or indirect as effects on plants or invertebrates can be transmitted up the food chain to vertebrates such as birds.

*Table 8. Some key changes on European farmland since the 1960s that have affected biodiversity (*Newton, 2004; Stoate *et al*, 2001)

Farming practice	Examples of effects on farmland environment and habitats
Increased mechanisation	More efficient harvesting with less waste and spillage of seeds for birds, invertebrates and mammals to eat.
Increased inputs	Higher crop growth rates and density. Leads to reduced nesting opportunities for birds; reduced floral diversity; less food for wildlife generally.
More and earlier autumn-sowing	Loss of over-winter stubbles and the seeds they contain. Leads to lack of food for invertebrates, birds and mammals.
Simplified crop rotations	Reduced habitat diversity at farm and landscape scales – large scale monocultures reduce feeding and nesting opportunities for birds.
Drainage	Loss of wet meadows. Leads to loss of wetland-dependent flora and fauna (including wading birds).
Switch from hay to silage	More frequent cutting, reducing floral diversity and hence invertebrate diversity. Destruction of bird nests.
Increased stock densities	Increased trampling and soil compaction. Loss of bird nests and reductions in soil organism numbers.

Following the Rio Convention on Biological Diversity, commitments have been made to reduce declines in biodiversity by 2010. For farmland in the EU, this should partly be achieved by the modulation of CAP funds away from production towards rural development, including agri-environment schemes.

Conservation Agriculture and Terrestrial Biodiversity
The benefits of Conservation Agriculture include:

- Increased ground cover can be advantageous for ground-nesting birds

- Greater precision in pesticide use can reduce the impact on non-target species
- More diverse rotations give greater feeding and nesting opportunities and reduce the build-up of pests

A skylark nest in winter wheat established by conservation tillage
Photo by R Field

Conservation tillage can have a range of benefits for wildlife and, although these are not unequivocal, some generalisations can be made. Larger invertebrate species are often more adversely affected by mouldboard ploughing. Earthworm populations are reduced by ploughing, as are sawflies. Generally, cultivated soils have reduced diversity and numbers of soil micro-organisms compared to uncultivated soils.

Conservation tillage leaves more weed seeds and grain on the surface; an advantage for seed-eating birds and mammals. Higher numbers of birds have been associated with winter arable fields under conservation tillage in the UK and USA.

Some specific examples of Conservation Agriculture benefits for wildlife are illustrated on the following pages.

Skylarks

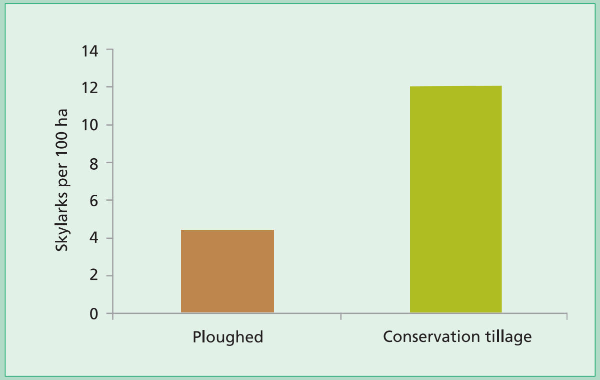
The Skylark (*Alauda arvensis*) is widespread throughout Europe. It nests and forages on the ground in a range of open landscapes. Adults mainly eat seeds in winter, but the chicks are fed on invertebrates.

Like many farmland birds, skylark populations have markedly declined. The prime reason for this on arable farms is the switch from spring to autumn sowing. Modern grassland management is also detrimental, with few broad-leaf plants to provide food, and repeated cutting destroying nests.

Conservation Agriculture can play a role in the recovery of skylark populations. On arable land, more complicated rotations increase opportunities for successful nesting and feeding throughout the year, and better-targeted pesticide use plus conservation tillage improves food supplies. Indeed, skylarks do seem to respond to conservation tillage in the UK. More targeted fertilization of grassland has similar benefits.

Skylark (Alauda arvensis)
Photo by N Blake (rspb-images.com)

Observations of skylarks during January - March in UK winter crops under conservation tillage or ploughing
(Adapted from Cunningham *et al*, 2005)

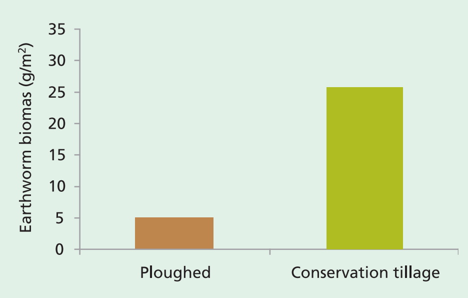


Earthworms

Earthworms are important indicators of soil health and play a variety of roles in agro-ecosystems. Earthworm numbers in arable soils are considerably lower than those under grass. A population of 400-500 earthworms per square metre has been proposed as a target population for healthy agricultural soils.

Earthworms incorporate organic matter into the soil, stimulating decomposition, humus formation, nutrient cycling and the development of soil structure. In agricultural ecosystems the abundance of earthworms is influenced by the amount, quality and placement of organic matter, the amount of disturbance or cultivation and, rarely, the use of agrochemicals.

Deep burrowing earthworm Lumbricus terrestris



Earthworm biomass from plots either ploughed or under conservation tillage in Hungary (www.sowap.org)

Non-inversion tillage has been shown to provide a more favourable soil environment for earthworms. In a Conservation Agriculture system, more selective use of pesticides, especially for slug control, can also be beneficial to earthworms. Careful choice of active ingredient and use of minimum infestation thresholds will reduce the risk to earthworms.

Soil microbiology

Micro-organisms play a key role in soil health, regulating carbon and nutrient cycling and in their interactions with plants. The total biomass of soil micro-organisms often exceeds that of plants, animals and micro-organisms above ground in agricultural systems, but typically is only a few percent of the total soil organic matter.

Plant residues represent an important source of energy for soil micro-organisms. Soil structure has a large influence on soil microbiology, affecting colonisation, gas and water exchange. Tillage methods, therefore, can greatly affect the biomass and community structure of soil micro-organisms.

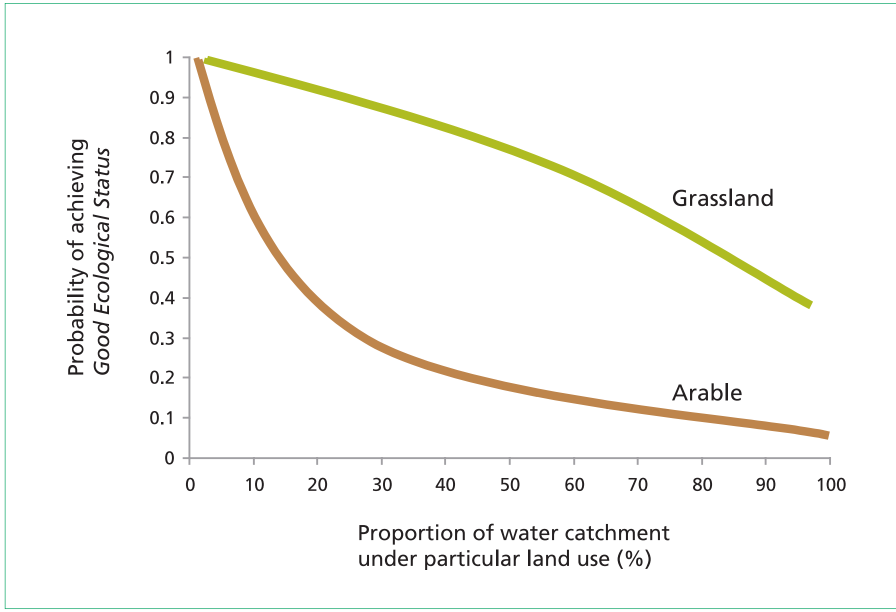
Those that involve periodic and extensive soil disturbance accelerate both carbon and nutrient cycling, resulting in a decrease in soil organic matter, reduced micro-organism biomass, and increased concentrations of mineral nutrients. Denitrifying bacteria may also be favoured, with associated losses of nitrogen oxides.

Under Conservation Agriculture, plant residues are concentrated nearer the surface horizons of the soil than in conventionally tilled soils. These residues are incorporated into the soil by earthworms and fungal translocation. The relatively slow rate of incorporation results in gradients in micro-organism biomass and community structure with depth.

Aquatic Biodiversity

The general impacts of agriculture on the quality of freshwater ecosystems are clear, and can be easily demonstrated by comparison with streams and ponds in uncultivated catchment areas. Typically, freshwaters in agricultural areas support a smaller proportion of sensitive plants and animals. Streams and rivers in agricultural catchments usually remain in good condition until about 30-50% of the area is cultivated (Fig 6). The proportion may be smaller for lakes and ponds, which have a lower capacity for dilution of pollutants.

Figure 6. Likelihood of rivers in Ireland achieving Good ecological status under the Water Framework Directive depending on the proportion of the catchment which is under pasture or under arable land (Adapted from Donahue *et al*, 2006)



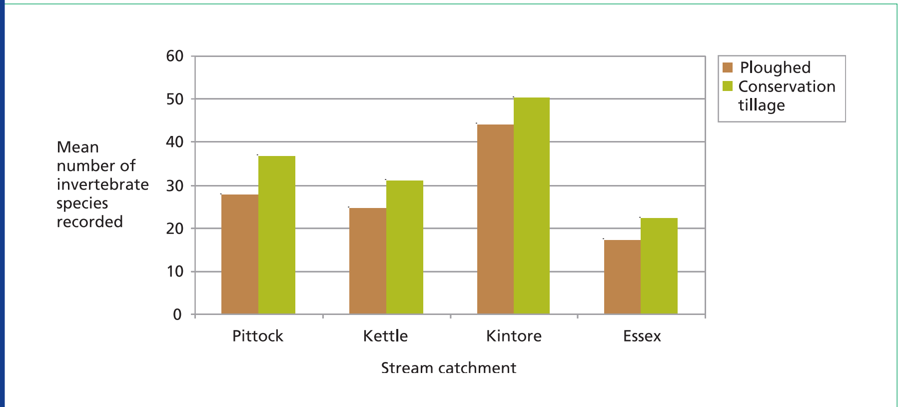
Conservation Agriculture and Aquatic Biodiversity

The benefits of Conservation Agriculture for aquatic organisms have so far mainly been deduced from the fact that water quality is improved, rather than by direct observation of recovery of abundance or diversity of those organisms, or improvements in ecological processes.

Invertebrates

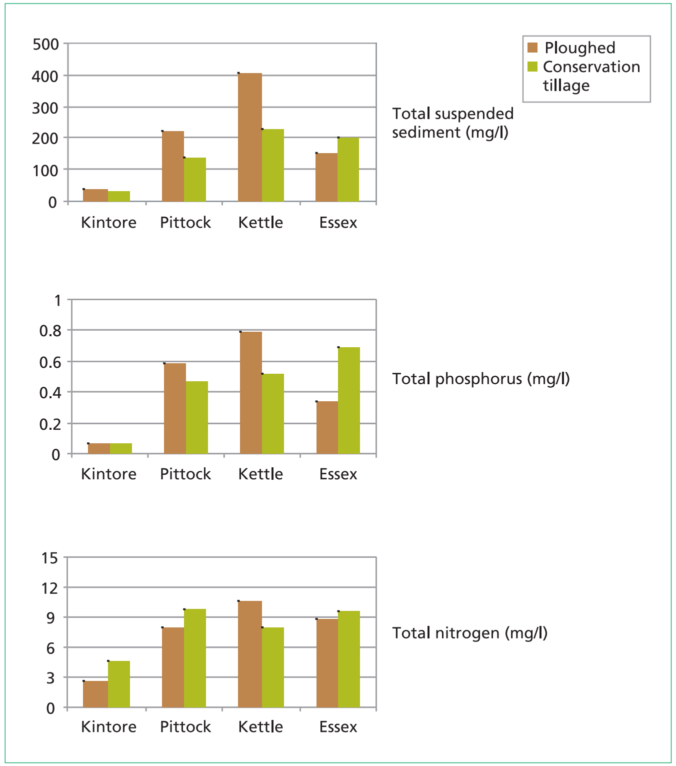
Amongst the relatively few studies that have been done, invertebrate populations in small streams in south-western Ontario (Canada) showed a consistent increase in species richness when streams in Conservation Agriculture landscapes were compared with those in conventionally ploughed areas (Fig 7). Streams in areas of Conservation Agriculture also had higher numbers of sensitive mayflies, caddis flies and stoneflies.

Figure 7. Comparison of the number of aquatic invertebrate species found in streams in ploughed and conservation tilled areas in south-western Ontario
(Barton and Farmer, 1997)



At present, the precise mechanism by which Conservation Agriculture provides benefits for aquatic biota is not clear, as can be seen in the variability in chemical composition of streams in the Ontario study (Fig 8). Thus, three out of four streams in areas where Conservation Agriculture was practiced had higher annual mean total nitrogen concentrations than the conventionally cultivated streams yet still supported richer macro-invertebrate populations. Normally, higher total nitrogen levels would be seen as an indication of poorer water quality.

Figure 8. Water quality in four paired catchments (ploughed and conservation tillage) described in Figure 7
(Barton and Farmer, 1997)



Fish
The negative impacts on fish of excess sediment deposition are well-known, with effects particularly apparent on salmonid species. Sources from arable agriculture are clearly important in causing silting up of spawning beds in some river systems: Conservation Agriculture is likely to reduce the stress on spawning grounds.

Excessive deposition of sediment can be detrimental to salmon

Summary of Benefits and Limitations

Conservation tillage systems have the following benefits for biodiversity:

- Crop residues, spilt grain and weed seeds left on or near the soil surface are important food sources
- Crop residues provide habitats for invertebrates and ground nesting birds
- Earthworm abundance increases
- Total soil biomass increases
- Reduced sediment and nutrient loads entering waterbodies

Rotations and cover crops give benefits in:

- A wider range of invertebrates and micro-flora is encouraged
- Greater within- and between-field habitat diversity gives better foraging and breeding opportunities for mammals and birds
- Reduced pesticide use minimises the impact on non-target organisms and reduces drift and run-off into non-cropped areas and water bodies

REFLECTIONS

If Conservation Agriculture was indeed the *'greatest soil conservation practice to come along in the 20th century'*, why has uptake in Europe lagged behind the rest of the world?

We set out to examine the extent to which the principles of Conservation Agriculture have been applied to crop production, to understand the drivers and constraints behind their implementation, and to seek evidence of the benefits. This has provided the context for considering the wider use of this integrated, yet flexible approach to meet the demands of recently introduced and developing European legislation to protect soil and water.

Realistically, agronomic practices which address environmental aims will only succeed if they can also maintain or strengthen the profitability of European agriculture and the livelihoods of its farmers. To fully assess whether Conservation Agriculture can tackle the needs of soil and water protection and support an economically thriving European crop sector, we need to reflect on the evidence and return to the questions we posed in the Introduction.

- **Can Conservation Agriculture protect soil and water in Europe and enhance crop production and biodiversity?**

The evidence suggests that environmental benefits, both on and off the farm, can be delivered across the range of European cropping systems. Over time, soil structure and health improve and biodiversity is encouraged. Soil erosion and diffuse water pollution are reduced. In the long run, costs of labour, energy and, often, agrochemical and fertilizer inputs decrease, even if yields are sometimes lower.

- **Are there particular limitations to the effectiveness of Conservation Agriculture or constraints on its implementation?**

Adopting Conservation Agriculture often means that investments in new equipment are necessary, and there are a number of issues concerning each of the three main elements.

Minimal mechanical soil disturbance
Earlier attempts at conservation tillage in some European countries left many early adopter farmers disillusioned and financially disadvantaged by disappointing crops.

> *"To be economically attractive for farmers, Conservation Agriculture must be perceived to provide a net economic benefit either through lower production costs or higher crop yields, higher net returns, lower business risks, or some combination of these."*
> (Sanchez-Giron *et al*, 2004)

There are undoubtedly some problems to overcome. Careful planning and preparation are necessary, for mistakes may take much time and effort to rectify later. Not all soil types are suitable, although pragmatic adaptations, *eg* moving from no-till to strip tillage, may extend the range. Equally, the lack of cultivation means that care must be taken to avoid soil compaction.

Uncertainty remains as to whether conservation tillage inevitably leads to more compaction than conventional tillage, especially on sandy soils. The temporary increase in the macropore space through tillage may increase initial water infiltration and this is sometimes reduced by the compact soil structure in no-till soils. Fields under conservation tillage, and especially no-till, have a higher load bearing capacity. This means that no-till fields, in particular, are less dependent than ploughed fields on favourable soil moisture conditions for the timeliness of operations such as fertilizer application and spraying. However, heavy machinery traffic and animal grazing under very wet conditions must be reduced to a minimum, as only tillage is able to remedy structural damage immediately.

Without ploughing, Conservation Agriculture systems depend on herbicides to provide effective weed control. While herbicide use increases, at least in the transition years, there is little evidence of increased risk of water pollution or impacts on in-field biodiversity. Broad-spectrum (non-selective) herbicides without residual activity in the soil are especially important.

Permanent soil cover
Maintaining a ground cover does pose some problems. Cutting through residues is an issue when sowing arable crops, requiring specialist drills. In the case of green inter-row covers in perennials, limiting competition for water by managing the growth of the cover is essential.

There are some conflicts which will always need careful consideration. Early drilling of a winter cereal or oilseed rape, or planting a cover crop, will protect the soil, but this may not be as beneficial to wildlife, particularly ground nesting birds, as leaving an over wintering stubble. Improving the yield of grassland by encouraging more productive species may disadvantage biodiversity.

Diversified crop rotations
Rotations in Conservation Agriculture must balance the selection of crops which are economically profitable in their own right with the benefits each crop may bring over the longer term.

The evidence presented in this book, is for the most part, an appraisal of short and long-term research on small plots or field-scale trials. These are unlikely to have had to contend with the conflicting demands and time constraints encountered by farmers in their everyday work. Therefore, the benefits highlighted may represent a best-case scenario, although conversely, practising farmers may be best placed to fully realise the advantages because of their own personal experiences and their longer-term commitment to their land and cropping system.

Does Conservation Agriculture have the potential for wider adoption in Europe and what are the ways forward?

All the evidence suggests that Conservation Agriculture can help Member States deliver parts of the Water Framework Directive and address some of the threats to European soils. While its potential to sequester carbon in soils may help meet some of the requirements of the Kyoto Protocol, further research is needed on the role of nitrous oxide in such situations.

Conservation Agriculture is not a single, prescriptive system. Rather, it is a set of principles to be applied carefully and intelligently to a variety of different soil types, crops, climates and farm objectives. Early adopters, and ultimately advocates, of Conservation Agriculture are most likely to be found in younger or more entrepreneurial farmers, more willing and able to change their approach and systems.

While know-how and tenacity are often essential requirements for such new adopters of this technology, if Conservation Agriculture is to expand in Europe, further assistance for farmers will be vital, particularly as

> *"(soil) conservation is not profitable everywhere"* Hoag (2004)

This may be financial or technical support, or both, at least during the years of transition to full implementation, if farmers are to deliver the benefits. This review has addressed general points on a relatively broad platform. It has not been the intent to include detail which is needed on a crop and country specific level, and often this information is simply not available.

Pre-requisites to expansion in Europe are a common understanding of the principles involved in Conservation Agriculture and a common terminology which we have formed a basis for in this book.

The SOWAP and ProTerra projects have been part of the effort to expand the base of knowledge on the performance of Conservation Agriculture. More is required, through co-ordinated European, regional and local initiatives and partnerships; more extensive and effective dissemination of the knowledge gained is needed; and innovative ways of applying this knowledge will always be important. Constraints to adoption and the conflicts and trade-offs that may arise on the farm, and affect the wider environment, must be understood better to be successful.

Looking forward, Conservation Agriculture must also rise to the challenges of the future, responding to a changing climate and producing crops for new markets. This will enable an ever increasing number of farmers to adapt their cropping systems to protect soil and water while enhancing biodiversity, productivity, and profitability.

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5. **Eurostat:**
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   http://epp.eurostat.cec.eu.int
6. **Faostat:**
   UN Food and Agriculture Organisation statistical information service.
   http://faostat.fao.org
7. **KASSA:**
   Knowledge Assessment and Sharing on Agriculture (EC-funded project).
   http://kassa.cirad.fr
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